BMT WBM

Tweed River Entrance Sand Bypassing Reassessment of Long Term Average Annual Net Sand Transport Rate

R.B17328.002.02.doc

September 2011

Tweed River Entrance Sand Bypassing

Re-assessment of Long Term Average Sand Transport Rate

Prepared For:	NSW Land & property Management Authority
Prepared By:	BMT WBM Pty Ltd (Member of the BMT group of companies)

BMT WBM

DOCUMENT CONTROL SHEET

<table>
<tr><td>

BMT WBM Pty Ltd

BMT WBM Pty Ltd
Level 8, 200 Creek Street
Brisbane 4000
Queensland Australia
PO Box 203 Spring Hill 4004

Tel: +61 7 3831 6744
Fax: + 61 7 3832 3627

ABN 54 010 830 421

www.wbmpl.com.au

</td><td>

Document :   R.B17328.002.02.doc

Project Manager :   DCP

Client :   NSW Land & property Management Authority

Client Contact: George Elias

Client Reference

</td></tr>
</table>

Title :	Tweed River Entrance Sand Bypassing Re-assessment of Long Term Average Sand Transport Rate
Author :	D C Patterson
Synopsis :	This report describes the procedure, analysis details and results of the re-assessment of the Long Term Average (LTA) sand transport rate at Letitia Spit for application to management of the sand bypassing. Contents include discussion of the re-assessment strategy, coastal and ocean processes relating to the LTA, modelling of waves and sand transport, analysis and interpretation of the results of the surveys quantifying quantities of sand in various compartments of the system and results of the analyses of the LTA, natural bypassing from NSW to Qld and sand transport rates along Letitia Spit and at Snapper Rocks. Discussion of the trends and uncertainties in the analyses is presented, together with assessment of the long term context of the behaviour to date and likely future trends.

REVISION/CHECKING HISTORY

REVISION NUMBER	DATE OF ISSUE	CHECKED BY		ISSUED BY	
0	19/10/2009	IA Teakle / Prof C Apelt		D C Patterson	
1	15/09/2011	I A Teakle		D C Patterson	
2	03/10/2011	I A Teakle		D C Patterson	

DISTRIBUTION

DESTINATION	REVISION			
	0	1	2	3
Lands Dept	PDF	PDF	PDF	
BMT WBM File	1	1	1	
BMT WBM Library	1	1	1	

BMT WBM

CONTENTS

BMT WBM

LIST OF FIGURES

BMT WBM

BMT WBM

LIST OF TABLES

BMT WBM

EXECUTIVE SUMMARY

Background

A comprehensive reassessment of the Long Term Average (LTA) sand transport rate for the Tweed River Entrance Sand Bypassing Project (TRESBP) has been undertaken. The LTA has been determined on the basis of its definition under the legislation. This determination is dependent on the assessment of natural bypassing of sand to southern Queensland beaches (among other factors), which in turn is dependent on how the TRESBP sand bypassing system is operated.

An assessment strategy was adopted that made maximum use of the considerable survey data obtained from the monitoring program implemented over the period from 1993 to date, including the period of Stage 1 initial entrance dredging that commenced in 1995, through the period of sand bypassing operations that commenced in 2001. The LTA assessment method was determined on the basis of its definition in the Deed of Agreement as (essentially) the long term average of the sand transport into Letitia Spit minus the natural bypassing to Queensland, which may be expressed in terms of the net sand volume change along the Letitia Spit/Tweed River entrance coastal unit, accounting for the gain or loss to or from the river, and the volumetric rate of the bypass system pumping and entrance dredging.

Additionally, the component sand transport rates at various locations along Letitia Spit and the natural bypassing have been determined. This necessarily required calculation of a reference sand transport rate. Currumbin, at the northern end of the monitoring survey compartments, was adopted as the most suitable reference location for that purpose, being less subject to complexities in wave propagation and sand transport processes than other locations. A comprehensive SWAN wave propagation and sand transport calculation procedure was adopted, utilising conventional coastal engineering practice. The wave propagation analysis was calibrated to measured nearshore wave data. The CERC and Queens sand transport relationships were utilised, with coefficients calibrated to the known annual average net longshore transport rate through the region of 500,000 to 550,000m^3/yr for the available wave data, noting that the rate derived is dependent on the period of data used. The two calibrated relationships yielded directly equivalent sand transport rates. The sand transport results from the Queens relationship are presented in this report.

The analysis undertaken has been based on analysis of the average values of the respective surveyed sand quantities and component sand transport rate values, determined in a monthly time series format from the available data. Thus, the variability and prevailing trends of behaviour have been identified, particularly in the context of patterns relating to the period prior to and since the sand bypassing operations commenced in 2001 and the influence of the Supplementary Increment that was incorporated in the sand bypassing delivery over the first 6 years of its operation.

LTA and Sand Transport Rates

The component monthly LTA values for the period of the operations and monitoring analysed varied significantly over time, averaging approximately 509,000 to 513,000m^3/yr for the bypassing period 2001 to 2009. This represents an increase of 2% over the initially adopted rate of 500,000m^3/yr. The analysis indicates that it increased from about 162,000m^3/yr for the period 1995 to 2000 prior to commencement of sand bypassing operations. The component sand transport processes over the

BMT WBM

period 2001 to 2009 involved an average annual net longshore transport into Letitia Spit of about 553,000 m^3/yr and natural bypassing of about 40,500m^3/yr.

The transport along the central and northern parts of Letitia Spit has been substantially affected by the sand bypass system activities, through changes in the shoreline alignment. Rates of transport approximately 1,000m south of the southern training wall increased from about 600,000m^3/yr prior to the sand bypassing operations, increasing to an average of 752,000 m^3/yr for 2001 to 2009.

The monthly temporal pattern of sand transport into and along Letitia Spit appears to be subject to strong 'slug' like behaviour that cannot be calculated using the conventional sand transport formulae. Large sand transport slugs of up to 170,000m^3/month were identified to have occurred in early 2003 and in 2007 and early 2008. This contrasts significantly with the temporal pattern at Currumbin, which is generally more uniform. However, because of the shoreline alignment there, the Currumbin transport is subject to occasional high transport associated with larger waves from more easterly directions, as occurred during early 2009, reaching 130,000 and 200,000 m^3 in the single months of April and May 2009 respectively. This relatively short period of high transport increased the average annual net rate from about 506,000 m^3/yr for 1995 to 2008 to 527,000 m^3/yr for 1995 to 2009, with 735,000 m^3 being transported there in the single year August 2008 to August 2009.

The slug transport in 2003 and 2007-08 appears to be the result of periodic strong inputs of sand to Letitia Spit from Dreamtime Beach past Fingal. This increased the transport of sand to the sand bypass system and led to a higher rate of both delivery of sand to Queensland via the sand bypassing operations and natural bypassing at those times.

The natural bypassing has been reduced by both the Stage 1 initial dredging at the river entrance in the mid to late 1990s and commencement of the sand bypassing operations in 2001. An average annual natural bypassing rate of 322,000m^3/yr has been determined for the period 1995 to 2000 associated with the period of dredging. It has subsequently reduced to an average of 40,500m^3/yr for the period 2001 to 2009 as a result of the bypassing activities, although it has varied significantly.

Longer Term Context

An analysis based on the adopted uniformity of the annual average net transport through the local beach system has been undertaken to assess the longer term context of the results derived from the available data. This is based on monthly values of a weighted mean deep water wave energy flux parameter and site-specific energy weighted wave direction parameter functions that relate the local sand transport regime at various locations to the deep water wave direction. The analysis undertaken indicates that the long term average annual longshore sand transport along the regional beach system is approximately 550,000m^3/yr.

Additionally, there is a leakage of sand through the jetty system that leads to a requirement for entrance dredging as part of the sand bypass system operations. Not all of the leakage of sand to the entrance needs to be dredged to maintain the entrance channel and the balance passes through as the natural bypassing. The appropriate LTA rate depends on the interception rate of the jetty system and the entrance channel dredging carried out to meet the channel depth criterion in determining the natural bypassing rate.

BMT WBM

Based on the trends derived, for a sustainable long term average situation, the leakage through the jetty system is likely to be about 30% of the net sand transport, approximately 164,000m^3/yr. This corresponds to an effective jetty pumping rate of 382,000m^3/yr. Adopting a dredging need of 80% of the transport past the south wall, based on the available information, the dredging required would be 131,000m^3/yr and the natural bypassing 33,000m^3/yr.

Recommendations

The assessed LTA rate from the long term context analysis is in the range 509,000 to 517,000m^3/yr, compared with 509,000 to 513,000m^3/yr derived directly from the data for the period 2001-2009. This result is within a surprisingly a small range, given the potential and actual high variability of the processes and the uncertainties inherent in the assessment. It is considered appropriate to give greater weighting to the result obtained directly from the survey data.

Accordingly, a reassessed LTA rate of 510,000m^3/yr has been adopted.

The proportion of the LTA that would be pumped compared with that dredged could vary substantially, depending on the proportion of the sand transport that the jetty pumping system is able to capture. For optimum utilisation of the jetty system infrastructure, the target jetty pumping rate should be as high as possible, up to the LTA rate. Nevertheless, dredging to achieve suitable conditions in the entrance channel will most probably be needed from time to time because the sand bypassing jetty is not able to intercept all the sand during high sand transport events.

Careful ongoing monitoring and review of the operations are needed to assess progressively how the system operations are trending and, in particular, the development of a longer term pattern of dredging and its influence on the natural bypassing rates and the trend towards the situation in which the LTA is being achieved as the long term average delivery by the sand bypassing operations, subject to natural temporal fluctuations.

The monitoring to date has been comprehensive and invaluable as a data source for this reassessment of the LTA. The identification of a minor leakage of sand to deeper water beyond the 20m limit of the calculation compartments in the vicinity of the entrance suggests that there would be considerable value gained over the future longer term in extending at least some of the surveys along that area somewhat further offshore.

BMT WBM

1 INTRODUCTION

1.1 Background

1.1.1 Overview

BMT WBM was commissioned to undertake re-assessment of the Long Term Average (LTA) sand transport rate for the Tweed River Entrance Sand Bypassing Project. The focus of the study is on the LTA and its component processes of longshore littoral sand transport and natural bypassing to Queensland beaches, incorporating analysis and review of resulting coastal changes along both the Letitia Spit/Tweed River entrance area and the downdrift southern Gold Coast beaches.

At the time of this assessment, the sand bypassing system had been in operation since April 2001, with over eight years of operational experience and considerable monitoring data available. Prior to commencement of the sand bypassing operations, initial Stage 1 dredging that commenced in 1995 was used to transfer sand accumulated at the Tweed River entrance to Queensland. The monitoring also covers that period. While the LTA is the basis of the target sand quantities to be delivered by the system, a balance quantity (the Supplementary Increment) remained to be transferred at the commencement of bypassing operations and was incorporated into the quantities delivered over the first six annual periods.

This report sets out the results of the study undertaken, including discussion of the re-assessment strategy, coastal and ocean processes relating to the LTA, modelling of waves and sand transport, analysis and interpretation of the results of the surveys quantifying quantities of sand in various compartments of the system and results of the analyses of the LTA, natural bypassing from NSW to Qld and sand transport rates along Letitia Spit and at Snapper Rocks and Currumbin. Discussion of the key issues and uncertainties in the analyses is presented.

1.1.2 Legislative provisions

Under the Deed of Agreement (DOA), the LTA is defined as:

"the long term average annual net littoral transport of sand that would, in the absence of any artificial actions to influence it, cross a line perpendicular to the coastline, situated one kilometre south of the southern training wall at the Tweed River entrance and extending to the 20 metre depth contour, less the annual net quantity of sand which, after the commissioning of the System, crosses that line and reaches Queensland, or the coastal waters of the State of Queensland as defined in the Coastal Waters (State Powers) Act, 1980 (Cth), by natural means".

In summary, the LTA may be expressed as the long term average of:

Natural net longshore sand transport at Letitia Spit – Natural bypassing to southern Gold Coast

Each of these transport components varies from year to year. Clearly, the natural bypassing to Gold Coast depends intimately on the nature and effectiveness of the sand bypassing system operations, as well as the net sand transport along Letitia Spit. Further, the net transport at Letitia Spit to be used in the LTA is that which would occur, or when considering the period of sand bypassing operations to

date, which would have occurred, in the absence of any impacts the sand bypassing system or other artificial actions may have had on the Letitia Spit processes.

Neither of the transport rates can be measured directly. They must be determined from other factors that have been measured in the extensive monitoring program implemented to date and/or by suitable and sufficient modelling analysis of the component sand transport rates.

To date, as provided for in the Deed of Agreement, the LTA has been defined as 500,000 m^3/yr based on:

- Previous calculated estimates of the annual average net sand transport along Letitia Spit of approximately 500,000 m^3/yr; and

- An implicit adopted assumption that the natural bypassing would be small or negligible following commissioning of the sand bypassing system.

The Deed of Agreement requires that the LTA be re-assessed. Over eight years of experience with implementation of the system and considerable measured monitoring data have been utilised to assist in such re-assessment, the subject of this study.

1.1.3 Bypass System Placement at Duranbah

The majority of the bypass pumping and dredging is placed directly to Queensland. In that context, the LTA relates predominantly to the annual increment of the quantity to be delivered to Queensland. However, a proportion of the sand pumping is placed at Duranbah in NSW, with the aim of providing sand for beach and/or inner nearshore replenishment. The intent is that the sand placed there will be transported to Queensland by the natural processes. However, that quantity does not strictly comply with the defined natural bypassing, not having reached Queensland after passing the line 1,000m south of the walls by completely 'natural means'.

The fate of the sand placed at Duranbah is difficult to determine, particularly distinguishing it from the fate of sand transported past the river entrance by natural means. If it is assumed that sand placed at Duranbah has been effectively bypassed to Queensland, then:

- Any net gain at Duranbah represents natural transport past the entrance that has not reached Queensland;

- Any net loss of sand from Duranbah represents an excess amount that has reached Queensland by purely natural means and is part of the natural bypassing; and

- The bypassing by natural means is the total wave-current driven transport past the NSW/Qld border minus the quantity placed at Duranbah by the sand bypassing operations.

This has been adopted herein and is of significance in application of the calculation process for the LTA, as outlined in section 2.3.

1.2 Study Scope

The aim of the study is to re-assess the Long Term Average Annual Net Sand Transport Rate (LTA) in the most comprehensive and meaningful way feasible, taking maximum advantage of the data and knowledge now available. More broadly, the study also aims to advance the present status of

BMT WBM

knowledge of the wave and sand transport processes relating to the LTA for application to ongoing management of the bypassing system. The study outcomes thus need to include detailed analysis of the LTA component processes as defined in the Deed of Agreement (annual net littoral drift and natural bypassing) and related processes of the bypass pumping and dredging and net changes in coastal compartment quantities both annually and over the longer term. In particular, the inter-active causes and effects between these processes need to be identified within the limits of feasible accuracy.

Further, the study seeks to provide, as part of the deliverables, additional or updated methods and/or procedures and comments on data collection that will assist for the purposes of future estimates of the LTA.

It is to be noted that the initial analysis work for this study was undertaken on the basis of the data available to 2008. It was decided during the course of the study to extend the database of the re-assessment to include the monitoring surveys of 2009. As such, initial analyses to calibrate the calculated average annual sand transport rates derived from the wave data were based on the data to 2008. Subsequent extension of the database by a further year meant that the annual average rates became somewhat different as a result of incorporating the additional survey and wave data.

BMT WBM

2   LTA RE-ASSESSMENT STRATEGY

2.1   General Considerations

There is a direct relationship between the LTA and the way in which the sand bypass system is operated, since the operations and efficiency of the system affect the nature and extent of any natural bypassing. Broadly, the average annual target delivery by the system (pumping plus dredging quantity) should equal the LTA under the Deed of Agreement (DOA). However, the DOA includes provision also for an initial 6 year period of Supplementary Increment to be delivered to compensate for accumulation of sand at the entrance between 1990 and the commencement of operation of the bypassing system in April 2001 to offset ongoing sand losses from the southern Gold Coast beaches. Inclusion of this quantity, approximately 1.66 million cubic metres, in the delivery via the jetty system has affected the way in which the coastal system has responded and needs to be considered in the LTA reassessment.

It is recognised that the monitoring data as well as the modelling and analyses to be undertaken contain uncertainties and potential error margins that need to be understood. Flexibility to adapt and/or modify the approach or emphasis in response to the findings that emerge as the study progresses is needed.

In that context, the key challenges of the study are to:

- Determine the inter-dependence of the processes involved and the sustainable LTA that will satisfy the navigation and sand supply objectives of the two states;

- Undertake the analysis of the LTA with sufficiently reliable accuracy that the present knowledge and assumptions are significantly improved, representing a significant step forward from the initial assumptions about the LTA and its application set out in the Deed of Agreement; and

- Establish a sound basis for future re-assessments of the LTA in terms of suitable methodology and monitoring data.

By necessity, the LTA re-assessment depends on analysis of the past behaviour of the coastal system in response to the particular jetty-based operations and dredging undertaken to date. This needs to be used to give knowledge and understanding of the component processes of the LTA and the effect of artificial bypassing operations on the LTA in order to form the basis of future management.

2.2   Re-Assessment Strategy

The LTA re-assessment strategy pursued in this study is based on time series (monthly/annual) analysis of the LTA components over the 2001-2009 period of sand bypass operations together with the longer context of the previous dredging that commenced in 1995 and the surveyed changes in sand quantities since 1993. The LTA has been determined from the annual average of the component values thus derived. The longer term context of this annual average value has been reviewed, as outlined in Chapter 7.

The aim of the study is to ensure that the Long Term Average annual net sand transport rate is re-assessed in the most comprehensive and meaningful way feasible, utilising the data and knowledge now available.

The general approach adopted involves consideration of the whole range of available data and information of relevance and significance to quantifying the processes that have taken place to date. While it is recognised that individual theoretical calculations and/or monitoring data sets are subject to errors that need to be understood and dealt with appropriately, the overall sediment budget comprising inputs, outputs and quantity changes within designated control volumes need to be consistent. Both local and regional sand budgets need to make consistent sense temporally and spatially in quantifying the LTA components.

2.3   LTA Definition and Calculation Approach

Under the Deed of Agreement, the LTA is given as the long term average annual value of:

Natural net longshore sand transport at Letitia Spit – Natural bypassing to southern Gold Coast   (1)

Each of these transport rates varies from year to year. Neither of these transport rates can be measured directly and must be determined from other factors that have been measured in the extensive monitoring program implemented to date and/or calculated from theoretical modelling.

If it is assumed that all sand pumping/dredging, including that placed at Duranbah, is effectively delivered directly to Queensland, then consideration of the sand budget for Letitia Spit (Figure 2-1) shows that:

Net Quantity Change = Transport in – Natural Bypassing – Sand Pumping/Dredging + River supply

Re-arrangement thus gives, considering long term average values:

LTA = Transport in – Natural Bypassing   (1a)
LTA = Pumping/Dredging (total) + Net Quantity Change – River supply   (1b)

(Note: The net quantity change along Letitia Spit has been negative over the bypassing period)
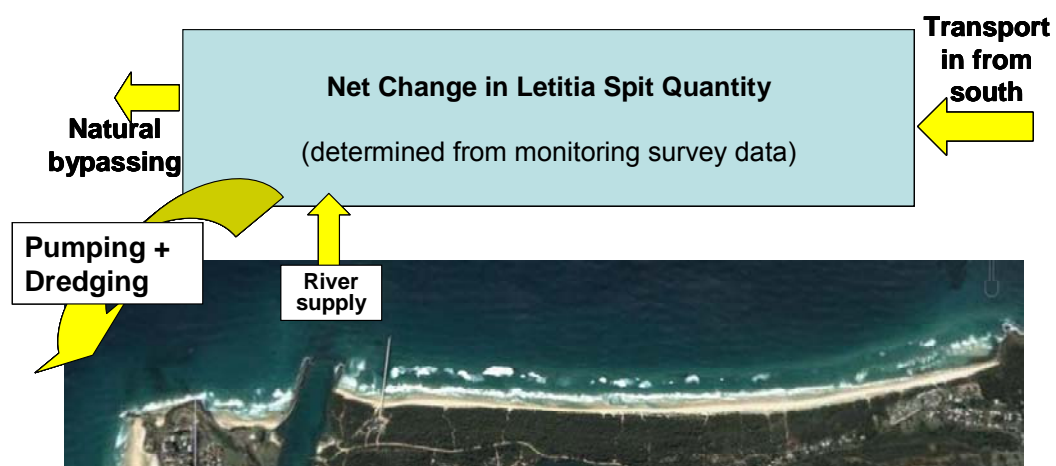
Figure 2-1   Conceptual sand budget for Letitia Spit

As such, direct assessment of the LTA may be achieved directly from the bypass system sand delivery records and measured survey data using equation (1b), at least as averaged over the period of available monitoring data, provided the quantity calculation compartments are chosen such that the transport in along Letitia Spit is sufficiently compatible with that at the location defined in the Deed of Agreement (DOA).

The variability of the progressive annual components of the (Transport in – Natural Bypassing) rates over the period of operation to date may be determined by analysis of the annual records of pumping/dredging sand delivery and the net quantity change along Letitia Spit. An estimate of the LTA may be made on the basis of averaging these annual components, provided:

- The annual periods used correspond to periods when the objectives of both states are met; and

- The period involved is sufficiently long.

A summary analysis of the changes in sand quantities within the various compartments along Letitia Spit and around the entrance area surveyed as part of the monitoring of the bypass system operations is presented and discussed in Chapter 3. The results of the LTA analysis based on Equation 1b are presented in Chapter 4.

2.4   Natural Sand Bypassing to Queensland

The total sand supply to the Queensland beach system will include that sand transported by waves and currents as natural bypassing in addition to the sand pumped and dredged directly to Queensland or via Duranbah as part of the bypass system pumping/dredging operations and previous dredging activities. This has been assessed and quantified in the present study. For the purpose of this study, the location of natural bypassing is taken as the alignment of the NSW-Qld border, consistent with the provisions of the DOA.

It is likely that there was significant natural bypassing of sand prior to and during the initial stages of the Stage 1 dredging and into the early period of the sand bypass system operations. Investigations prior to the works (Roelvink & Murray 1992) indicate that, at that time, the rate of natural sand bypassing of Point Danger was about 350,000-400,000 m^3/yr. This would have been slowly increasing at the time, but probably would have reduced as dredging commenced and the flow of sand from the south was intercepted.

Using the sand budget as illustrated in Figure 2-2, together with adjustment for the fact that not all of the transport across the NSW/Qld border is 'natural bypassing' as discussed in Section 1.1.3, quantification of the natural bypassing of sand can be achieved on the basis of the available monitoring survey data to quantify the net benefit to the southern Gold Coast area, together with:

- The known pumping and dredging quantities, and

- Knowledge of the longshore transport out to the north at Currumbin.

This leads to Equation (2a).

Natural Bypassing = Tran$_{Currumbin}$ + ΔQ (Qld) – Sand Pumping/Dredging (total)   (2a)
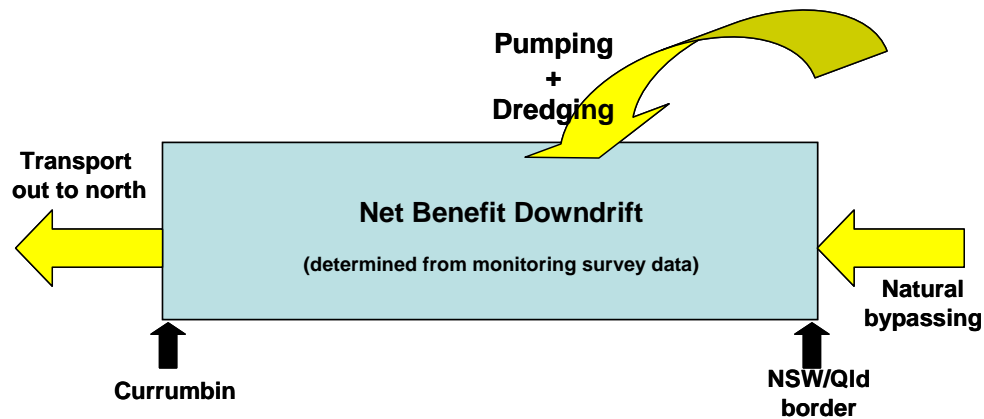
Figure 2-2   Conceptual quantification of natural bypassing

The total sand transport past the NSW/Qld border is the 'natural bypassing' plus the sand placed at Duranbah, for reasons outlined above, and is given by Equation 2b in which the Pumping/Dredging quantities are those delivered directly to Queensland and exclude the placement at Duranbah.

Total transport at NSW/Qld border = Tran$_{Currumbin}$ + ΔQ (Qld) – Pumping/Dredging (Qld)   (2b)

For this analysis, the net sand transport out to the north at Currumbin over the years covered by the monitoring is needed. It will have varied from year to year with the incident wave conditions. By necessity, this has to be determined by theoretical means using the available directional wave data and conventional wave propagation and longshore transport calculation procedures.

A summary analysis of the changes in sand quantities within the various compartments along Letitia Spit and around the entrance area surveyed as part of the monitoring of the sand bypass system operation is presented and discussed in Chapter 3. The LTA rates derived directly from that data using Equation 1b are presented in Chapter 4.

The results of analysis of the monthly longshore sand transport rates at Currumbin are presented in Chapter 5. The analysis of natural bypassing rates across the NSW/Qld border using Equation 2 is presented in Chapter 6.

2.5   LTA Calculated From Measured Queensland Quantity Changes

Equation 2a above for the natural bypassing may be combined with the sand transport along Letitia Spit as an alternative means of calculating the LTA. That is:

LTA = (Tran$_{Letitia}$ – Tran$_{Currumbin}$) - Net Benefit Qld +Pumping/Dredging (total)   (2c)

For this, the transport rates at both Letitia Spit and Currumbin are needed. The Letitia Spit transport may be calculated either directly from wave data or indirectly via the natural bypassing from Equation 2a, as described below.

It is of note that, to the extent that the transport rates at Letitia Spit and Currumbin are essentially equal, at least averaged over the longer term, the LTA would be given by:

LTA = Pumping/Dredging - Net Benefit Qld   (2d)

BMT WBM

2.6   Calculation of Longshore Sand Transport Rates

Longshore sand transport rates have been calculated using two systematic approaches, namely:

- Theoretical analysis based on recorded directional wave data with wave propagation and sand transport modelling; and

- Having calculated the natural bypassing at the NSW/Qld border (as above), analysis of the incremental rates into each of the survey compartments along Letitia Spit to Snapper Rocks based on sand budget considerations.

The theoretical calculations are described in detail in Chapter 5.

The incremental rates derived from sand budget considerations, utilising the surveyed quantities together with known dredging and pumping rates, are based on the conceptual considerations illustrated in Figure 2-3. It should be noted that this approach requires as its basis the transport at the NSW/Qld border as derived from the theoretically calculated transport rate at Currumbin.
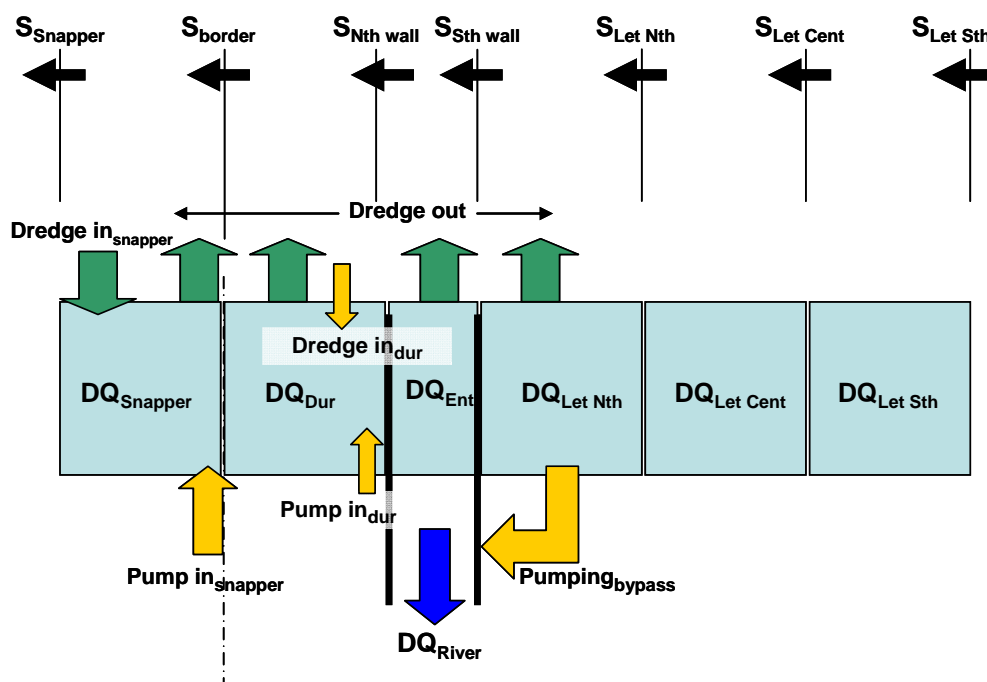
Figure 2-3   Conceptual sand budget for Letitia transport calculations

Thus, sand transport rates (denoted herein as S) may be calculated as follows:

$$S_{Snapper} = S_{border} - DQ_{Snapper} + (Dredge\ in_{snapper} - Dredge\ out_{snapper}) + Pump\ in_{snapper} \qquad (3a)$$

$$S_{Nth\ wall} = S_{border} + DQ_{Dur} + (Dredge\ out_{dur} - Dredge\ in_{dur}) - Pump\ in_{dur} \qquad (3b)$$

$$S_{Sth\ wall} = S_{Nth\ wall} + DQ_{Ent} + Dredge\ out_{entt} + DQ_{River} \qquad (3c)$$

$$S_{LetNth} = S_{Sth\ wall} + DQ_{LetNth} + Dredge\ out_{Let\ Nth} + Pumping_{bypass} \qquad (3d)$$

$$S_{LetCent} = S_{Nth\ wall} + DQ_{LetCent} \qquad (3e)$$

$$S_{LetSth} = S_{LetCent} + DQ_{LetSth} \qquad (3f)$$

These rates of transport are all those which have been affected to varying degrees by the dredging and pumping operations. Only the transport at Letitia$_{Sth}$ might be reasonably consistent with that occurring " *in the absence of any artificial actions to influence it* " as per the LTA definition. That is, apart possibly from Letitia$_{Sth}$ these rates cannot be used directly in the LTA calculation. Some adjustment for the effects of the pumping and dredging operations on the shoreline alignment would need to be made if they are to be used in that way.

Nevertheless, transport rates calculated in this manner are of considerable interest and provide a comparative basis for those for Letitia Spit calculated directly from the Tweed wave data (Chapter 5).

2.7   Uncertainty and Calibration Issues

There are uncertainties and error margins in the calculation of the LTA and the sand transport rates. In principle, errors may be introduced through:

Surveyed quantities:

- Systematic errors such as incorrect datum correction or equipment calibration;

- Random errors in taking each depth sounding;

- Spatial sampling error if the survey coverage is insufficiently refined.

Sand bypass system quantities:

- Systematic errors in sediment concentration and/or flow measurements in the bypass jetty delivery system;

- Errors in estimating the equivalent sand volumes in the dredge hopper.

Longshore transport calculated from wave data:

- Random errors in wave data sampling;

- Wave data deficiency in representation of coexistent wave trains as a single height, period and direction combination based on the spectral peak values;

- Systematic error inherent in the wave transformation analysis;

- Errors in the theory for predicting breaking wave conditions;

- Systematic error inherent in choice of representative shoreline alignment;

- Error in the theory for calculating sand transport;

- Calibration error.

The sensitivity of the LTA to such errors together with calibration of the coefficients in the sand transport calculation relationships involved have been taken into consideration in the assessments made. Broadly, the transport rates derived need to fit consistently with sand budget quantities measured and calculated, providing a basis on which the LTA and sand transport rates may be correlated and rationalised.

The LTA may be estimated directly from the survey data and sand bypass operations (pumping and dredging) quantities via Equation 1b. As such, the potential error in the LTA is subject only to the

errors in the quantities derived from the surveys and bypassing system. Considerable design control has been incorporated in measuring the pumping and dredging quantities and it is expected that errors in those quantities are relatively minor, though not able to be quantified. Survey quantity errors are likely to be significant but are random rather than cumulative. Thus, these errors will become relatively less significant when averaged over a progressively longer time-frame.

Any gross survey errors may be identified by reviewing the time-series of quantities within each compartment, with changes in areas subject to major extraction or placement of sand more directly related to those activities, whereas more remote areas experience slower progressive change. Review of the survey quantities has been undertaken in this manner and some discrepancies identified and corrected. In particular, a relatively minor but significant loss of sand to deep water beyond the limit of the calculation compartments in the vicinity of the river entrance was identified and has been accounted for in the assessments undertaken.

Determination of the component sand transport and natural bypassing rates is dependent on theoretical calculation of sand transport from the wave data for at least one location (Currumbin for Equation 2a). Currumbin is considered the most suitable location for the reference calculations because it is a relatively exposed site for wave propagation and is not subject to significant natural changes in shoreline alignment or sand transport process anomalies that may be affected by the sand bypass system operations.

There will be error in the calculated sand transport at Currumbin for the reasons outlined above. However, systematic error there should be acceptably minimal provided wave propagation to the site is sufficiently reliable and sand transport relationship coefficients are suitably calibrated. Considerable previous investigation has shown the longer term annual average net transport to be about $500,000m^3$/yr or possibly up to $550,000m^3$/yr, as discussed in Section 5.3.1. That is, a reasonable basis for calibration of the sand transport methodology and coefficients has already been established in previous research in the form of a target annual average net transport rate for the region.   For this investigation, a thorough and systematic methodology for analysing wave propagation and sand transport rates has been applied and calibration coefficients set to match the this target annual average net rate for Currumbin.

To assess whether or not systematic errors unique to the analysis for Currumbin the site are affecting the result and coefficient calibration there, a compatible but independent analysis of the rates at Letitia Spit has also been undertaken. If the calibrated coefficients are adequately universal for the region, it would be expected that such analysis would yield results that are compatible with transport rates derived indirectly via Equation 2b and Equation 3d. Further, the LTA derived using Equation 1b will represent a lower limit for the transport into Letitia Spit, given that the natural bypassing is unlikely to be negative, providing a further basis for assessing the validity of the calculated transport rates and the coefficients used.

BMT WBM

3   SAND QUANTITY CHANGES DERIVED FROM SURVEYS

3.1   Monitoring Program Surveys

Comprehensive survey monitoring has been undertaken as part of the TRESB project since 1995, commencing with the Stage 1 initial dredging undertaken at that time to restore sand quantities to Queensland and establish improved navigation conditions at and in the region of the Tweed River entrance. These surveys follow and augment surveys undertaken by the Queensland Beach Protection Authority since 1966 and Gold Coast City Council for monitoring of beach nourishment programs.

The surveys have been carried out regularly, at least once per year, and analysed by the NSW Department of Lands in terms of sand quantity changes along the section of coast from Fingal to Currumbin and shifts in the location of the shoreline and various contours along Letitia Spit. While the surveys prior to 2000 are not as comprehensive in their spatial extent as those since then, useful survey information is available for the dates listed in Table 3-1 within the various analysis compartments outlined in Section 3.2.

Table 3-1   Schedule of monitoring surveys

Letitia South & Letitia Central	Letitia North & River Entrance	Duranbah	Snapper Rocks to North Kirra	Bilinga South to Currumbin
May – June 1993	May – June 1993	May – June 1993	May – June 1993	May – June 1993
May – June 1994	May – June 1994	May – June 1994	May – June 1994	May – June 1994
19/05/95 to 27/05/95	April - May 1995	Apr – May 1995	Apr – May 1995	Apr – May 1995
11/05/96 to 28/05/96	11/05/96 to 28/05/96	11/05/96 to 28/05/96	11/05/96 to 28/05/96	May 1996
		10/02/97 to 12/02/97	6/02/97 to 7/02/97	
13/08/97 to 15/08/97	13/08/97 to 15/08/97	13/08/97 to 15/08/97	19/09/97 to 1/10/97	19/09/97 to 1/10/97
27/04/98 to 19/05/98	27/04/98 to 19/05/98	27/04/98 to 19/05/98	27/04/98 to 19/05/98	27/04/98 to 19/05/98
		5/11/98 to 9/11/98		
		21/04/99 to 22/04/99		
19/02/2000	19/02/00 to 9/03/00	31/03/2000	19/03/00 to 28/03/00	19/03/00 to 28/03/00
7/12/2000	28/11/00 to 07/12/00	28/11/00 to 07/12/00	28/11/00 to 14/12/00	15/12/00 to 14/02/01
9/08/01 to 10/08/01	09/08/01 to 10/08/01	09/08/01 to 10/08/01	09/08/01 to 10/08/01	20/08/01 to 22/08/01
29/11/2002	18/03/02 to 11/04/02	18/03/02 to 20/03/02	18/03/02 to 11/04/02	
	29/11/02 to 06/12/02	29/11/02 to 06/12/02	21/11/02 to 22/11/02	16/11/02 to 7/11/02
15/11/2003	10/07/2003	10/07/2003	16/06/03 to 29/06/02	26/06/2003
10/10/04 to 29/10/04	27/01/04 to 16/03/04	16/03/2004	10/03/04	
	10/10/04 to 29/10/04	10/10/04 to 29/10/04	10/10/04 to 29/10/04	10/10/04 to 29/10/04
24/07/05 to 27/07/05	24/07/05 to 25/07/05	24/07/05 to 25/07/05	25/07/05 to 27/07/05	25/07/05 to 3/08/05
31/07/06 to 3/08/06	31/07/06 to 3/08/06	31/07/06 to 3/08/06	13/07/06 to 11/08/06	4/08/06 to 22/08/06
18/04/07 to 19/04/07	17/04/07 to 19/04/07			
	17/09/07 to 19/09/07	25/07/07 to 27/07/07	18/07/07 to 19/07/07	25/07/07 to 27/07/07
6/05/08 to 7/05/08	06/05/08 to 07/05/08	06/05/08 to 07/05/08	06/05/08 to 07/05/08	
15/07/08 to 16/07/08	11/07/08 to 22/07/08	2/07/08 to 4/07/08	2/07/08 to 4/07/08	6/08/08 to 7/08/08
27/03/09 to 30/07/09	27/07/09 to 30/08/09	27/07/09	5/08/09 to 6/08/09	26/08/09 to 27/08/09

3.2 Surveyed Quantities

3.2.1 Analysis Compartments

Sand quantity analyses have been undertaken by NSW Department of Lands to determine progressive changes within various compartments within the overall study region from Fingal to Currumbin. Those compartments are shown in Figure 3-1 and have been used in the present study either separately or in combination for the purpose of LTA and sand transport calculations. The survey lines covering Letitia Spit and the entrance area are shown in Figure 3-2.

Figure 3-1 Sand quantity calculation compartments

BMT WBM

Figure 3-2   Survey profile lines – Letitia Spit and river mouth area
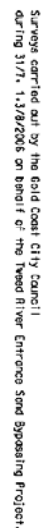
Additionally, surveys have been undertaken of the quantities of sand within the Tweed River to identify changes there associated with movement of sand to or from the river reaches. Those surveys that comprehensively cover the whole system (Figure 3-3), including the entrance area, extend over the period since February 2000. Prior to that time, only approximate data are available indicating a progressively reducing upstream movement of sand. Further, review of the surveyed quantity changes over the longer term of the data identifies a slight movement of sand to deeper water beyond 20m depth offshore from the river entrance that is estimated to have been about 18,000m^3/yr for the period 1993 to 2000, 12,300m^3/yr from 2000 to 2005 and only 1,450m^3/yr from 2005 to 2009. While relatively minor, it is of the same order as the river quantities and has been accounted for in the assessments as a progressive loss from the 'entrance' compartment.
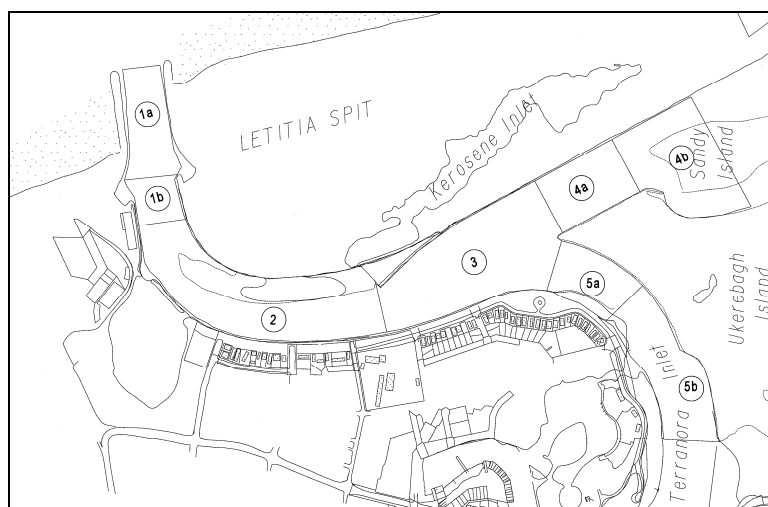
Figure 3-3   Survey compartments within Tweed River

3.2.2   Monthly Time Series

Monthly time series of the quantity changes within each of the analysis compartments have been determined on the basis of:

- The survey data for the dates as listed in Table 3-1; and

- A monthly breakdown of the known quantities of dredging and bypass pumping removed from and placed into each of the various compartments respectively.

This has been achieved by a procedure in which it is adopted that, between each date of survey within each compartment, the measured change is the result of a combination of the known artificial inputs and/or outputs and an assumed underlying constant rate change in sand volume for the period between surveys.

The results of this analysis to July 2009 are shown in Figure 3-4 for the NSW compartments (top), including the river and deep water quantities, and Queensland compartments (bottom). The compartment locations of gain and loss in each case are identified. The resulting total cumulative quantity changes are shown in Figure 3-5. This figure illustrates the progressive reduction of a net quantity of approximately 3.75million cubic metres from Letitia Spit and the entrance/river areas (including Duranbah) and a corresponding gain of about 4.51million cubic metres to Gold Coast beaches since 1993. The corresponding quantities since March 1995 when Stage 1 dredging for the

BMT WBM

TRESB project commenced are a net loss of 4.47 million cubic metres from NSW and a net gain of about 4.98 million cubic metres to Queensland.

The net loss from NSW and the net gain to Queensland over the period of the sand bypassing operations since January 2001 are 2.48 million and 2.65 million cubic metres respectively. These quantities could be expected to match if the rates of sand supply at Fingal and transport out at Currumbin are equal, although this may not be the case.

The reasons for the mismatch between the total quantities lost from NSW and gained at Queensland beaches over the longer periods are not immediately apparent. It could be due to inaccuracies in the surveys and/or an imbalance in the net quantities entering and leaving the overall coastal compartment covered by the surveys. This is explored further in Chapter 7.

Provision has been made in the quantities for a net loss of sand to deep water within the NSW compartments in the vicinity of the entrance at the varying rates (as above) determined from the survey data. However this cannot be properly quantified as not all of the surveys extend sufficiently far offshore. The surveys within the Queensland areas show that there is no loss or gain of sand across the 20m depth limit of the surveys there, with no measurable change in the bed levels at water depths greater than about 15m. While there may be some survey error at such depths, it is of a random rather than systematic nature.

3.2.3 Survey Quantity Accuracy

By necessity, it is assumed for the purpose of the calculation of the LTA and natural bypassing that the quantities derived from the surveys undertaken are sufficiently accurate, within acceptable limits. However, errors may arise due to:

- Insufficient spatial resolution of the survey sampling; and/or
- Measurement error or inaccuracy.

Careful attention has been paid over the years to ensuring that the spatial resolution of the surveys is fine enough for accurate calculation of quantities using modern GIS techniques. The survey line layout for the area south from Snapper Rocks along Letitia Spit is shown in Figure 3-2. Further, strict protocols and procedures are followed to maximise the accuracy of the survey measurements made in terms of:

- Spatial positioning;
- Calibration and setup of the depth sounding equipment;
- Allowance for wave action; and
- Reduction to provide for tidal variations.
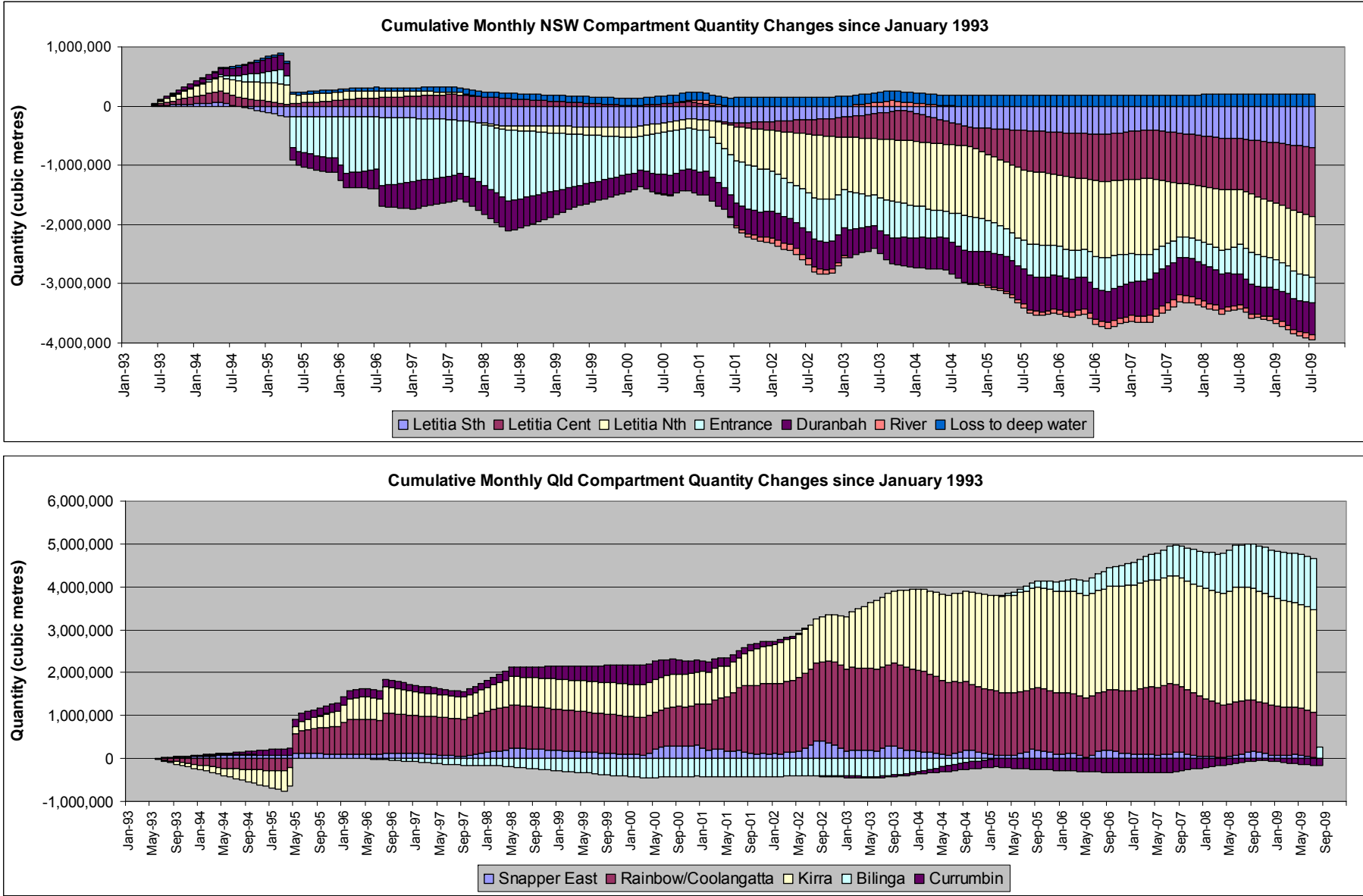
Figure 3-4   Cumulative monthly compartment quantity changes in NSW (top) and Qld (bottom)

Total Cumulative Quantity Change in NSW & Qld since January 1993
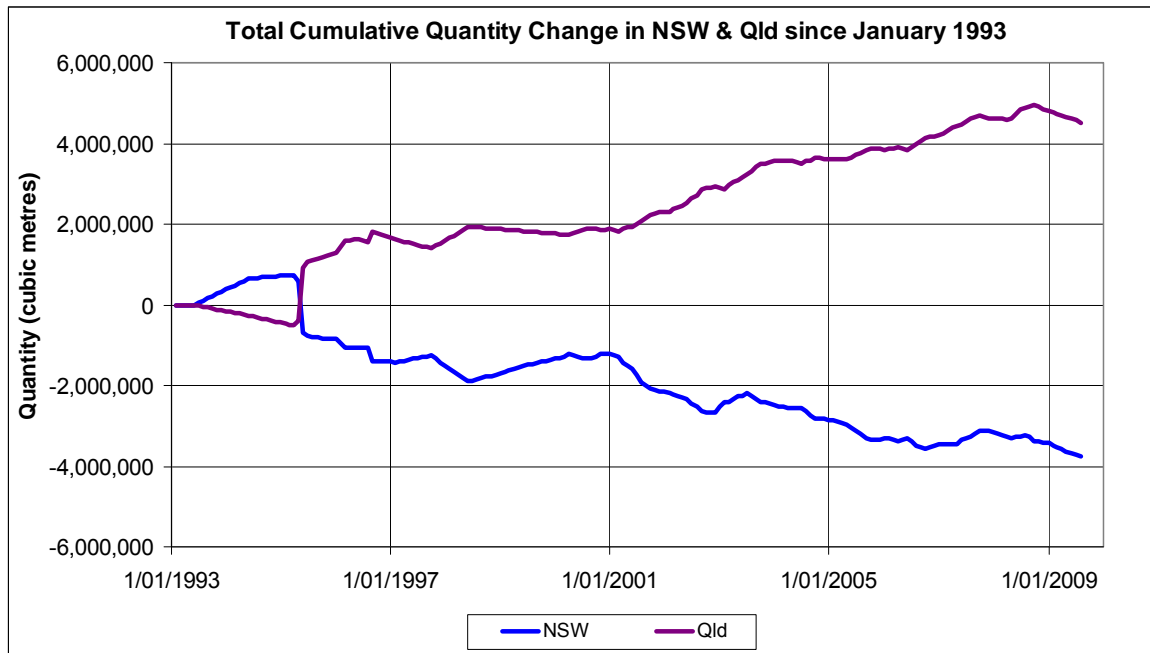
Figure 3-5   Cumulative total change in sand quantities in NSW & Qld since 1993

It is not feasible to quantify reliably the potential error in the quantities obtained. However, it is noted that overall errors in the quantities to be used for the LTA analysis will be minimised due to:

- The random nature of errors in individual depth readings associated with wave motion;

- The independence of measurements undertaken each day over the extended period of each survey exercise, leading to 'averaging out' of any systematic errors on any specific day; and

- The independence of each survey exercise with respect to the constant survey datum (AHD), such that any errors in each survey exercise may be offset by the relative reference to the previous and next survey.

Additionally, the progressive changes in the quantities derived for each compartment have been reviewed to identify and ensure close scrutiny of any apparent discrepancies. Several survey results were checked on that basis and some errors corrected. Figure 3-4 shows relatively smooth progressive changes in final total quantities, without any obvious 'random' variability from one survey to the next, with the significant short term variations clearly associated with dredging and placement events. This suggests that each of the progressive surveys is reasonably consistent with the previous and subsequent survey, without any obvious error.

The analysis procedure may have some error due to occasional mismatches in the timing of surveys in the respective compartments, sometimes resulting from delays due to bad weather during the progress of the survey campaigns. This may result in sand identified in a compartment at one time moving into an adjacent compartment yet to be surveyed. While this is unavoidable, the monthly time series approach adopted for the analysis minimises the errors introduced.

4   LTA CALCULATED FROM SURVEY DATA: EQUATION 1B

4.1   Considerations

A key outcome of this study is the incremental time series of the LTA components since 1993 to July 2009. The Deed of Agreement requires that the Annual Increment (yearly target sand delivery) for the sand bypass system is equal to the LTA, subject to provision for an initial Supplementary Increment over the first 6 years. The LTA definition specifies that the location for the net littoral sand transport is '…a line perpendicular to the coastline, situated one kilometre south of the southern training wall'. The LTA involves the transport that would cross that line 'in the absence of any artificial actions to influence it'.

It is clear that, at that location, the natural sand transport patterns have been influenced by the sand bypassing operations, evidenced by the retreat of the shoreline as well as reduced quantity of sand in the nearshore profile south from there. It is probable that the natural transport rate further south nearer to Fingal has been influenced much less or not at all by the sand bypassing operations.

As such, Equation 1b has been applied with respect to the whole length of Letitia Spit to the southern limit of the surveys (Letitia South compartment), as shown in Figure 4-1. The average annual rate of these values since 2001 indicates the LTA based on the actual behaviour over the 8 years of sand bypassing operations. Comparison of the monthly values derived from Equation 1b with the bypass system delivery (pumping + dredging) undertaken over the period is shown in Figure 4-2.
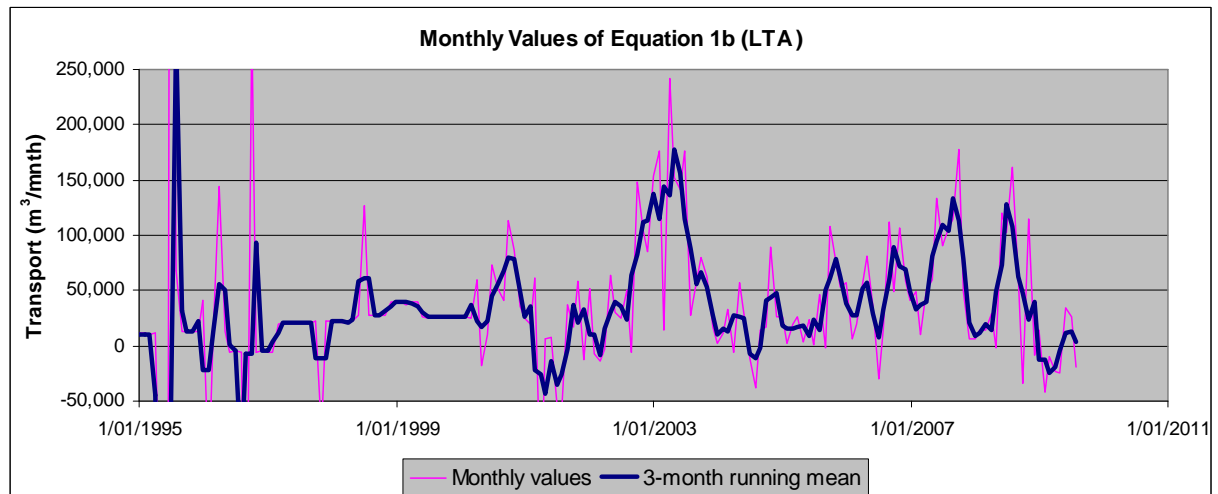
Figure 4-1   Monthly analysis of Equation 1b (LTA)

BMT WBM
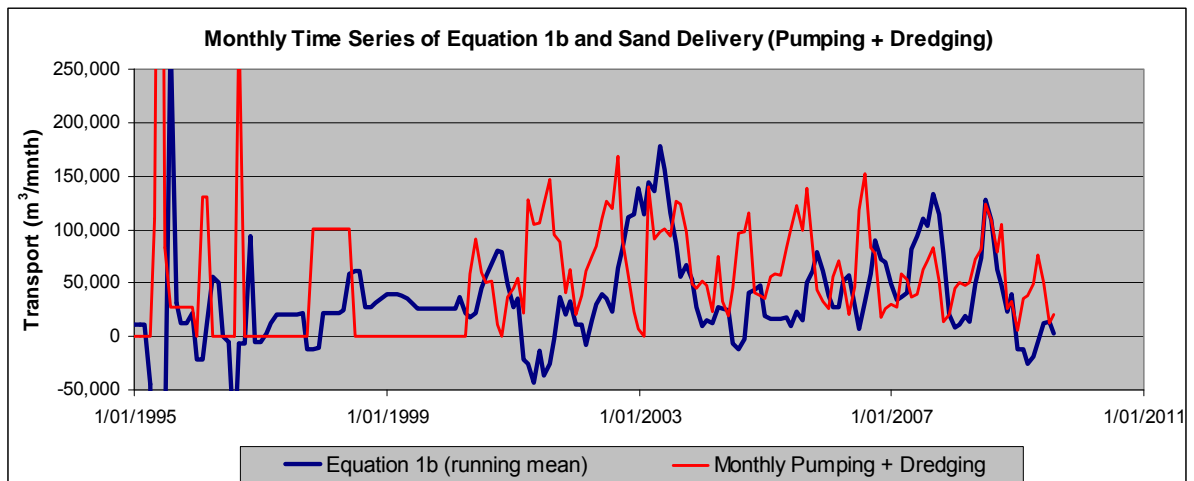
Figure 4-2   Monthly time series of Equation 1b and sand delivery undertaken

The large spikes in the calculated values prior to 1997 most probably result from slight mismatches in the timings of the dredging/placement events relative to the adopted survey dates at that time. The values since 2001 are considerably more consistent.

The average annual LTA rate thus derived for the period from January 2001 to July 2009, covering the period of sand bypass operations, is 509,000m^3/yr. As discussed in Section 2.7, this represents the probable lower limit for the rate of sand supply into Letitia Spit, given that the natural bypassing is unlikely to be less than zero and most probably significantly more than zero. This is consistent with the previous studies that have provided an estimate of the annual average net transport through this region of 500,000-550,000m^3/yr.

The average annual rate of total bypass pumping plus dredging for the same period since January 2001, including the Supplementary Increment period, was 806,000m^3/yr. This excess of sand delivery relative to the net supply of sand is consistent within a minor error margin with the measured net loss of sand from Letitia Spit of 2.48 million cubic metres for that period.

The average LTA rate derived for the period 1995 to 2000 (inclusive), prior to bypassing, was 162,000m^3/yr, indicative of the higher rate of natural bypassing at that time during the initial Stage 1 dredging but prior to commencement of the bypass system operations.

5 ANALYSIS OF LONGSHORE SAND TRANSPORT FROM RECORDED WAVES

5.1 Background

A considerable amount of previous research has been undertaken into the wave climate and longshore sand transport regime in the Tweed River mouth region, with highly varied results. This highlights the difficulty of obtaining quantitatively accurate rates of longshore transport, due to uncertainties in:

- The deep water directional wave climate, which has become reasonably well defined only since directional recorders have been in operation, since 1995 at the Tweed site, 1997 at the Brisbane site, and 2000 at Byron. Recorders at Gold Coast (offshore from the Seaway) and temporarily at Bilinga have also been directional more recently.

- Modelling of wave propagation from the deep water recorder sites to the nearshore locations where sand transport calculations are made. This is particularly difficult along the Letitia Spit area due to the effects of the Fingal Reef.

- The sand transport calculation relationships, their formulation and calibration coefficients.

Accordingly, based on the results obtained from several different and independent attempts at calculating the annual average net transport rate (Pattearson & Patterson 1981; Roelvink & Murray 1993; Hyder *et al* 1997), a rate of 500,000m^3/yr has been adopted as the most reasonable best estimate. This has been used in the Deed of Agreement as the LTA rate to date, with provision for re-assessment following a period of additional data collection and experience with the sand bypass operations.

5.2 Directional Deep Water Wave Climate

5.2.1 Deep Water Data

There is now a substantial record of continuous data from Tweed since 1995, 'Brisbane' off Point Lookout over the period 1997 to present and 'Byron' since late 1999. The Byron data contains many gaps due to interference with the transmitted signal. The directional wave climates from Brisbane (Pt Lookout) and Cape Byron have been compared with regard to their time series and statistical occurrence patterns for height and period and, particularly, their directional distribution and influence on longshore sand transport (Patterson 2007b).

The significant wave height (H$_s$) and period (spectral peak period T$_p$) time series at the two sites generally correspond closely (Figure 5-1). However there are some differences from time to time associated with tracking of weather systems, particularly frontal lows and spatially small storms, over their immediate region.

Figure 5-2 indicates close wave height correlation between the sites in terms of probabilities of exceedance, with some discrepancy for the higher low probability waves probably due to limited available extreme wave data. Figure 5-3 indicates statistical similarity of wave periods between the two sites. The wave directions (related to the spectral peak) at the two sites generally have

reasonably close correlation when they clearly experience the same regional synoptic weather systems (Figure 5-1). However, it is apparent that the Brisbane recorder does not experience the more southerly waves to the extent that the Byron recorder does. Figure 5-4 illustrates the statistical distribution of occurrences of the spectral peak directions. This shows that there is a clear difference in the directional distribution of wave occurrences and thus directional wave energy between the two recorder sites. This is likely to be due to the effects of both:

- Somewhat different exposure due to their spatial separation within the synoptic weather cells affecting the region; and

- Refraction/diffraction effects of Cape Byron and/or the continental shelf for the southerly waves, as occur with extra-tropical lows off NSW.
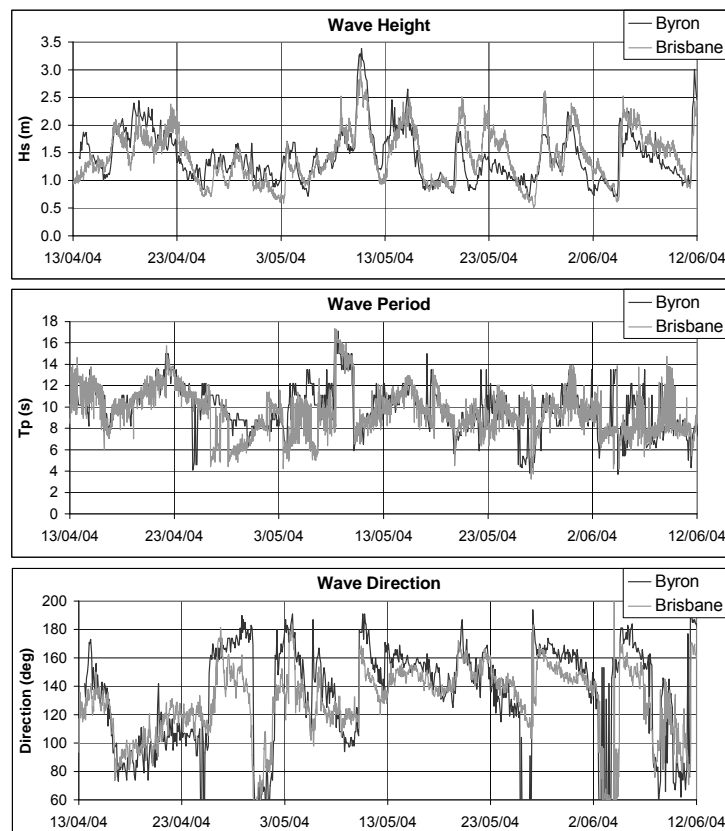
Figure 5-1   Typical wave height, period and direction time series
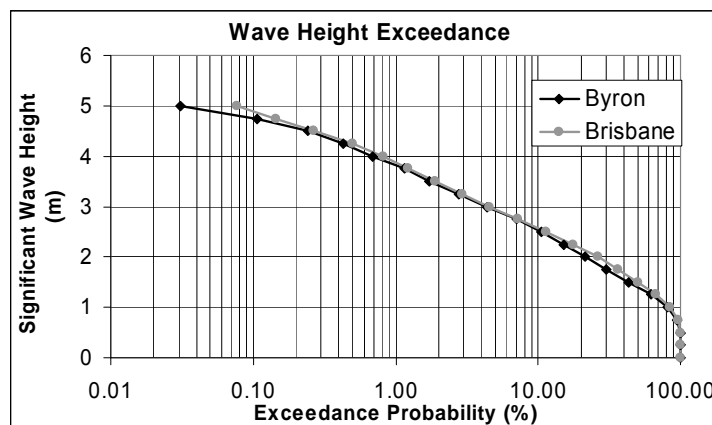
Figure 5-2   Wave height exceedances: Byron & Brisbane

BMT WBM
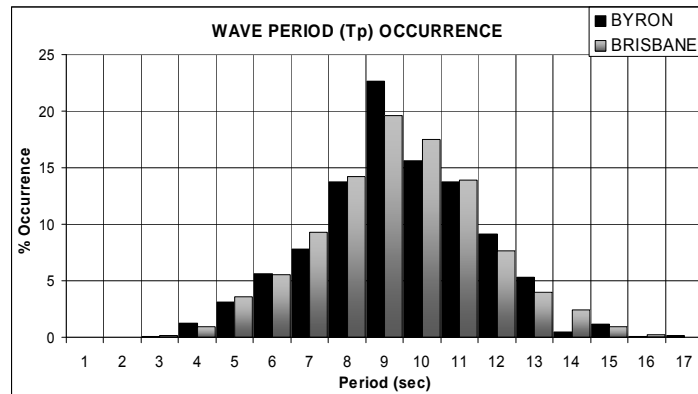
Figure 5-3   Typical wave period occurrence probabilities (%): Byron & Brisbane
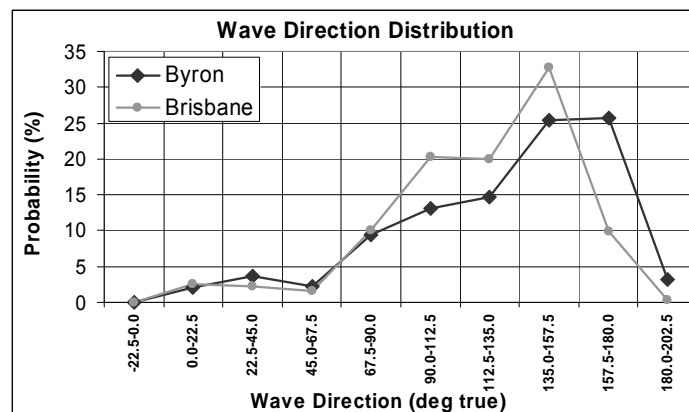
Figure 5-4   Wave direction occurrence distribution: Byron & Brisbane

This has substantial significance for wave propagation relationships and calculation of sand transport rates on the basis of each of the two sets of recorded data. It cannot be assumed that the two data sets are directly equivalent, despite being for essentially the same water depth (approx 80m).

Further, attempts to derive a single deep water wave time series that has consistency with both of the two recorders has proven to be inconclusive because:

- The Byron data is too short and contains too many gaps in data to be used as the primary source of recorded data, despite its preferred location; and

- The Brisbane data does not provide a suitable basis for establishing the deep water southerly wave conditions (160-200 degrees) that are known to occur but which are effectively 'lost' from the Brisbane data set.

Accordingly, a deep water data set has been obtained from the global wave model accessed through ARGOSS (Netherlands), as discussed in Section 5.2.3.

5.2.2   Tweed Directional Wave Data

Directional wave recording has been undertaken at the Tweed Waverider location since 1995, representing the longest available comprehensive data set. The Tweed site was chosen to be sufficiently inshore to avoid the need for wave transformation past the Fingal Reef, while sufficiently offshore to be applicable along much of Letitia Spit and the Tweed River mouth area. As such, it does not represent the deep water conditions, but is directly applicable to the present study.

BMT WBM

5.2.3 ARGOSS Global Wave Model Data

Because of the issues with the recorded data at Brisbane and Byron as discussed above, an extended time series of directional spectral wave data has been obtained from BMT Argoss, Netherlands. This is for a location at approximately 28° 10'S, 153° 53'E (offshore from Point Danger) in about 150+m depth and includes:

- 17+ years wave hindcast of directional wave spectra and derived parameters covering the years 1992 to August 2009, with a time step of 3 hours;

- Wave data of format:

  ➢ directional wave spectra;

  ➢ the following wave parameters:

    ▪ Hs, Hmax, Tp, Tp Dir, Tz and Dir (wind sea);

    ▪ Hs, Hmax, Tp, Tp Dir, Tz and Dir (swell);

    ▪ Hs, Hmax, Tp, Tp Dir, Tz and Dir (total);

- Wind speed and direction.

This has been utilised in the present study primarily as an additional source of wave data to assess the longer term context of the wave conditions and derived LTA, as discussed in Chapter 7.

The Argoss wave data has been compared with the recorded data at Brisbane and Byron. A typical time series comparison for year 2001 is shown in Figure 5-5. This indicates reasonable agreement, but with differences expected in the context that it is for an exposed deep water site whereas the recorders are in depths less than 80m on the continental shelf and the Brisbane recorder in particular is somewhat sheltered from the more southerly waves.

5.3 Sand Transport Analysis Methodologies

Two broad approaches to calculation of longshore sand transport are commonly used, namely:

- 1-dimensional methods that yield a total transport rate for a given incident wave condition as a function of the longshore component of the breaking wave energy flux; and

- 2-dimensional methods that apply spatially varying wave fields and associated wave radiation stresses to generate longshore currents, together with combined wave-current relationships for sand transport at each location within the model domain.

The most widely used of the 1-dimensional methods are the CERC formula (US Army Corps of Engineers 1984, 2002; Smith et al 2003) and the 'Queens' formula (Kamphius 1991). The format of these formulations may be expressed in several ways, most commonly as follows:

BMT WBM
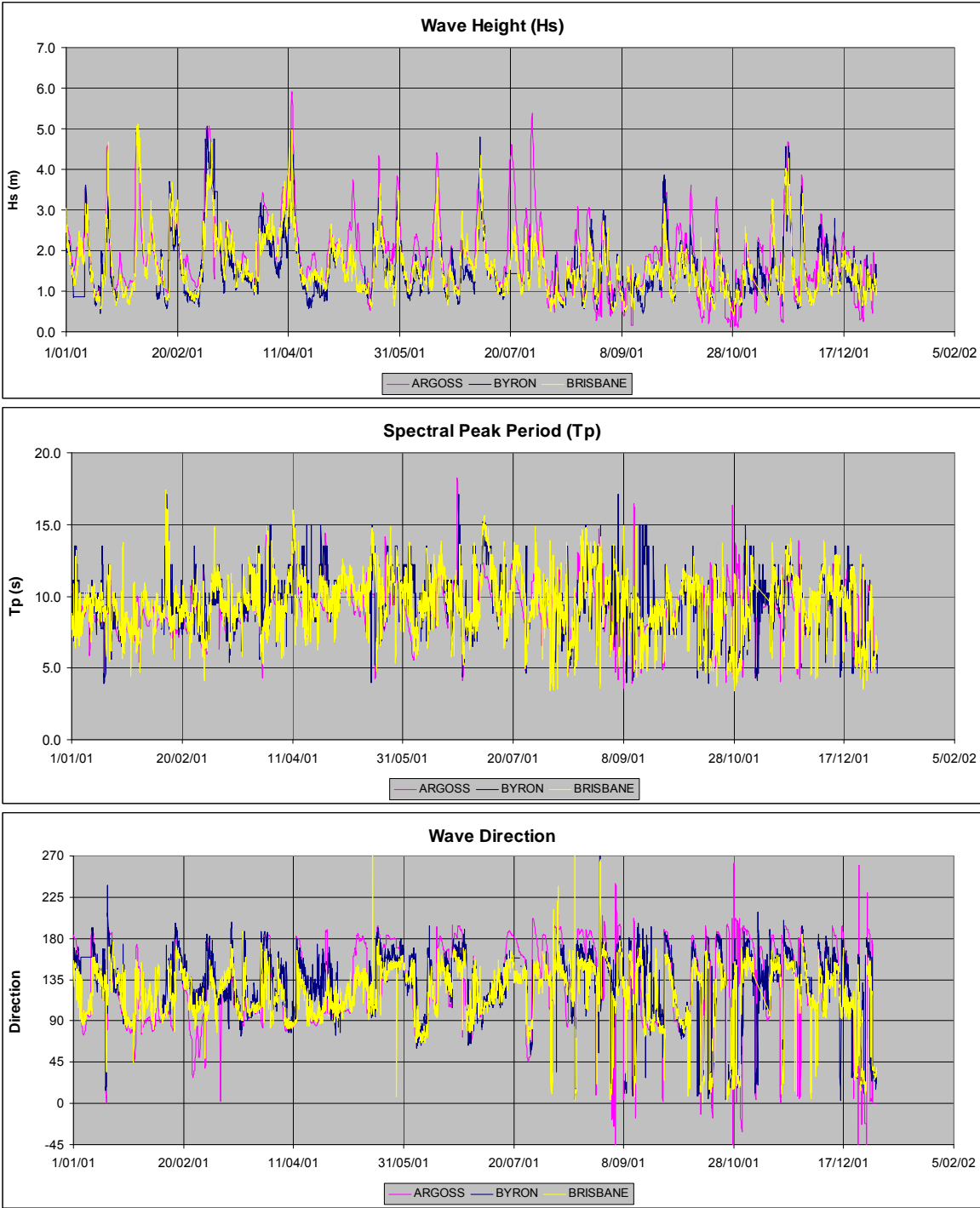
Figure 5-5   Comparison of Argoss wave model data with recorded data

BMT WBM

CERC
$$Q_l = K \left[\frac{\rho \sqrt{g}}{16\gamma^{\frac{1}{2}}(\rho_s - \rho)(1-n)} \right] H_b^{\frac{5}{2}} \sin(2\alpha_b)$$

Queens
$$Q_l = K_q \left[\frac{\rho}{\rho_s(1-n)} \right] L_o^{1.25} T_p^{-1} H_b^{2} m_b^{0.75} D_{50}^{-0.25} \sin^{0.6}(2\alpha_b)$$

where:

K = Dimensionless Coefficient

K_q = Coefficient typically (approx 1.33 for m³/s or 41x10⁴ for m³/yr)

H_b = Breaking significant wave height

T_p = Spectral peak energy period

ρ_s = Density of sediment

ρ = Density of water

g = Acceleration of gravity

n = Sediment porosity

γ = Wave breaker index

α = Wave breaking angle

m_b = Nearshore profile slope

D_{50} = Median sediment grain size

It should be noted that the CERC formulation above makes the shallow water assumptions that:

1. The wave group velocity at breaking C_g is approximately equal to the phase velocity C; and

2. The phase velocity may be approximated as $\sqrt{(gd)}$.

These assumptions break down for large breaking wave heights and BMT WBM recommends use of the full relationship for energy flux ($\overline{EC_g}$), with the sand transport rate expressed as:

CERC_2a $Q_l = K_1 H_b^2 C_g \sin(2\alpha_b)$

or, as reworked for the case of contours straight and parallel to the shoreline:

CERC_2b $Q_l = K_1 H_o^2 C_b \sin(2\alpha_o)$

where K_1 is again a calibration coefficient relating to the bulk volumetric sand transport rate.

The CERC formula relies on the dimensionless coefficient K (or K_1) for calibration. With the correct application of this coefficient as a calibration parameter, accuracy better than ±50% may be obtained with respect to rates for individual wave cases (Huchzermeyer, 2005; King, 2006; Smith, 2006).

The CERC equation continues to be useful primarily because of its simplicity and because of the failure of more sophisticated models to clearly demonstrate substantially superior accuracy relative to the effort required to employ them (King 2006).

BMT WBM

Research has been conducted to provide estimates for appropriate K values relating to grain size. For grain sizes less than the 1.0mm the Coastal Engineering Manual (Rosati *et al*, 2006) provides an approximate guide for appropriate K values. Figure 5-6 shows the Coastal Engineering Manual data (based on H_{rms} wave heights) (Rosati *et al*, 2006). For sediment sizes greater than 1.0mm King (2006) completed a thorough literature review and collated the data provided in Figure 5-7. King recommends the use of the curve identified as "Equation 8" in Figure 5-7.

The Queens formula contains explicit dependence on grain size, beach slope and wave period that is not included in the CERC formula.
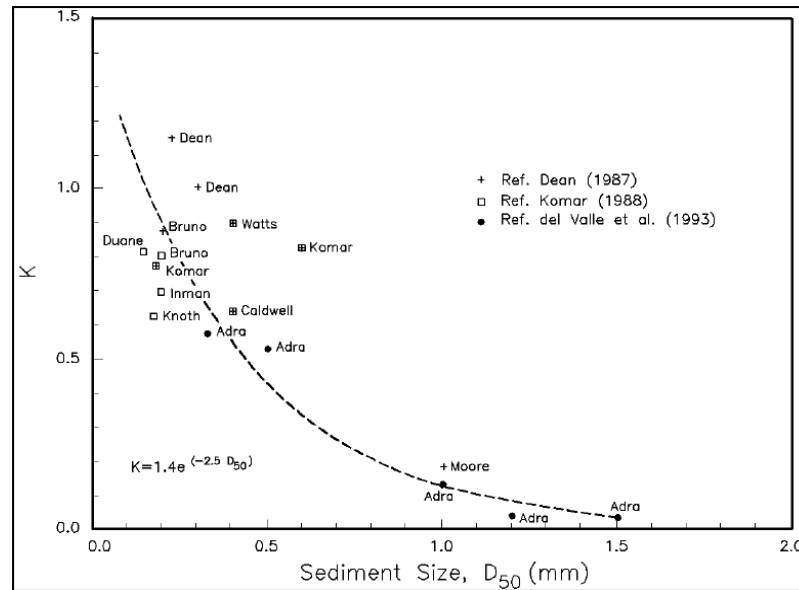
Figure 5-6   Coefficient K - grain size D_{50} < 1.0mm (Rosati *et al*, 2006)
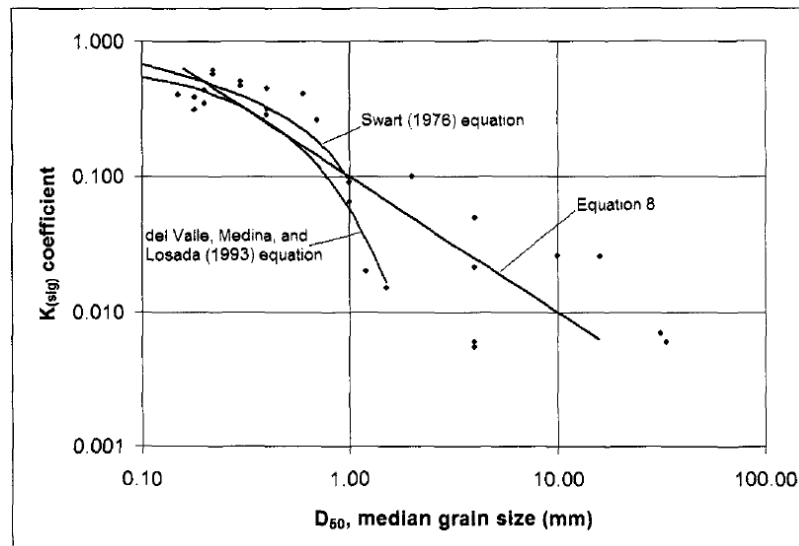
Figure 5-7   Coefficient K - grain size D_{50} > 1.0mm (King 2006)

Comparisons between the Queens formula and the CERC equation from various sources (Smith 2006; Huchzermeyer 2005; Wang et al 2002) indicate that the Queens formula is preferred over an un-calibrated CERC equation. However, if the CERC equation is calibrated using recorded/estimated littoral drift volumes, both methods provide comparable results. The CERC formula predicted

BMT WBM

inconsistent transport under spilling and plunging breaker types. However, by including wave period, the Queens formula accounted for this difference better. General experience is that the originally suggested K value of 0.39 in the CERC formula over-predicts the transport rate. There are differences also relating to larger storm waves and low wave conditions. As a guide, the recommendation is that CERC will provide an upper bound and Queens a lower bound to long term net transport rates.

Patterson (2007b) applied both Queens formula and the CERC_2a form of the CERC relationship for the beaches of northern NSW and SE Queensland and, for input of the significant wave height, found an appropriate value for K_1 of 9.6×10^{-3} to give the transport as m^3/s, equivalent to approximately 0.3×10^6 for m^3/yr, when calibrating to an annual average net transport of 500,000 m^3/yr for the Gold Coast beach system. For a porosity (n) of 0.35, it can be shown that the coefficient $K = 16.85\,K_1$, indicating a calibrated value of 0.16 for m^3/s. This is significantly less than the originally suggested value of 0.39.

With regard to calibration of the Queens formula, the coefficient K_q may be considered together with several of the constant parameters as part of the calibration process. For example, adopted values of porosity (0.35 to 0.4), salinity (25 to 35 ppt) and effective beach slope may all affect the outcome. For a beach with barred profile that affects the position of wave breaking, depending on wave height and tide level, specification of a single slope value may not be valid. Patterson (2007b) found that the recommended value of K_q calibrated well to the average annual net rate of 500,000 m^3/yr for n = 0.35, salinity of 30 ppt and a slope of 1 in 33.

5.3.1 Previous Longshore Transport Investigations

In all of the previous assessments, calculation of sand transport rates and, in particular, transport rate differentials determined theoretically from wave data proved to be sensitive to the directional wave climate used. While good data for height and period (spectral form) were available for many years, wave direction information was, for all the earlier studies, based predominantly on hindcasting.

The so-called Delft Report (Delft Hydraulics Laboratory 1970) used quite coarse wave data from ship observations in conjunction with analysis of survey data on the rate of sand accumulation against the Tweed River training walls and concluded that the annual net longshore transport for the Gold Coast was about 480,000 m^3/yr at both Letitia Spit and The Spit (Gold Coast). However they determined a rate of only 180,000 m^3/yr at Tugun, indicating significant sand loss off Point Danger and associated shoreline erosion of 300,000 m^3/yr along the Gold Coast. Pattearson & Patterson (1983) used additional recorded wave data with hindcast directions to determine that the longshore transport rate along the Gold Coast was essentially constant at about 500,000 m^3/yr with, at most, only a minimal gradient. This was confirmed by further investigations undertaken by Delft Hydraulics (Roelvink & Murray 1993), based on additional analysis and extensive analysis of survey data to confirm the quantities and rates of accumulation and erosion caused by the Tweed River training walls following their construction in 1962.

Macdonald & Patterson (1984) used analysis of survey data to show that the erosion that was occurring along the Gold Coast was caused predominantly by coastal structures including training walls, groynes and seawalls with balance between the updrift accretion and downdrift erosion, confirming that the net longshore transport rate was essentially uniform along the Coast. Andrews & Nielsen (2001) analysed comprehensive survey data and bypassing rates, together with 2-

BMT WBM

dimensional modelling of longshore transport, at and adjacent to the Gold Coast Seaway to assess the nature and rates of sand accumulation on the ebb delta bar there. They found a total net longshore transport at the Nerang sand bypass system of about 635,000m^3/yr of which 440,000m^3/yr were being artificially bypassed. Patterson (2007a) determined a local gradient of 80,000m^3/yr in the longshore transport rate between Surfers Paradise and the Seaway, supplied by a local input of sand from the depleting remnant bar lobe in deeper water along the Spit, suggesting a net longshore transport rate at Surfers Paradise of 550,000m^3/yr.

For the Tweed River entrance area, 2-dimensional modelling was undertaken by WBM to identify the cross-shore distribution of the longshore transport as part of the EIS/IAS for the sand bypassing (Hyder et al 1997; Patterson 1999). It utilised the van Rijn sand transport methodology (van Rijn 1989) based on the available BMO global wave model data for the period 1989-1995 and, without modification of conventional relationship coefficients in any attempt to 'calibrate' the calculated rates, derived an annual average net longshore sand transport rate for Letitia Spit over that period of 545,000m^3/yr. For other sites in the area, around Snapper Rocks to Kirra, the average varied from a low of 493,000 to a high of 601,000m^3/yr. The average for all sites was 551,000m^3/yr and the standard deviation of variability was 49,100m^3/yr (9%). In the absence of any other long term directional wave data at that time, it was not known how reliable or representative this data or the sand transport rates determined were.

The 2-dimensional modelling indicated that longshore sand transport occurs typically out to water depths up to 12-15m at Letitia Spit, with typically 65% occurring between water depths of 2 and 8 metres, about 25% in depths less than 2m and 10% in deeper water out to about 15 metres. Macdonald & Patterson (1984) supported that finding, presenting survey data showing that the downdrift erosion effect of the Tweed River training walls, related directly to longshore transport losses, extended out to about 12-15 metres water depth at Coolangatta/Kirra.

5.3.2 Calculation of Longshore Sand Transport Rates

5.3.2.1 Scope and Application of Calculated Rates

While the LTA may be derived directly from the survey data using Equation 1b, it is necessary to calculate the net longshore sand transport rates at one or more locations to determine the component values and trends of the Letitia Spit transport and natural bypassing. Transport rates have been calculated directly from the wave data for Currumbin (south of Elephant Rock) to satisfy the required input to the calculation of natural bypassing (Equation 2) and the LTA using Equation 2b. As well, rates at Letitia Spit have been calculated from the wave data for direct comparison with those derived separately from the natural bypassing and other measured data.

Additionally rates have been calculated for other sites in the region including Cudgen (south of Kingscliff) and Dreamtime Beach for general comparison and application to assessment of the long term context, as discussed in Chapter 7. Estimates of the transport at Cudgen and Dreamtime Beach sites provide additional information for understanding of sand supply to Letitia Spit and the sensitivity of the longshore transport processes in the region to varying deep water wave conditions.

For Letitia Spit, previous experience has shown that wave refraction and longshore transport calculation at or near Fingal, derived from either the Tweed recorder or deep water recorders is not reliably accurate because of its close proximity to the Fingal Reef and Cook Island. The specified

location for the LTA assessment is removed from those influences and is more suitable for application of the Tweed recorder wave data.

5.3.2.2 Procedure for Calculation of Longshore Sand Transport

The conventional 1-dimensional littoral sand transport relationships (CERC; Queens) have been used. Consistency between the various sites to be analysed was achieved by applying directly a compatible methodology with identical coefficients for all sites. This involved:

- Analysis of spectral wave propagation from deep water using SWAN to provide refraction transformation relationships to both the recorder locations and various nearshore locations in 10m depth along the coast;

- On the basis of these transformation relationships, secondary relationships between the recorders and from each recorder to the nearshore calculation sites were derived, allowing a flexible basis for both validating the propagation analysis and determining input time series wave information into the sand transport calculations;

- For each wave record in the data time series:

  - Representation of wave conditions in terms of the significant wave height (H_s), spectral peak period (T_p) and direction at the spectral peak as routinely analysed by the respective agencies (no spectral resolution of sea and swell);

  - Estimation of the bed friction provision based on wave height and direction;

  - Further propagation to the break point to estimate breaker height and angle on the basis that the nearshore contours shallower than 10m are essentially straight and parallel; and

  - Calculation of the longshore transport rate for that time increment.

A time series of longshore transport has been determined for each location from which monthly/annual net transport results may be derived. While the absolute results contain some uncertainty, subject to calibration, the relative transport results should be consistently compatible and will give a reliable indication of any significant gradients and differentials.

Both the Brisbane and Tweed directional wave data have been used to calculate transport rates for Letitia Spit and Currumbin, based on wave propagation modelling to those locations. The transport results from each recorder source have been compared.

5.4 Wave Propagation Modelling

5.4.1 Model Setup

While the Tweed recorder data may be applied directly to theoretical calculation of littoral drift rates along Letitia Spit, calculation of transport at other locations, particularly Currumbin for assessment of natural bypassing, requires regional wave propagation modelling to establish the relationships between each recorder site and sand transport assessment location for the range of prevailing deep water wave conditions. SWAN wave propagation modelling has been used for that purpose. A series of nested 500m to 50m models have been established, as shown in Figure 5-8. SWAN modelling was carried out for a range of representative wave conditions and the results at different

locations were used to develop a series of transformation tables for conversion of wave height and direction from each of the reference recorders to the calculation sites has been created as lookup tables accessed by the time series wave propagation and longshore sand transport modelling software.
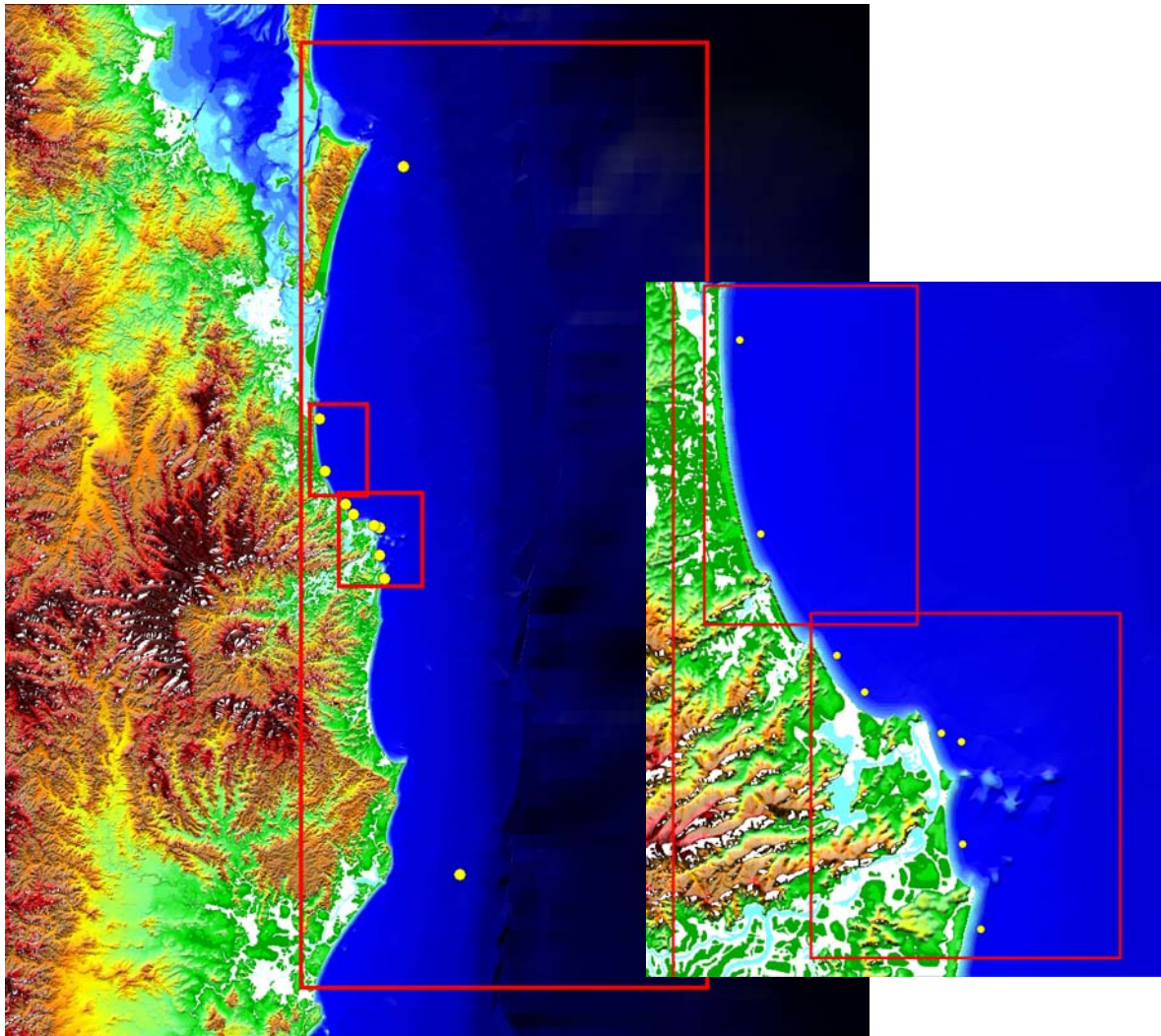
Figure 5-8   SWAN nested wave propagation models

A major factor in this assessment is the effect of the Fingal Reef which extends considerably to seaward (some 5-6km) of Fingal. Experience to date has been that this is extremely difficult to model in either 1-D or 2-D modelling frameworks. The present study has attempted to identify means of either representing the reef more simply to obtain sufficiently accurate results from 2-D modelling or using direct data correlation methods to define the relationship between wave conditions at the Tweed recorder and the other recorders, particularly for the more southerly waves affected. This is discussed further below.

5.4.2   Wave Propagation Modelling Calibration

Calibration of the wave propagation modelling, predominantly for bed friction and directional spreading, has been undertaken by cross-correlating the results (height, period and direction) from the model using Brisbane as the reference source with those measured at each of the nearshore recorder locations at Bilinga (Figure 5-9), Gold Coast (Figure 5-10) and Tweed (Figure 5-11) in terms

of comparison of the wave time series for each site. The consistent match of results is subject to compatibility of the wave trains affecting the deep water and nearshore sites at any given time, as identified by compatibility of the sequence of spectral peak energy periods (Tp), which is not always the case. As well, a similar comparison is made for Bilinga waves derived from the Tweed recorder (Figure 5-12). Comparison of the Bilinga waves predicted from the Brisbane and Tweed source recorded data is shown in Figure 5-13.

These results indicate the following:

- Propagation from deep water to the Tweed recorder site remains problematic, with the wave direction results being less than ideal while the wave height and period show quite good correlation;

- The relationships between the Brisbane recorder and Bilinga and Gold Coast recorders give good results for transformation to those sites, with the Brisbane to Bilinga result somewhat better for directions;

- The relationship between the Tweed recorder and Bilinga gives reasonably good results for transformation directly from Tweed to Bilinga.

Thus, it is concluded that the wave propagation results are suitable for calculations of:

- Sand transport at Currumbin from Brisbane or Tweed data;

- Sand transport at Letitia Spit from Tweed data;

- Sand transport at other exposed sites (e.g.Cudgen) from Brisbane data.

The analyses undertaken include calculation of transport from both Tweed and Brisbane recorders for most sites, and the results compared.

BMT WBM
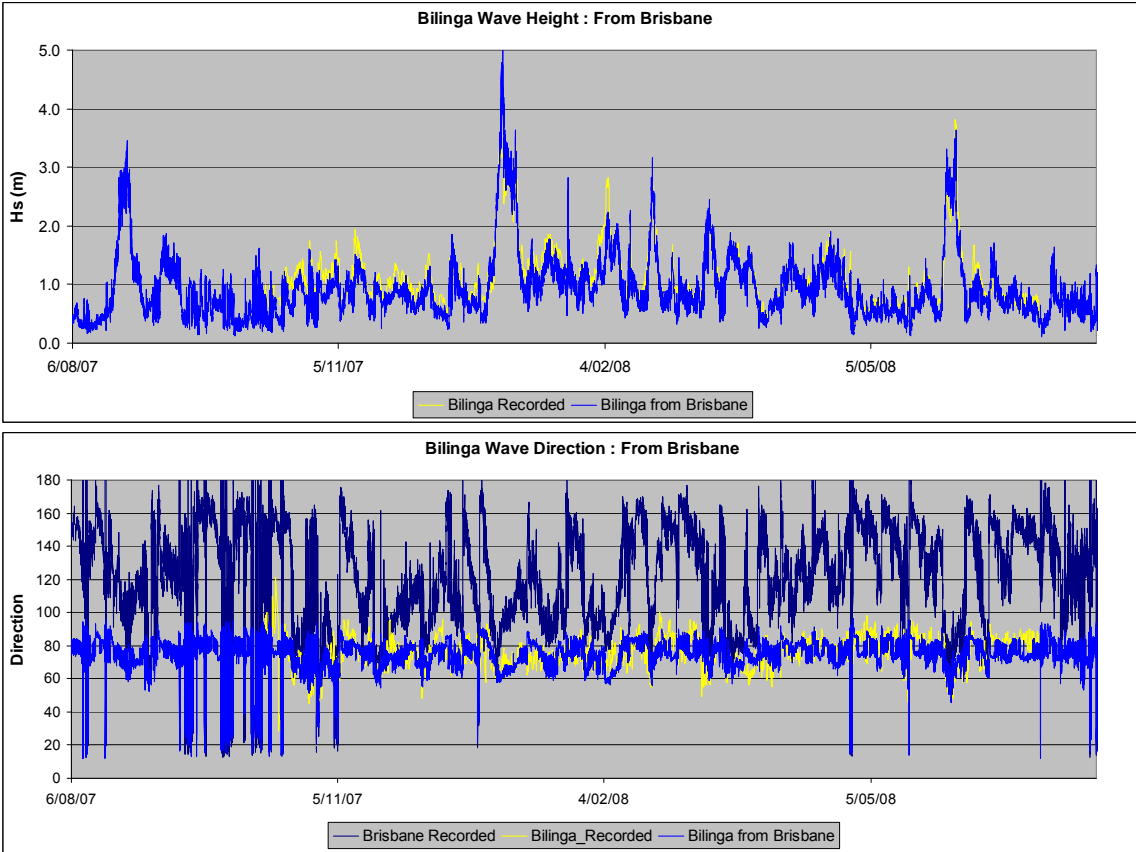
Figure 5-9   SWAN calibration: Bilinga from Brisbane recorder
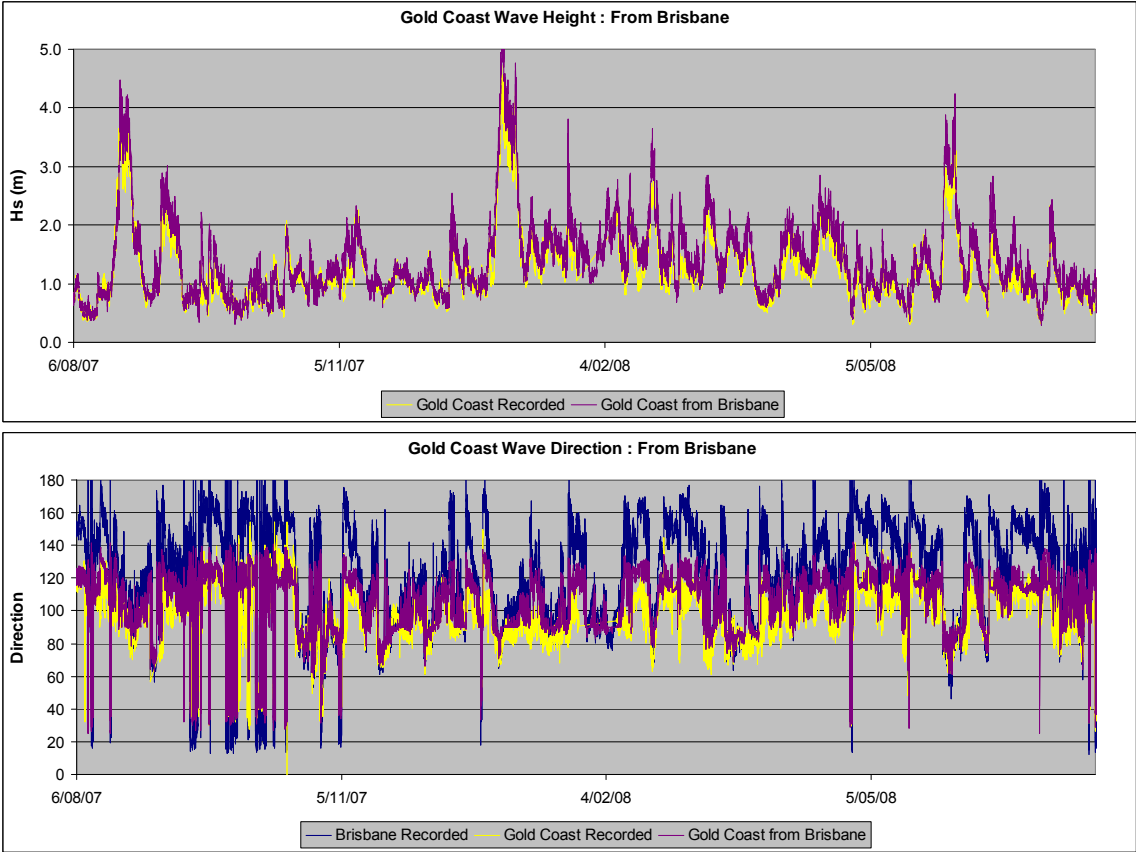
Figure 5-10   SWAN calibration: Gold Coast from Brisbane recorder
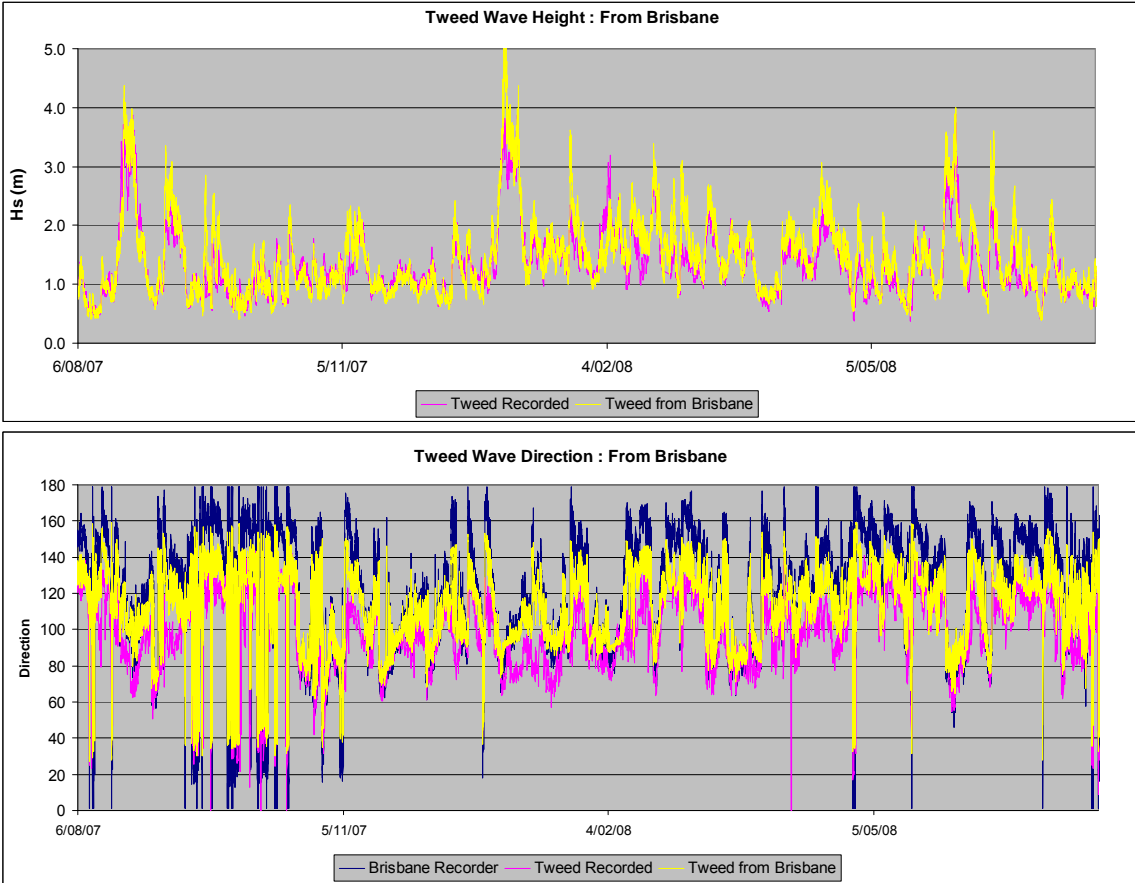
Figure 5-11   SWAN calibration: Tweed from Brisbane recorder
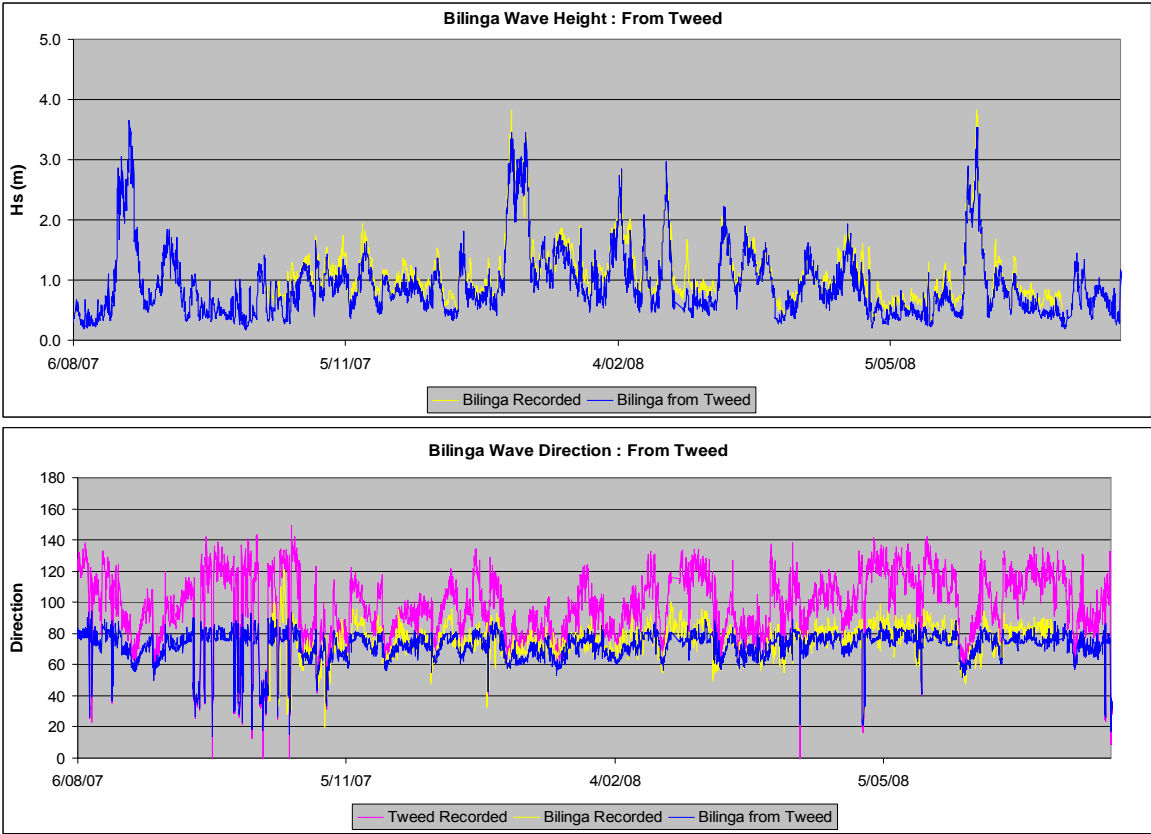
Figure 5-12   SWAN calibration: Bilinga from Tweed recorder
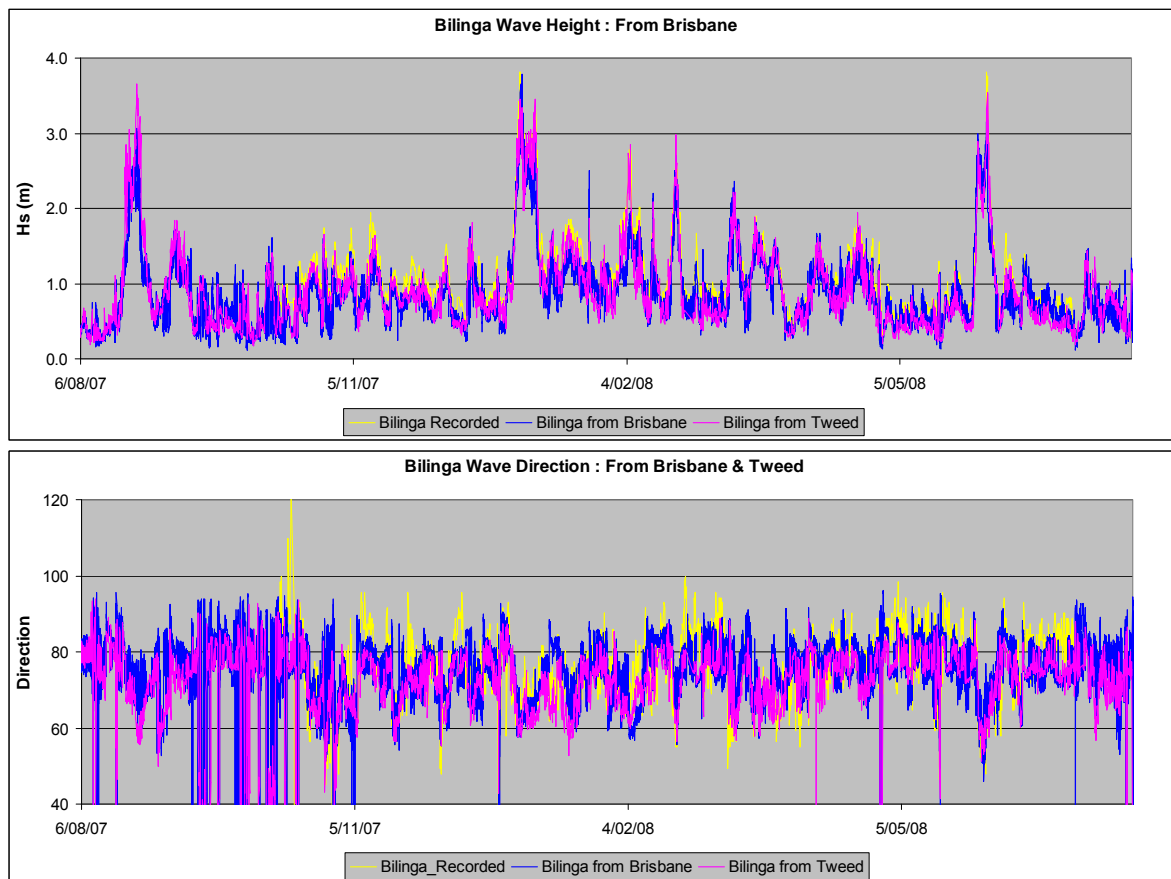
Figure 5-13   SWAN calibration: Bilinga from Tweed & Bilinga from Brisbane

5.5 Longshore Sand Transport at Letitia Spit and Currumbin

The LTA may be derived directly from the survey and sand delivery (pumping plus dredging) data (Equation 1b). However, theoretical calculation from wave data of longshore sand transport rates at Currumbin is required in Equation 2a for determination of the natural bypassing to Queensland. This may then be used to determine the longshore transport rates being supplied along Letitia Spit (via Equation 1a).

Theoretically calculated transport rates for Letitia Spit are useful for both:

- Correlation with rates derived from the natural bypassing and LTA for confirmation of the 'calibration' coefficients used in the CERC / Queens relationships; and

- Provision of a mechanism for determining what the rates there would have been in the absence of Letitia Spit shoreline alignment changes due to bypass system operations.

Because the wave propagation modelling has been shown to be acceptably accurate and reliable in terms of the relationships between both the Brisbane and Tweed recorders and Bilinga, both have been used for that purpose. Because of the longer data set, the Tweed data has been used as the primary input reference data for calculation of sand transport at both Letitia Spit and Currumbin. Time series results have been obtained using both the CERC and the Queens relationships for initial comparative purposes, each 'calibrated' to an average annual rate of approximately 500,000m^3/yr at

BMT WBM

Currumbin, for the period of wave data initially to 2008. Consistent with the discussion in Section 5.3, the coefficients used are:

CERC:
K_1 = 0.96x10^{-3} for m^3/s (equivalent to 0.303x10^6 for m^3/yr), equivalent to a *K* value of 0.16

Queens:
K_q =0 133x10^{-2}; m_b=0.03; n=0.35 for m^3/s.

The suitability of these calibrated coefficients is discussed further in Section 6.2.3.

5.5.1   Comparison of Calibrated CERC and Queens Formulae

Figure 5-14 shows a comparison of the monthly transport rates derived from both the CERC and Queens formulae for the Currumbin site, based on the Tweed recorded waves, for the period 1995 to 2008. This shows close agreement between the two methods once the coefficients are calibrated equivalently. Neither method appears superior. Accordingly, while the Queens method has been applied consistently in this study in terms of the calculated time series transport rates derived from the wave data, the results and study outcomes would be essentially identical using CERC.
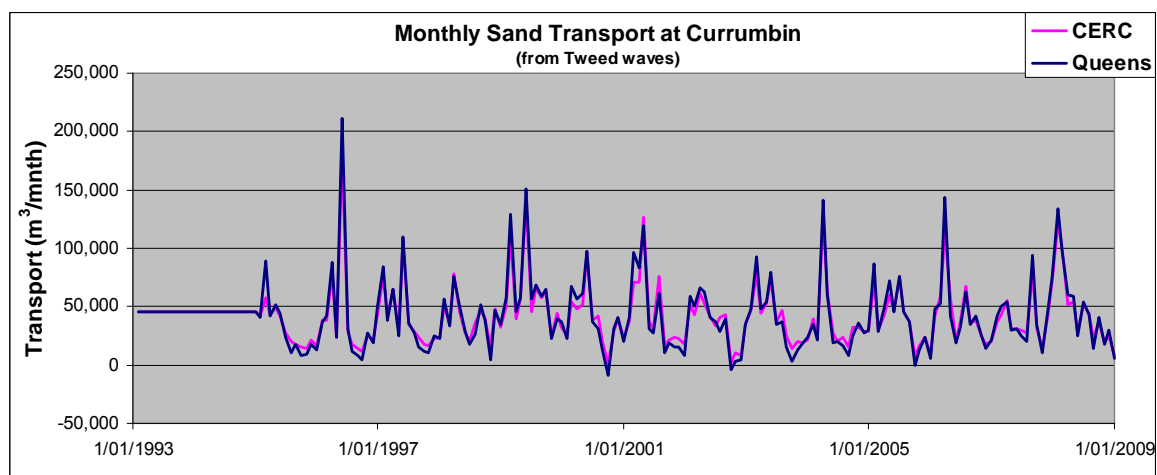
Figure 5-14   Comparison of CERC and Queens formulae at Currumbin

5.5.2   Transport Rates Calculated at Currumbin & Letitia Spit

Results of the calculation of transport at Currumbin based on the Queens formula, calibrated for the period 1995 to 2008 using both Brisbane and Tweed as the reference recorded wave data, are shown in Figure 5-15 and Table 5-1.

Table 5-1   Calculated transport at Currumbin

Annual Average Net Transport at Currumbin (m^3/yr)		
Period of Calculation	**From Brisbane waves**	**From Tweed waves**
1995 to 2008		506,000
1995 to 2009		527,000
1995 to 2000		511,000
1997 to 2009	553,000	540,000
2001 to 2009	548,000	537,000

BMT WBM
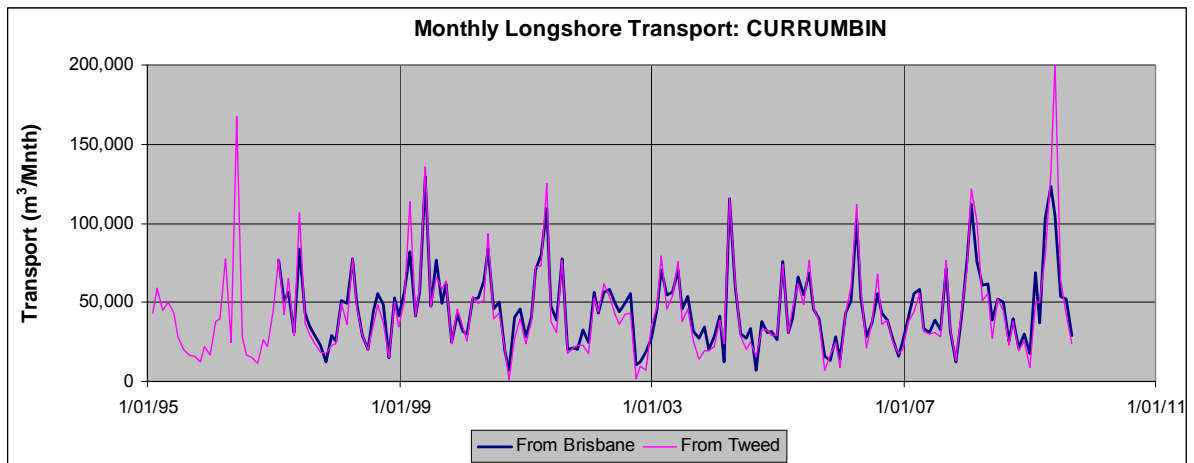
Figure 5-15   Currumbin monthly transport from Tweed & Brisbane waves

It can be seen that the annual average transport rates vary significantly, depending on the period covered, although all the rates determined lie typically in the range 500,000-550,000m^3/yr.   The calibrated result for Currumbin to 2008 is marginally higher than the target value, at 506,000m^3/yr. The annual average rate to July 2009 is significantly higher at 527,000m^3/yr (Tweed wave data), indicating a period during 2008-09 of wave conditions that cause relatively high transport at Currumbin, for example high wave energy from more easterly rather than southeast directions, as is evident in Figure 5-15.

These results show reasonable agreement for the two independent wave data sources for the periods from 1997 when both recorders were operating. The range of results obtained, from 500,000 to 550,000m^3/yr, is consistent with previous investigations, as discussed in Section 5.3.1.

The theoretical transport rates at Letitia Spit have been calculated for a location 1,000m south of the southern training wall, the location consistent with the Deed of Agreement and also where the propagated Tweed wave conditions are most readily applied.   However, at that location, the alignment of the shoreline has varied significantly since 2001 as a direct result of the sand bypass operations. As such, the transport rates there are not consistent with the natural supply to Letitia Spit past Fingal.

The shoreline alignment variation has been determined from a combination of the surveys and aerial photography, considering the RL 0.0m and the -2.5m contours in the surveys and the visible dune toe and high water mark in the photography. The time series of shoreline alignments is illustrated in Figure 5-16 and has been incorporated into the transport calculations. As such, the rates derived are an estimate of the actual rates, compatible with those derived directly from the natural bypassing and survey data, not those that would have occurred in the absence of the impacts of the sand bypass operations.
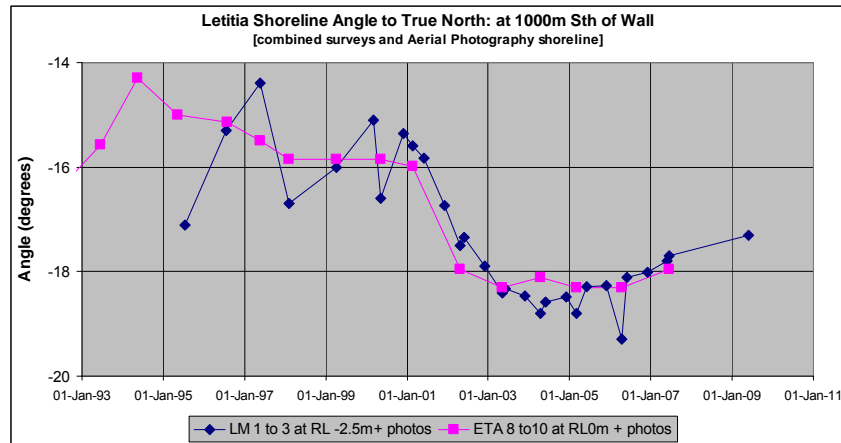
Figure 5-16 Variation in shoreline alignment at Letitia Spit

The calculated monthly transport rates for Letitia Spit are presented in Figure 5-17 and Table 5-2, utilising the shoreline angles shown in Figure 5-16. While there is reasonable agreement between the results from the two wave recorders, there are periods of significant difference (eg early 1999), leading to differences in the annual average results. The results for this site based on the Tweed recorder are preferred in this study.
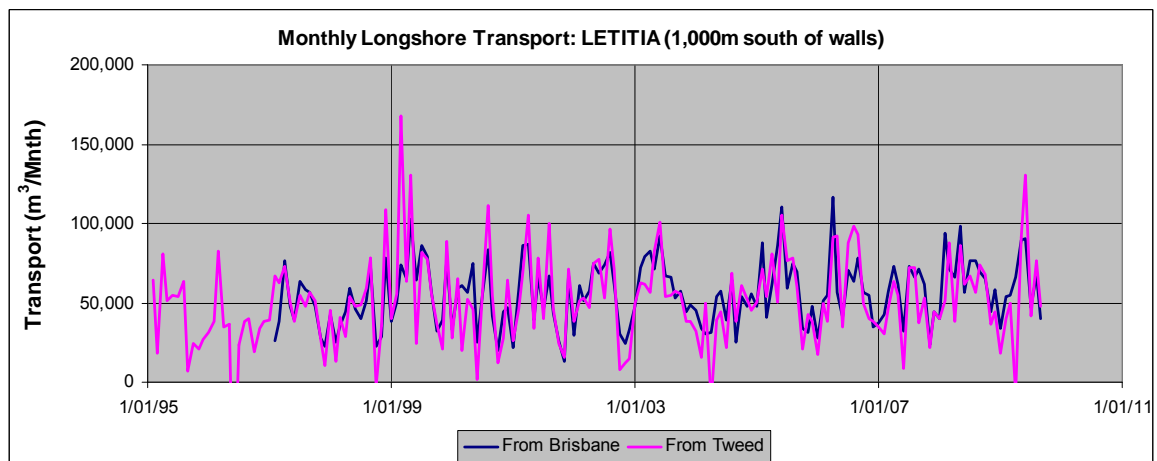
Figure 5-17 Letitia Spit transport from Tweed & Brisbane waves

Table 5-2   Calculated transport at Letitia 1,000m South of Walls

Annual Average Net Transport at Letitia Spit (m³/yr)		
Period of Calculation	**From Brisbane**	**From Tweed**
1995 to 2008		605,000
1995 to 2009		610,000
1995 to 2000		558,000
1997 to 2009	669,000	640,000
2001 to 2009	696,000	646,000

It is significant that, apart from the result for 1995-2000 prior to bypassing, these transport rates are significantly higher than those at Currumbin as a direct consequence of the changed shoreline alignment. The sand bypass operations have caused shoreline recession that has increased the effective breaking wave angles, thereby increasing the local transport rates significantly.

6   CALCULATION OF NATURAL BYPASSING AND LTA

6.1   Natural Bypassing & Total Transport at NSW/Qld Border

The monthly increments of the 'natural bypassing' and the total wave-current driven sand transport at the NSW/Qld border have been calculated using the monthly net sand transport rates at Currumbin and the monthly quantity changes along the Queensland beach system, in accordance with Equations 2a and 2b respectively. The time series results are shown in Figure 6-1.
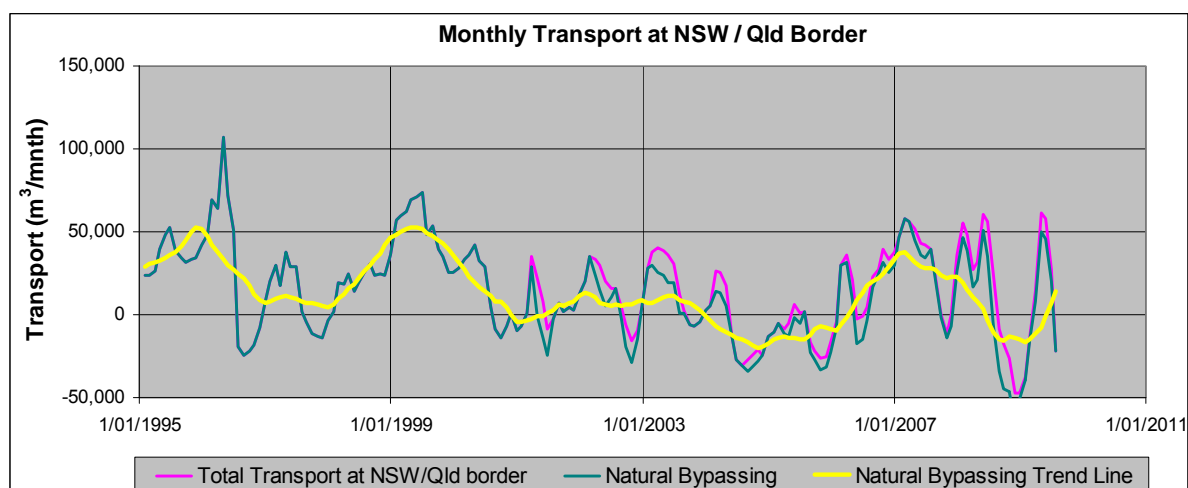
Figure 6-1   'Natural Bypassing' and total transport at NSW/Qld border

These rates show a clear trend of marked reduction in natural bypassing after commencement of the sand bypass operations in 2001. There are extended periods of negative (southward) transport across the border alignment indicating that sand discharged there from the bypass system outlet may drift south into the Duranbah embayment from time to time.

There is not a substantial difference between these transport rates, the placement at Duranbah being relatively minor. As such, issues relating to attempting to distinguish accurately between the transport across the Duranbah compartment of the sand passing the north training wall and that placed there are minor.

These results indicate the progressive sand transport rates at the border as listed in Table 6-1.

Table 6-1   Calculated transport at NSW/Qld Border

Annual Average Net Transport at NSW/Qld Border (m³/yr)		
Period of Calculation	**Natural Bypassing**	**Total Transport**
1995 to 2009	156,000	205,000
1995 to 2000	322,000	322,000
2001 to 2009	40,500	123,500

BMT WBM

6.2 Sand Transport at Snapper Rocks & Letitia Spit Sites

6.2.1 Rates Derived from Survey Data

The monthly net sand transport rates at the various locations along Letitia Spit and at Snapper Rocks have been calculated using Equations 3a to 3f, as outlined in Section 2.6. The rates thus derived are illustrated in Figure 6-2 and listed in Table 6-2.
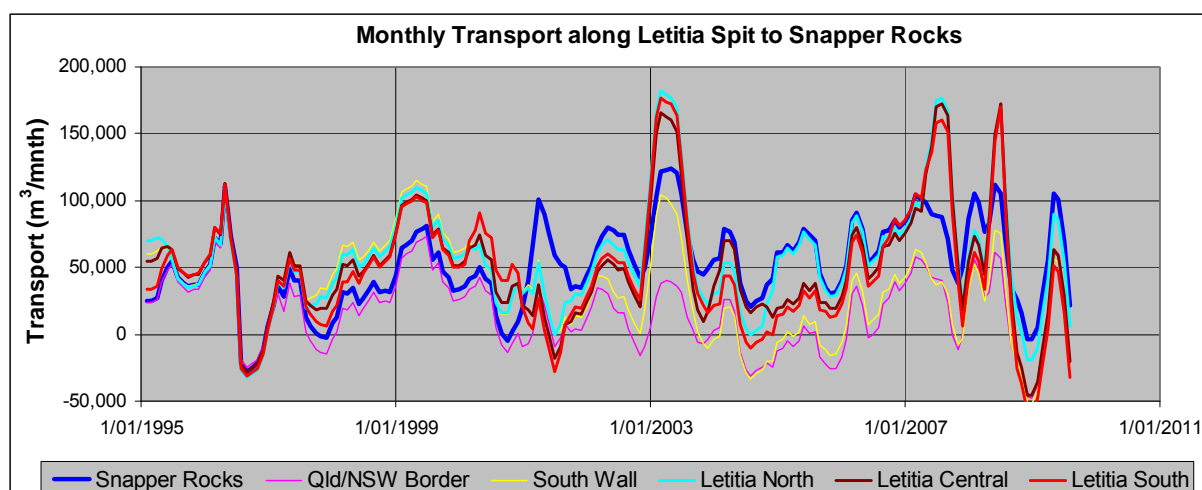
Figure 6-2   Monthly net transport along Letitia Spit

Table 6-2   Calculated transport at Letitia Spit

Period of Calculation	Average Annual Net Transport at Various Letitia Locations (m^3/yr)					
	Snapper	North Wall	South Wall	Letitia Nth	Letitia Cent	Letitia Sth
1995 to 2009	620,000	139,000	399,000	690,000	603,000	562,000
1995 to 2000	397,000	310,000	635,000	600,000	595,000	574,000
2001 to 2008	784,000	22,000	243,000	771,000	639,000	591,000
2001 to 2009	777,000	20,000	234,000	752,000	609,000	553,000

These may be used as an indicator of the validity of the calibration factors used for the theoretically calculated transport rates at Currumbin. For example, it is expected that the net transport rates at Snapper Rocks (Point Danger) would not fall below zero, despite the possible effect of the East Australian Current, while those at the NSW/Qld border most probably would from time to time. If the calculated Currumbin rates are too low, negative rates are likely be calculated at Snapper Rocks.

It can be seen in Figure 6-2 that, apart from a period in 1996 probably influenced by a mismatch in the relative timing of the surveys and/or dredging activities used in the calculation process rather than actual behaviour, the monthly net transport at Snapper Rocks does not fall below zero. The monthly net transports at the NSW/Qld border and at other sites near the river mouth are calculated to be down-coast occasionally.

Separate results are presented in Table 6-2 for the periods 2001 to 2008 and 2001 to 2009 respectively to highlight the relatively significant influence on the longer term average of the last year from 2008 to 2009.

Locations south of the training walls at Letitia North and Letitia Centre show significantly higher average annual net transport rates since sand bypass operations commenced in 2001 than had prevailed prior to that time. There has clearly been an induced increase in transport along Letitia Spit as a result of the sand bypass system operations in altering the shoreline alignment at those locations.

The derived rate at Letitia South for the period prior to bypassing 1995 – 2000 is 574,000m^3/yr, about 12% higher than the calculated rate of 511,000m^3/yr for the same period at Currumbin, on which these rates are based. This may be because some change to these rates is required through the 'calibration' process or that there was indeed a greater rate of transport coming into Letitia Spit past Fingal than occurred at Currumbin over that 6 year period.

Notably, the average annual transport rate at Letitia South over the period 2001 to 2008 is indicated to be 591,000m^3/yr, 17,000m^3/yr higher than the rate indicated for the 1995 to 2000 period. Figure 6-2 suggests that this higher rate results from specific periods of higher transport, in early 2003, mid 2007 and 2008. However, the quite low transport during the latter part of 2008 and 2009 has compensated such that the average rate of 553,000m^3/yr since 2001 is reasonably consistent with the longer term rate there since 1995 of 562,000m^3/yr.

6.2.2 Theoretical Versus Derived Rate at 1,000m South of Walls

The rate of longshore sand transport at the location 1,000m south of the southern training wall has been affected significantly by the sand bypass system activities. The shoreline alignment there has shifted significantly (Figure 5-16) and the transport rate increased accordingly, as shown in Figure 6-2 and Table 6-2.

On the basis that the division between the calculation compartments Letitia Centre and Letitia North is located approximately at the designated location 1,000m south of the walls, the derived transport rate there may be correlated directly with that calculated theoretically from the Tweed wave data. This comparison is illustrated in Figure 6-3 and presented in Table 6-3.
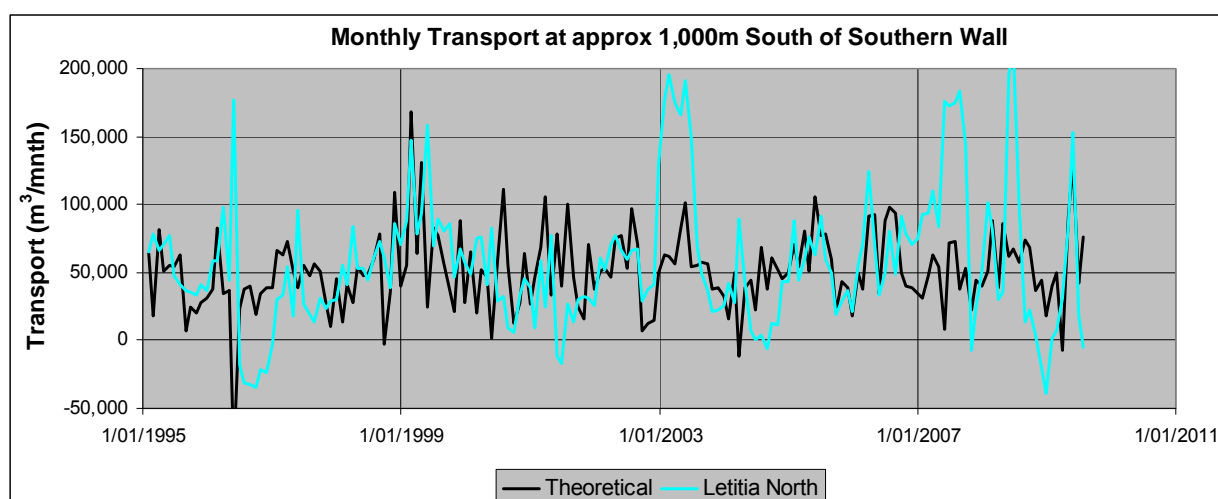

Figure 6-3   Monthly net transport 1,000m south of southern training wall

Table 6-3   Transport rates 1,000m South of Walls

Annual Average Net Transport at 1,000m south of walls (m³/yr)		
Period of Calculation	Derived from Surveys & Currumbin Transport	Theoretical from Waves
1995 to 2009	690,000	610,000
1995 to 2000	600,000	558,000
1995 to 2002	582,000	578,000
2001 to 2009	752,000	646,000

It can be seen (Figure 6-3) that there are significant differences between the derived and theoretical rates at certain times while quite close agreement is evident at other times. The periods of difference appear to involve short term (months) of transport spikes that are difficult to explain other than by processes acting there that the theoretical approach does not cater for. In particular, the derived rates indicate a 'slug' like pattern of behaviour, possibly related to mechanisms involved in the movement of sand through the gap between Cook Island and the mainland at Fingal. Such a slug pattern of behaviour is indicated also in Figure 6-4 which compares the cumulative transport at Letitia as derived from the data and from theory.
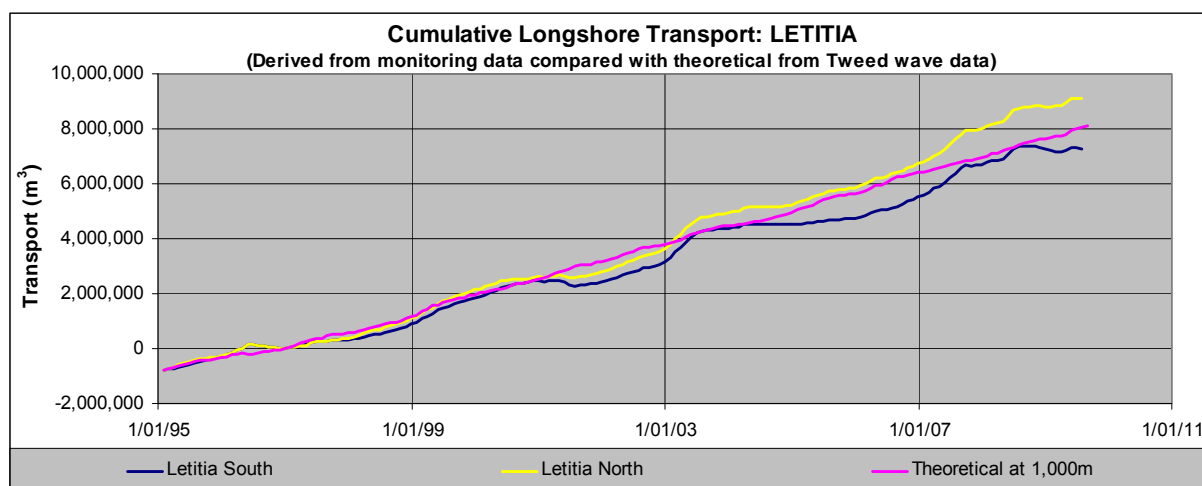
Figure 6-4   Cumulative sand transport at Letitia Spit

6.2.3   Sand Transport Calculation Calibration Coefficients

The primary calibration of the coefficients used in the CERC and Queens relationships is based on the previous investigations that show the longer term annual average net transport for the local region to be in the range 500,000m³/yr to 550,000m³/yr. This calibration of the coefficients was undertaken for the Currumbin site for the period of available wave data. If the calibrated coefficients derived for Currumbin are adequately universal for the region, it would be expected that transport rates at Letitia Spit calculated from the Tweed wave data would be compatible with transport rates derived indirectly via Equation 2b and Equation 3d.

The LTA rate of 509,000m³/yr derived for the period 2001 to 2009 using Equation 1b will represent a lower limit for the transport into Letitia Spit at Fingal, given that the natural bypassing is unlikely to be

BMT WBM

southward (negative). The assessed rate of supply into Letitia Spit at Letitia South for that period (2001-2009) is 553,000m^3/yr (Table 6-2), consistent with this LTA rate if the average natural bypassing is about 44,000m^3/yr for the period.

The transport rate at Letitia North is expected to be higher than that further south because of the influence of the sand bypass operations on the shoreline alignment since 2001. The theoretically determined transport for Letitia North at 1,000m south of the river has been based on shoreline alignments that have been measured from available survey and aerial photo data (Figure 5-16).

As it has emerged from the calculations, the behaviour of the longshore transport at Letitia Spit has clearly involved processes of short term 'slug' like behaviour that the theoretical methodology does not identify. The results for the period 1995-2002 (inclusive) in Table 6-3 are presented to indicate the degree of compatibility between the two results for the period in which there is no apparent major slug transport occurrence, yielding 578,000m^3/yr derived from the waves and 582,000m^3/yr derived from the surveys and Currumbin transport, agreement within less than 1%. This is probably a surprisingly good match under the circumstances.

This indicates that the longer term pattern of transport is being identified reasonably well by the theoretical method, but that there are circumstances when it does not identify the real processes taking place. Based on these results, there is no compelling reason to either increase or decrease the coefficient values as adopted for Currumbin. While the annual average net transport for 1995-2009 at Currumbin is determined to be 527,000m^3/yr (Table 5-1) and at Letitia South is 562,000m^3/yr (Table 6-2), there is no way to know whether or not this apparent discrepancy is real. Increasing the coefficient values to match these rates would cause a mismatch at Letitia North for the non-slug period 1995-2002 (Table 6-3). The occurrences of sand transport slugs into and along Letitia Spit, which cannot be identified in the theoretical method, adds to the complexity of this analysis.

For the present, until further data are obtained, it is adopted that the coefficients values as calibrated for Currumbin are the most suitable to be used at this stage, on the basis that the evidence for any change is not yet apparent and no alternative approach to calibration is yet available. If valid, the long term average annual net transport rates at Letitia South and Currumbin based on these coefficients should become essentially the same. Discussion of the long term context of the analyses based on the available data to date is outlined in Chapter 7.

6.3   Long Term Average (LTA)

The Long Term Average has been calculated using both Equations 1b and 2c. Equation 1b utilises only the measured data from surveys and the bypass pumping and dredging, whereas Equation 2c utilises the measured survey data in combination with the theoretically calculated longshore transport at Currumbin, from which the Letitia South transport is calculated. There should be direct equivalence between these values, subject to the potential errors inherent in the two different methods.

The calculated LTA rates thus determined, with Equation 2c based on the Currumbin transport rates calibrated to an average value of approximately 506,000m^3/yr over the period 1995 to 2009, are illustrated in Figure 6-5 and presented in Table 6-4.

BMT WBM
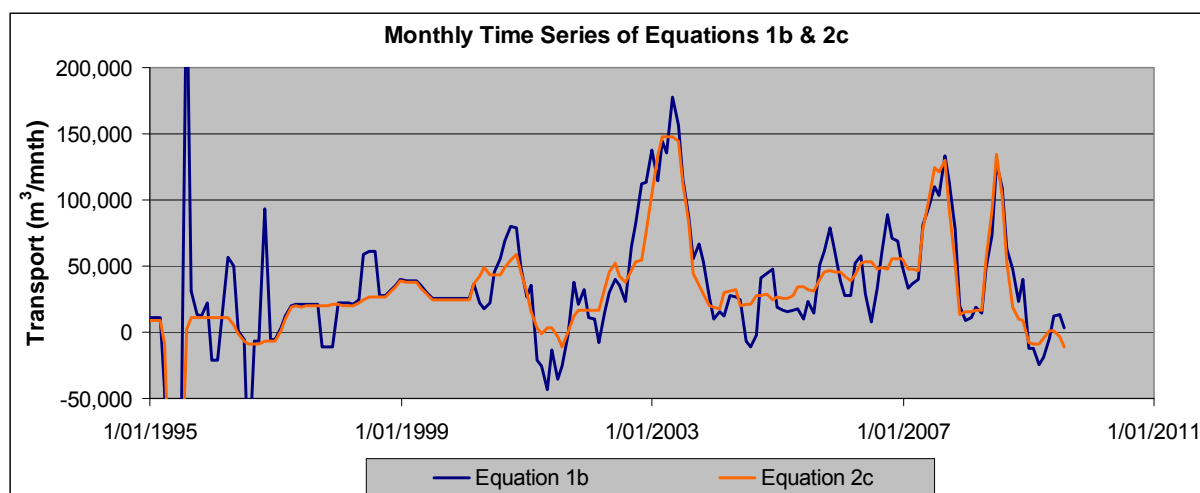
Figure 6-5   LTA trend values from Equations 1b and 2b

Table 6-4   Long term average values

Long Term Average (m³/yr)		
Period of Calculation	Equation 1b	Equation 2c
1995 to 2009	376,000	371,000
1995 to 2000	185,000	169,000
2001 to 2009	509,000	513,000

The trend lines in Figure 6-5 and the values in Table 6-3 are in close quantitative agreement between the results determined from the two methods. This is to be expected since they are derived ultimately from equivalent inputs. Nevertheless, the consistency confirms the accuracy of the calculations undertaken.

The LTA rate depends on the effects of the sand bypass operations and, in particular, exhibits different results depending on the impact of the system operations on natural bypassing. Thus, the annual average value of the trend values in Figure 6-5 has increased from about 170,000-185,000m³/yr prior to commencement of sand bypass operations, when the navigational requirement was not satisfied, to about 509,000-513,000m³/yr since bypassing operations commenced due to reduction in the natural bypassing. This is reasonably consistent with the assessed long term average annual net transport rate at Letitia South of about 553,000m³/yr (Table 6-2) and the assessed natural bypassing since 2001 of 40,000-44,000m³/yr as determined in Section 6.1

7 CONTEXT OF 2001 -2009 IN THE LONGER TERM

7.1 General Considerations

It is likely that decadal weather and wave climate cycles of behaviour occur, possibly associated with El Nino/La Nina cycles or other influences. To the extent that such cycles have significant effects on sand transport, they may also impact on assessment of the natural bypassing and LTA. Even if good accuracy of the calculated transport rates is achieved for the period of bypassing operations, it is of benefit to know how that period fits into the long term pattern of wave climate variability for better understanding of the LTA.

Proxy indicators including the Southern Oscillation Index (SOI) have been reviewed. As well, an approach seeking to establish an indicator based on the relationship of derived sand transport with the measured wave energy and energy-weighted mean wave direction has been assessed.

These have sought to identify:

- Any distinct long term cyclic pattern of variability in annual wave conditions (energy/direction), or more random behaviour;

- Any distinct relationship between calculated annual/seasonal net transport rates and annual/seasonal mean energy-weighted deep water directions (and/or a combined energy/direction parameter); and

- To the extent feasible, identify the likely long term energy-weighted mean wave direction and associated average annual net transport rates at various beaches in the immediate region.

7.2 Wave Climate Variability

It is apparent that there is significant long term variability in occurrences of major storms and extensive beach erosion. In SE Queensland and northern New South Wales, this is related largely to occurrences of cyclones and extra-tropical low pressure systems in the near vicinity.

There is no single reliable and consistent long term measure of historical storm occurrences and intensities for the region. Wave recording has been undertaken for only the past 30 years. Within that timeframe, the frequency of recordings has increased since about 1990 such that the peak wave heights during storm events over the past decade are much better defined than they were previously.

A combination of cyclone occurrences in the region (Delft Hydraulics Laboratory 1970), available wave recordings and wave/wind observations at lighthouse locations in the Tweed, Gold and Sunshine Coast region have been used as an indicator of storm occurrences. For the recent recorded wave data, a significant wave height threshold of 5 metres has been used to define a 'major storm' event. For the wind data, a threshold of 80km/hr (approx 45 knots) has been used.

Figure 7-1 illustrates the occurrence history of major storms and cyclones in the Tweed Coast region, as identified in these various ways noting that, for the period up to 1960, only the Delft Report (1970) information has been used.
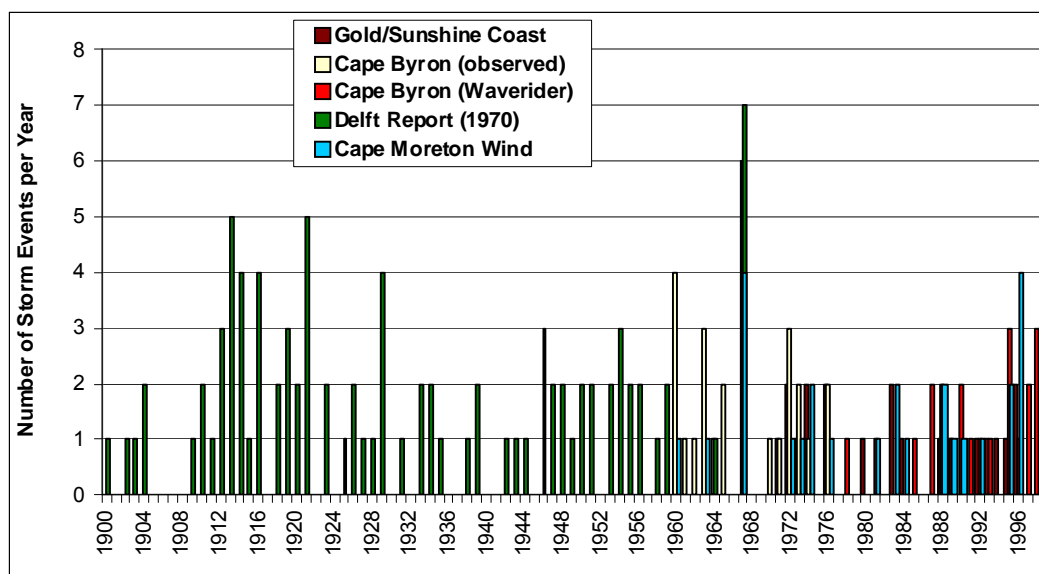
Figure 7-1   Major storm/cyclone occurrence history - Tweed Coast region

The storm occurrence pattern in Figure 7-1 should be regarded as indicative only. Nevertheless, it shows a weak pattern of increased storminess over the periods 1910-1930 and 1946-1976 and possible commencement of a new period of storm activity around 1995. In particular, the extreme intensity of storm activity during 1967 is clearly illustrated, described in the 1970 Delft Report as "in order of once in 200 or 300 years" probability of occurrence.

The SOI since 1900 is shown in Figure 7-2. The cumulative SOI pattern is shown in Figure 7-3. It is difficult to determine a clear relationship between the SOI and the occurrence of extended periods of increased or decreased storminess. However, the cumulative SOI pattern shows some consistency with storm occurrences in that it indicates:

- An increase from 1915 to 1939;

- Reduced levels from 1939 to 1950;

- A strong and steady increase from 1950 to 1976; and

- A marked decrease after 1976 to 1995, with a temporary increase around 1988-1990.

The 5-year average SOI has been generally below zero since 1976, consistent with anecdotal evidence of lack of major erosion over that period, and an upward trend from 1995 to 2000, also consistent with anecdotal evidence. Following a reduction from 2001 to 2004, the SOI has trended upwards again.
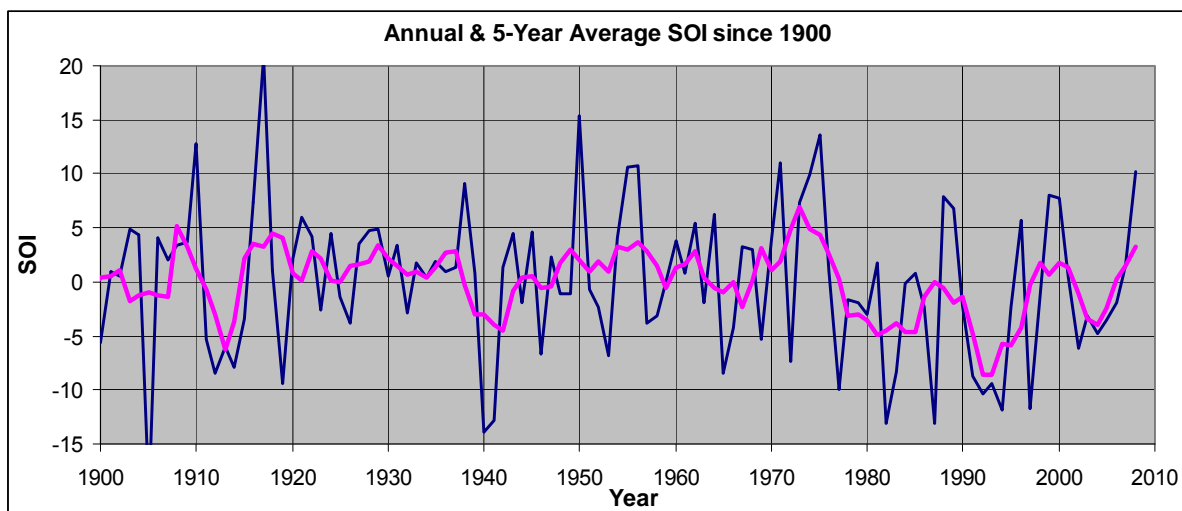
Figure 7-2   Annual average SOI since 1900
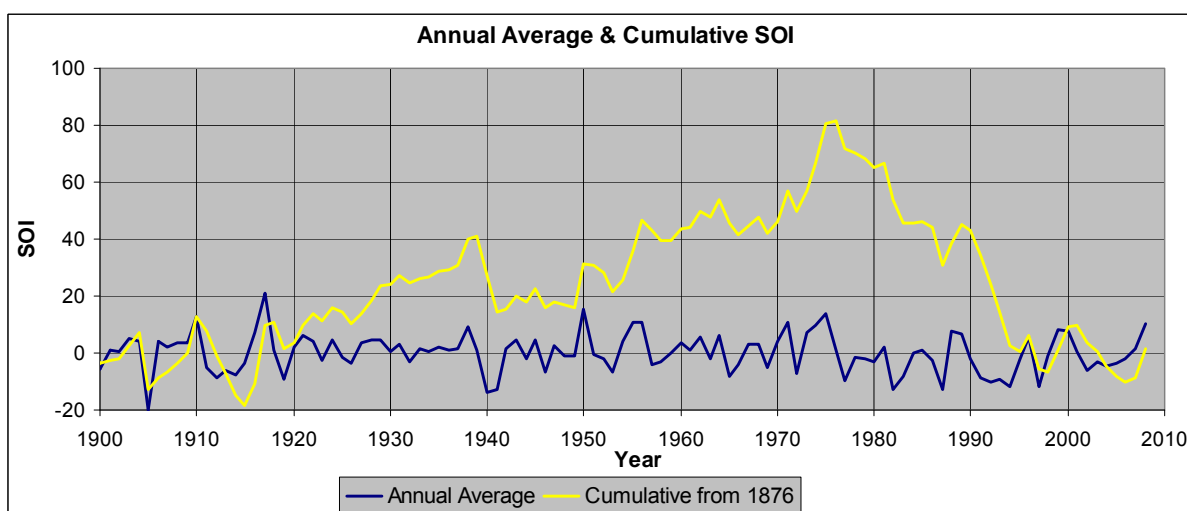
Figure 7-3   Annual average and cumulative SOI

Deep water directional global wave model wave data for the region since 1992 has been sourced from BMT ARGOSS, Netherlands, for use as a single representative indicator of the prevailing monthly deep water wave energy and energy-weighted directions. The ARGOSS data is sourced fundamentally from the WaveWatch III global wave model (as is the NOAA wave data), with the facility for some additional validation and/or refinement through in-house processing. This is available as a 3-hourly time series of sea and swell, together with the combined condition for significant wave height and spectral peak period. It provides a basis of determining the context of those parameters over the past 8 years relative to the 17 years since 1992.

The ARGOSS data is for a site in deep water about 32km offshore from the Gold Coast, near the edge of the continental shelf. As such, it includes some occurrences of both sea and swell that are directed seawards. The data has therefore been modified to remove those occurrences and only consider shoreward directed waves by:

•   Where only the 'sea' waves are directed seawards, the swell component is used; and

- Where swell also is directed seawards, the previous shoreward directed swell direction is maintained and the swell height reduced by a nominal proportion of 2% per 3 hour time increment in the time series.

Comparison of the ARGOSS data with both Brisbane and Byron is shown in Figure 7-4 as time series height, period and direction for 2003. This shows that the ARGOSS data generally corresponds well with the recorded data. As would be expected, occurrences of quite southerly waves show significant differences between it and the Brisbane data, with the more exposed deep water site not within the influence of the continental shelf experiencing more southerly directions and somewhat larger wave heights.

Further analysis of the wave direction occurrences for each of the Brisbane, Byron and ARGOSS data is presented in Figure 7-5. This shows a significant deficiency in the wave directions across the east to southeast sectors, with a marked shift away from the southeast towards the east directions. Comparison with corresponding synoptic charts and discussions with the ARGOSS researchers have not provided sufficient explanation for this problem as yet, however it is likely to be the result of the relatively coarse resolution of the wave / wind field model in this region. It is noteworthy that the NOAA wave data shows a similar problem.

To overcome this problem in the most practical way available, given that the Byron data contains too many extended gaps for practical use, a deep water wave climate (time series) has been derived through the combined use of the Brisbane and ARGOSS data involving:

- Back refraction by analytical means the Brisbane data from its recording site to equivalent deep water conditions, recognising that the more southerly wave components will not be suitable; and

- For events in which both the ARGOSS data and the back-refracted Brisbane data indicate southerly swell directions (adopted as greater than 140 degrees), the average of the ARGOSS and back-refracted Brisbane directions is adopted.

Figure 7-6 illustrates the resulting wave direction distribution, which appears reasonable in the context of the distribution for the more exposed Byron recorder. Clearly, this process assumes that the ARGOSS directions are more accurate for the southerly waves, indicated by Figure 7-4, however further research into the matter is needed.
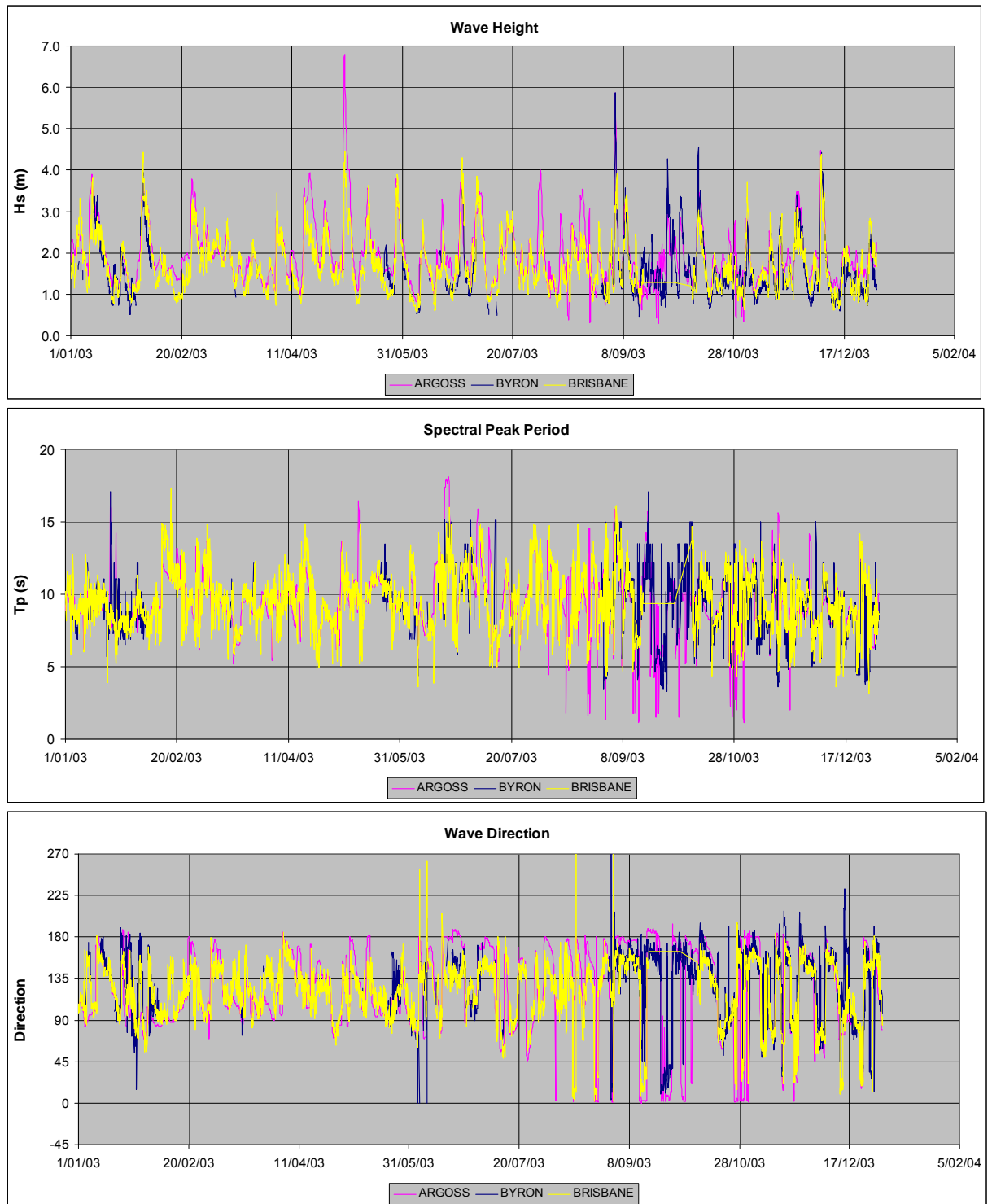
BMT WBM

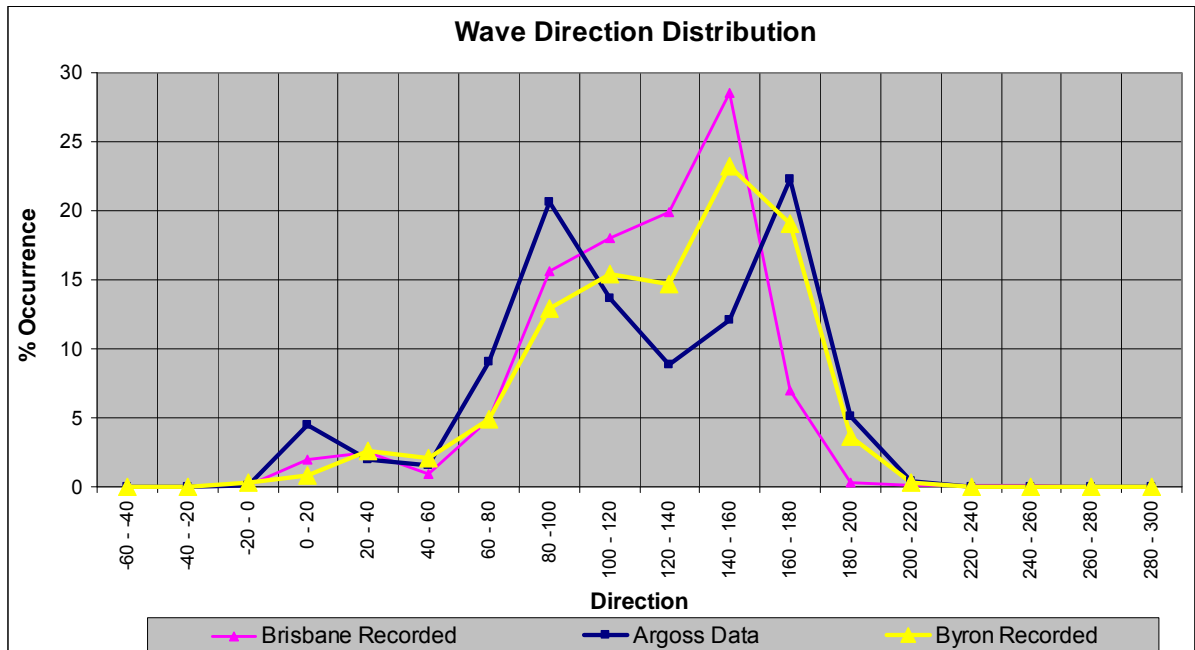**Figure 7-4   Comparison of ARGOSS and recorded wave data**

Figure 7-5   ARGOSS and recorded wave direction distribution
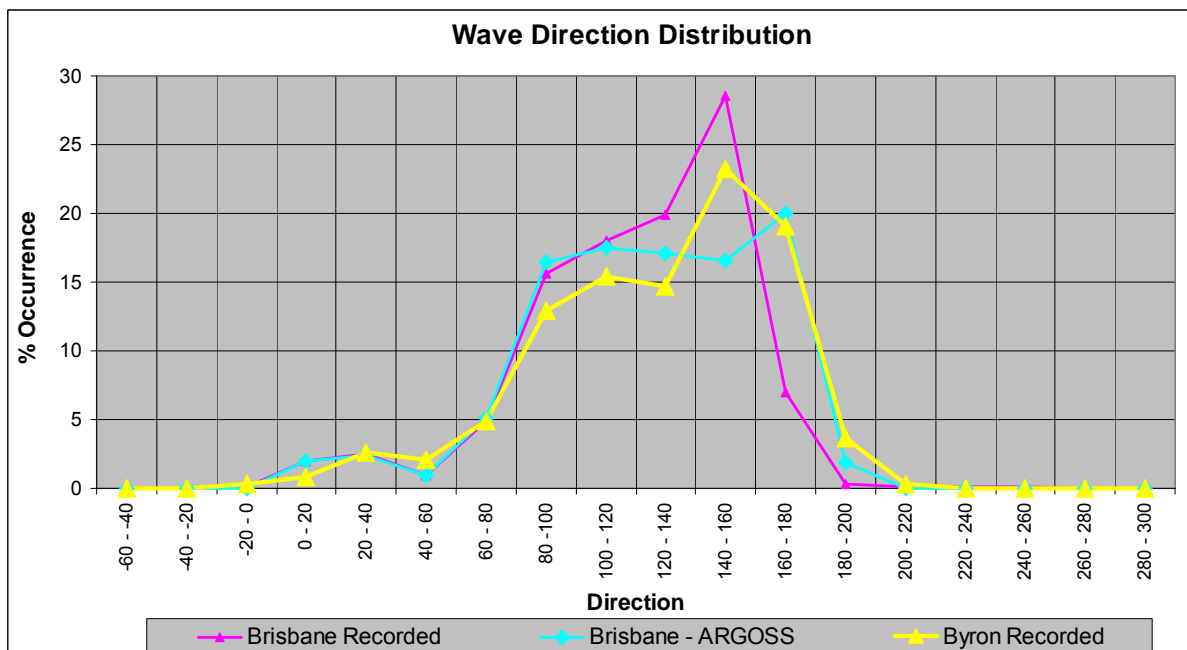

Figure 7-6   Derived deep water wave direction distribution

BMT WBM

7.3 Energy-weighted Deep Water Mean Wave Direction

In order that variability of the deep water mean wave directions has direct relationship to the process of longshore sand transport at the beaches, wave energy flux and energy-weighted mean wave direction parameters have been adopted on the basis of the relationship for sand transport. While either the CERC or Queens relationship could be used equally effectively for this purpose, the CERC equation for longshore sand transport is more readily converted to a form that involves the deep water wave height and angle and has been utilised to derive energy weighted parameters in the form:

CERC_2b $Q = K_1\, H_o^{\,2}\, C_b . \sin(2\alpha_o)$

In order that this relationship contains only deep water parameters for wave energy flux and direction, this relationship may be modified to include an approximation for C_b derived from the analytical solution for parallel nearshore contours as:

$$Q \propto g^{0.6} H_o^{\,2.4}\, T_p^{\,0.2}\, f^m(\text{Dir}_o) \tag{4}$$

Thus, the adopted wave energy flux and energy weighted direction parameters are:

$$\text{Wave energy flux parameter} = g^{0.6} H_o^{\,2.4}\, T_p^{\,0.2} \quad (\text{m}^3/\text{s}) \tag{5}$$

$$\text{Weighted mean direction} = \Sigma\, (g^{0.6} H_o^{\,2.4}\, T_p^{\,0.2}\, \text{Dir}_o\,) / \Sigma\, (g^{0.6} H_o^{\,2.4}\, T_p^{\,0.2}\,) \quad (\text{degrees}) \tag{6}$$

Plots of the time series values of the monthly mean energy and direction thus derived and the running 12-monthly means of those values are presented in Figure 7-7. Comparison of the Argoss values with the equivalent values derived from the Brisbane recorded data is shown in Figure 7-8, in this case showing the 6-monthly running mean values.

The average value of the weighted mean direction over the period of data is 137.0 degrees. The average value of the wave energy parameter is 9,044 (m^3/s).

There are some distinct trends in the wave energy and weighted mean wave direction plots, namely:

- Higher annual mean wave energy in 1999 and since the latter part of 2007, peaking in the first few months of 2009;

- Variable annual weighted mean direction around an average value of about 137 degrees, with a lower value through 1998 to 2001 and a progressive shift further to the southeast after 2001 to typically about 140 degrees;

- A combination of unusually high monthly wave energy (average 17,580m^3/s) and relatively more northerly (111 degrees) 3-monthly mean wave direction for March to June 2009.

The difference in weighted mean direction at the Brisbane recorder, which is more sheltered from the southerly waves, and the exposed deep water location is illustrated in Figure 7-8. This highlights the importance of using the more exposed site in this analysis.

The monthly SOI values for the corresponding period are shown in Figure 7-9. There does not appear to be any clear relationship between the SOI and the wave parameters.

BMT WBM
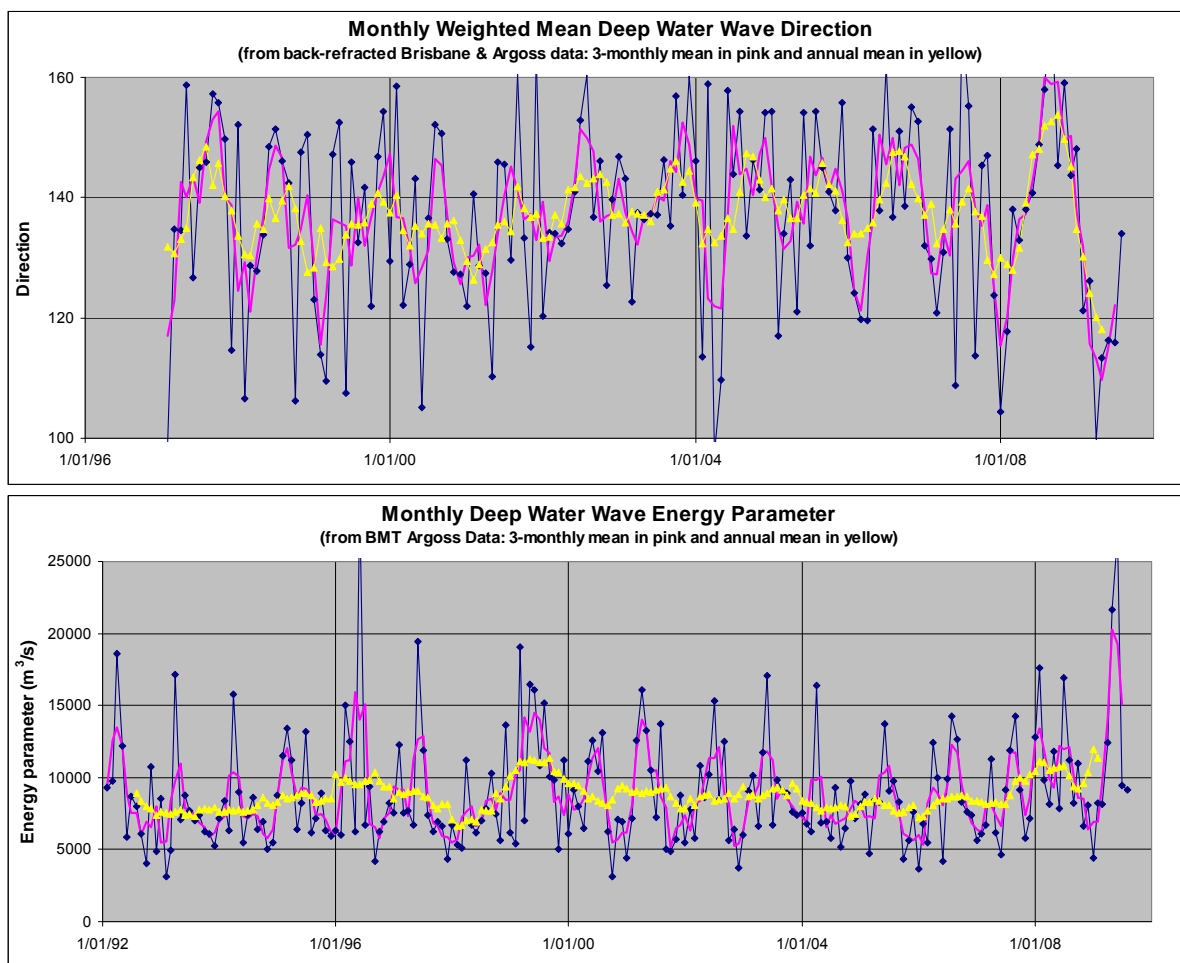
Figure 7-7 Monthly Mean Direction (top) and Energy (bottom) since 1997
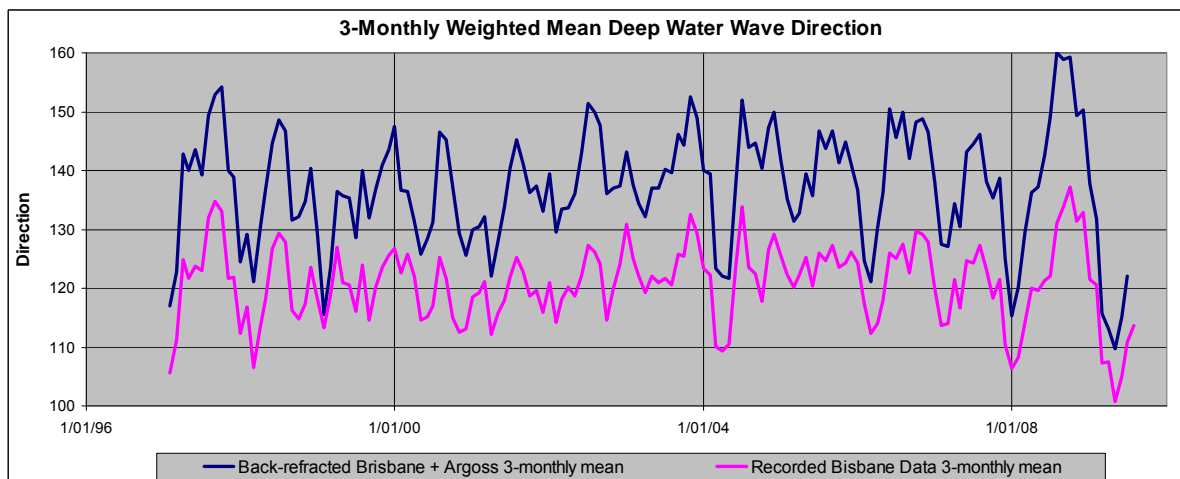
Figure 7-8 Recorded and back-refracted Brisbane monthly mean direction
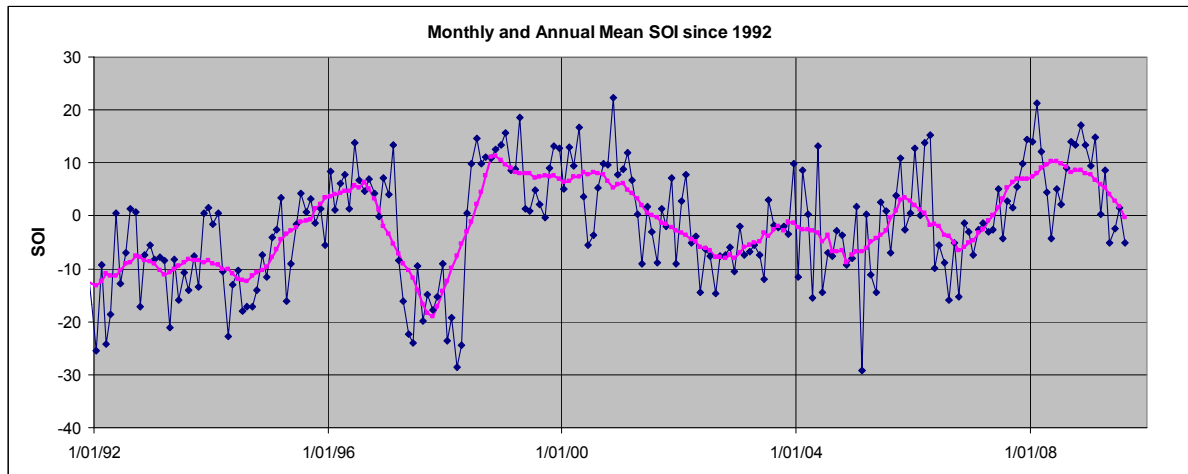
Figure 7-9   Monthly SOI since 1992

7.4   Site-Specific Longshore Transport Functions

The relationship for longshore transport given by Equation (4) implies that the time-averaged (monthly) transport rates may be derived from the monthly wave energy flux parameter and a site-specific function of the weighted mean direction parameter. The function $f^n(Dir_o)$ may be derived where both the monthly transport rates (Q) and the associated monthly wave energy flux parameter values are known. For compatibility of the transport rates between months relative to the long term mean condition, a normalised monthly wave energy parameter has been used, of the form:

$$Q_{monthly} \cdot (g^{0.6}H_o^{2.4}\ T_p^{0.2}\ )_{long\ term\ mean}\ /\ (g^{0.6}H_o^{2.4}\ T_p^{0.2})_{monthly} = f^n(Dir_o) \tag{7}$$

The values of $f^n(Dir_o)$ given by Equation (7) will be unique to each location along the coastline and may be calculated and graphed versus the deep water weighted mean direction for each location. Transport rates for particular month periods when the mean direction and/or the normalised wave energy parameter values are different from the long term mean values may be determined from the relationships derived.

Importantly, in the long term context, there should be a common direction, corresponding to the long term mean direction, at which the long term average annual net sand transport for each location occurs. On the basis that the annual average net longshore transport is uniform in the long term through this region from Cudgen to Burleigh, the functions for each of the sites should intersect at a deep water weighted mean direction and normalised wave energy flux parameter that are the long term average values of those parameters. When the long term mean wave energy flux parameter is applied, this will yield the long term average annual net longshore transport rate.

The monthly sand transport function values have been assessed in this way, using the monthly transport rates derived from the recorded wave data and the Queens relationship as outlined in Chapter 5. The fact that the Queens relationship has been used to calculate the transport rates while the CERC_2b relationship has been used to determine the weighting parameters is of no consequence for this purpose.   It has been shown that the calibrated CERC and Queens relationships yield directly equivalent transport rates, while the CERC_2b relationship is used merely as a reasonable proxi for sand transport as the basis for energy weighting the wave conditions.

To provide a general regional context and to avoid the problematic 'slug' behaviour identified along Letitia Spit, function values have been determined for Currumbin, Burleigh and Cudgen Beach. The Currumbin the transport rates for Currumbin have been derived from the Tweed wave recorder. Burleigh rates have been derived from the Brisbane recorded data and Cudgen rates are the average of those from the Tweed and Brisbane data. Plotted values of the monthly function values derived, together with fitted second order polynomial curves, are presented in Figure 7-10 and Figure 7-11 for the various locations.
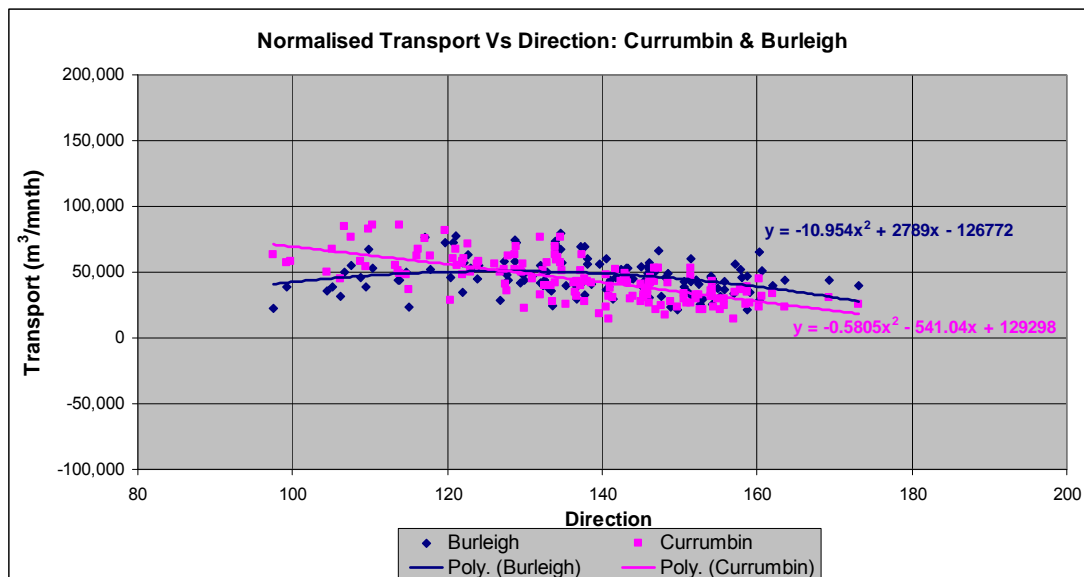
Figure 7-10   Normalised monthly transport versus mean direction: Burleigh & Currumbin
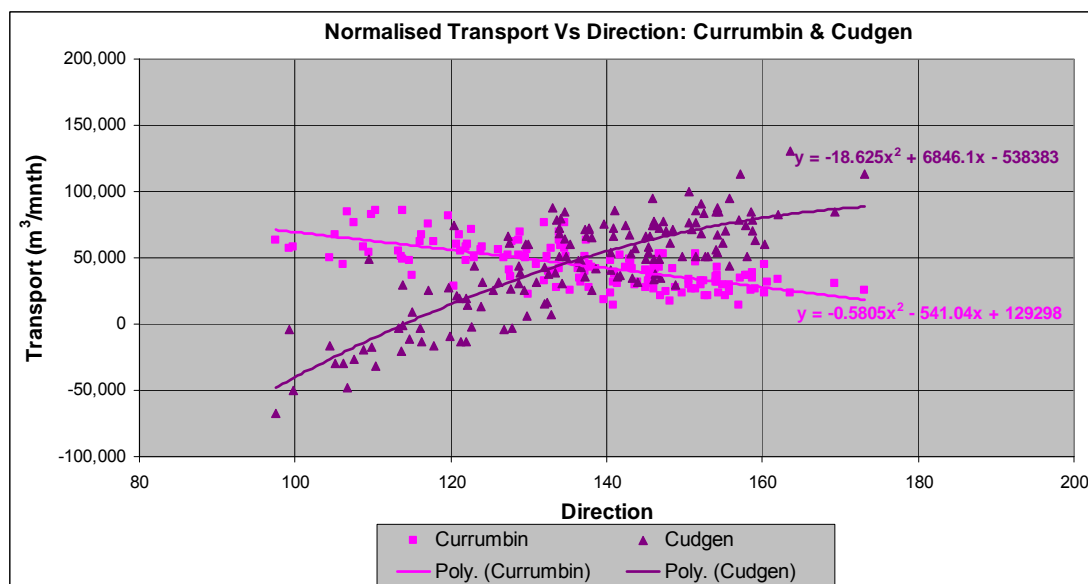
Figure 7-11   Normalised monthly transport versus mean direction: Currumbin & Cudgen

These trend lines are reasonably consistent show acceptably minor scatter, although even they have an R^2 value of only 0.5 to 0.7. Thus, this approach must be regarded as indicative only.

The intersection of the Currumbin and Cudgen lines indicates a long term weighted mean wave direction of about 134.72 degrees and a corresponding normalised longshore sand transport of 45,873m^3/month (550,000m^3/yr). This long term mean direction is less than that (137.0 degrees) for

BMT WBM

the period 1997 to 2009 derived from the deep water wave data. Nevertheless, for the Currumbin function trend line, a direction of 137.0 degrees corresponds to 43,940m^3/month (527,300m^3/yr), closely consistent with the calculated rate there of 527,000m^3/yr for 1995 to 2009.

To the extent that the above trend lines can be used as an indicator of the long term average values, it suggests:

- The long term average annual longshore sand transport through the beach system is approximately 550,000m^3/yr;

- The theoretically calculated transport at Currumbin for the period 1995 to August 2009 (of 527,000m^3/yr), based on calibration to 506,000m^3/yr for the period 1995 to 2008, is lower than the long term average;

- The calculated transport at Cudgen (537,000m^3/yr for 1995 to 2009 and 540,000m^3/yr since 2001) is consistently about 2% lower than the long term average rate;

- The transport rates determined at Letitia South, calculated from the data at 562,000m^3/yr for 1995 to 2009 and 553,000m^3/yr since 2001 (Table 6-2), are within 1-2% of the assessed long term average transport through the system.

It is noteworthy that the first 6 months of 2009 had a substantial impact on the annual average net longshore transport rates calculated, particularly in increasing the Currumbin rate and reducing the rate at Cudgen. The weighted mean direction for those 6 months was 115.5 degrees compared with the long term mean of 134.7 degrees and the mean wave energy parameter was 14,440m^3/s compared with the overall mean of about 9,040m^3/s. This has a profound effect on the transport by emphasising the up-coast rates along the northeast facing beach at Currumbin while retarding those at Cudgen which faces towards the east-southeast.

7.5   Sand Budget

The surveyed loss of sand from the Tweed River entrance and NSW beach system north from the Letitia South compartment on Letitia Spit since 1993 is 3.75 million m^3 compared with the net gain to Queensland beaches of 4.51 million m^3 (Figure 3-4). The equivalent quantities from the survey data for the period since January 1995, for which we have other corresponding analysis data on sand transport rates and differentials, are:

Loss from NSW north of Letitia South: 4.47 million m^3
Gain to Queensland beach system to Currumbin: 4.98 million m^3
Apparent net gain to the system covered by the surveys: 0.51 million m^3

The difference in these quantities can be explained only if:

- There is an additional area of net loss of sand within the NSW coastal system further south that has supplied sand to Letitia Spit and been delivered to Queensland; or

- There are relatively significant errors (approximately 10%) in the survey quantities.

It is considered unlikely that the error in the survey quantities would be this high. Accordingly, the most probable source of the discrepancy is a net loss of sand south of the calculation compartments along Letitia Spit.

The slug like behaviour of the transport into and through the Fingal area suggests that there may be periodic losses along Dreamtime Beach and/or further south at Cudgen. An initial assessment of this is provided by analysing the cumulative differential in sand supply from the south relative to the transport out to the north at Letitia South. This is most reliably done based on the calculated Cudgen rates, which are considered reasonably reliable.

The cumulative difference in quantity between Cudgen and Letitia South since 1995 is shown in Figure 7-12, relative to a zero value at the start of 2001.
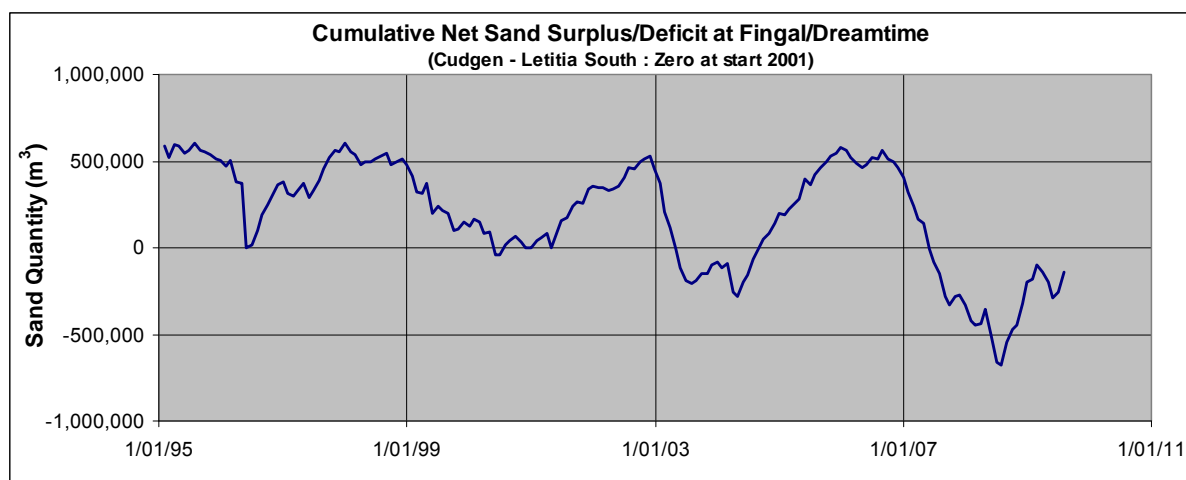
Figure 7-12 Cumulative difference in transport: Cudgen minus Letitia South

The trend indicated in Figure 7-12 is:

- Fluctuations of ±300,000 m^3 with little or no net change through to 2007;

- A rapid loss of about 1.2 million m^3 over the period January 2007 to July 2008; and

- Partial recovery of about 0.53 million m^3 over the year July 2008 to July 2009.

The estimated net loss from 1995 to July 2009 is 0.73 million m^3, about 0.22 million m^3 more than that indicated by the survey data. However, bearing in mind that the period covered is about 14.5 years, this difference may be explained by only 15,000m^3/yr error in the relative sand transport rates calculated for Cudgen and Letitia South, about 3%. Alternatively, the difference may be explained by a process in which some (0.51 million m^3) of the net loss from the Dreamtime/Cudgen area remains within and immediately south of the Letitia South compartment and its effect has not yet been transferred to Queensland.

No survey data is available to confirm or disprove this process. Recent inspection of Dreamtime Beach shows extensive erosion there that has not recovered to date (refer Photos 1 to 3). While the erosion into the dunes occurred during storms in March 2009, a pattern of sand loss from the nearshore sand transport zone followed by severe erosion of the upper beach/dune during the next storm period is typical and consistent with the suggested pattern of behaviour.

Photo 1: North Dreamtime Beach: August 2009

Photo 2: North Dreamtime Beach: August 2009

Photo 3: North Dreamtime Beach: August 2009

The rapid reductions in this sand quantity between Cudgen and Letitia South in 2003 and 2007 respectively (Figure 7-12), correspond to the periods of slug-like longshore transport calculated to have occurred along Letitia Spit. As such, this pattern of behaviour may be realistic. This slug-like pattern of behaviour in 2003 is also reflected in comparison of the isopach plots of accretion/erosion between November 2002 and November 2004 (Figure 7-13) in which widespread accretion is evident in Letitia South in November 2003 compared with the situations in 2002 and 2004. As well, the profile plot of ETA 4 just north of Fingal (Figure 7-14) shows a marked 'bulge' of sand above RL-8m in 2003, the largest volume in the profile over the period shown.

Change in Seabed Levels: February 2000 to November 2002

Change in Seabed Levels: February 2000 to November 2003

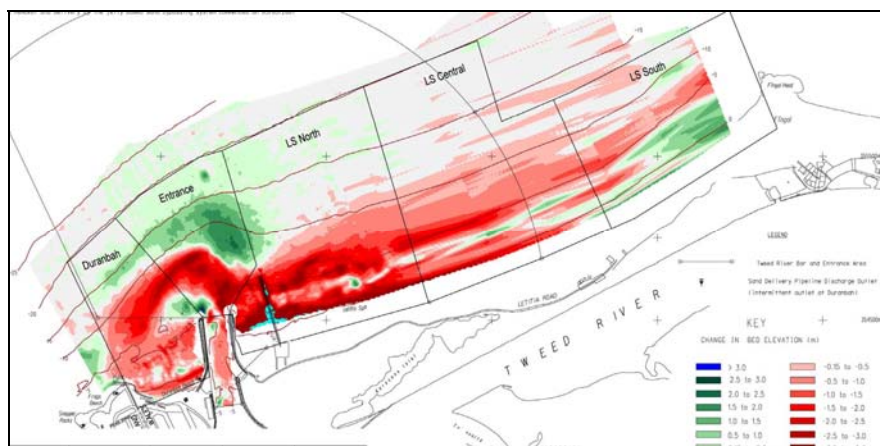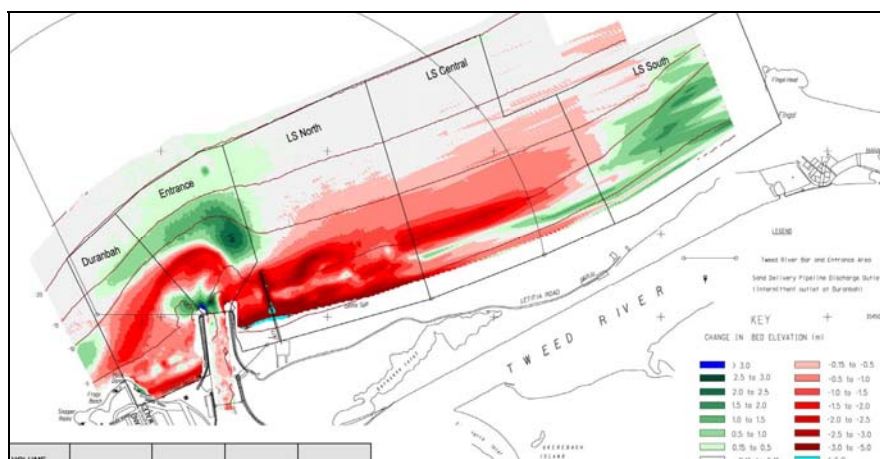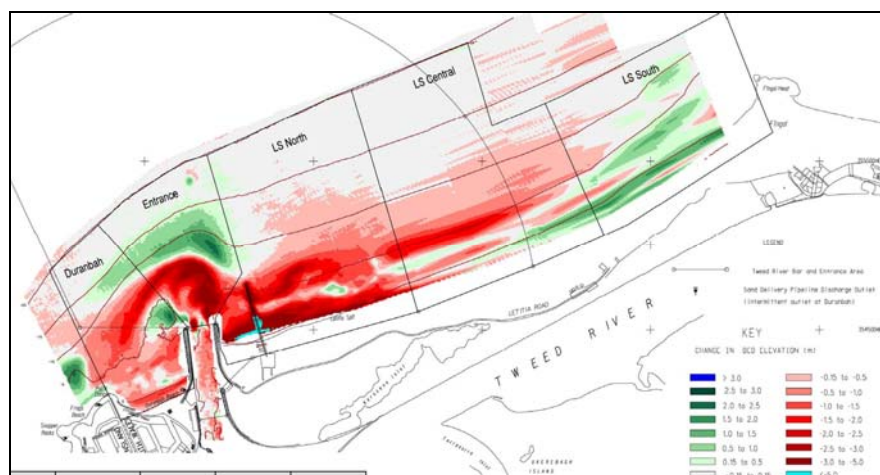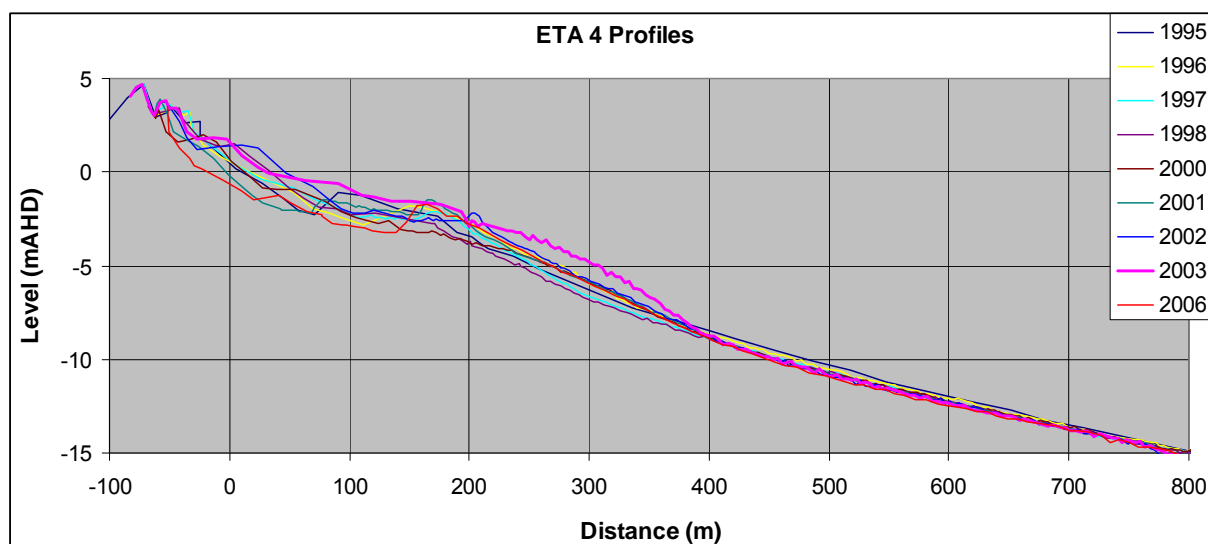**Change in Seabed Levels: February 2000 to November 2004**

Figure 7-13   Isopachs of bed level change: 2002 to 2004

BMT WBM

Figure 7-14   ETA 4 profile (Fingal): Sand 'bulge' in 2003

Further detail of the distribution of the overall net loss between Cudgen and Letitia South could be assessed on the basis of differentials relative to the transport at Dreamtime Beach. However, the calculated rates at Dreamtime Beach are probably the least reliable of all the locations assessed, the wave refraction to that site being affected by both the Fingal Reef and reefs off Cudgen Head. As such, this analysis must be regarded as approximate and indicative only.

Nevertheless, the cumulative transport for 1995 to 2009 calculated for Dreamtime Beach, estimated as the average of those derived from the Brisbane and Tweed recorded wave data, matches well with that at Letitia South, although higher than that at Currumbin (Figure 7-15). On the basis that the Dreamtime Beach rates thus derived are reasonable, the monthly and cumulative differential between the supply from there and the transport northwards from Fingal at Letitia South (refer Figure 7-16) have been determined as an indicator of the net surplus or deficit of sand in the local Fingal area immediately south of the Letitia South compartment, as presented in Figure 7-17 and Figure 7-18 respectively. The cumulative quantity has been determined relative to a zero value at the start of 2001 immediately prior to commencement of bypassing.
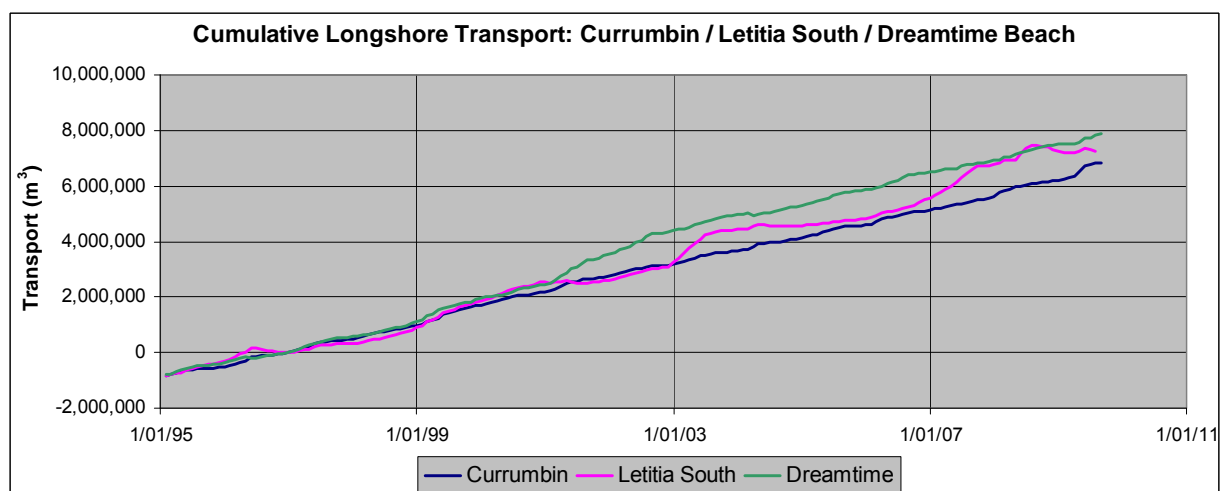
Figure 7-15   Cumulative monthly transport at Dreamtime Beach, Letitia South & Currumbin

BMT WBM

The cumulative difference in transport represents the surplus or deficit of sand at Fingal over the period, relative to the situation at the start of 2001. It can be seen in Figure 7-18 that there are two periods of prolonged accumulation of surplus sand at Fingal. These immediately precede the identified slugs of sand transport along Letitia Spit in 2003 and then 2007-08. These were followed by net losses of sand at the start of 2003 and from the start of 2007. The residual situation in July 2009 suggests a cumulative net gain of about 0.7 million m^3 of sand at Fingal, south of the surveyed Letitia South compartment.

To the extent that this is indicative of the real situation, it suggests that the overall net loss of 0.7 million m^3 between Cudgen and Letitia South is a concentrated loss of 1.4 million m^3 along the Kingscliff to Dreamtime Beach and at the northern end of Cudgen Beach combined with a net gain of 0.7 million m^3 at Fingal. The cumulative loss of 1.4 million m^3 calculated from the Cudgen to Dreamtime differential is illustrated in Figure 7-19.

Again, there is no survey data to verify this pattern of behaviour. Nevertheless, recent inspections show that extensive erosion does extend along both Dreamtime Beach and northern Cudgen Beach, with relatively minor recovery to date. This supports the likelihood of a substantial net loss of sand from this region and that a significant part of that loss has manifest as the slugs of transport along Letitia Spit in 2003 and in 2007-08, some of which has already been delivered to Queensland.
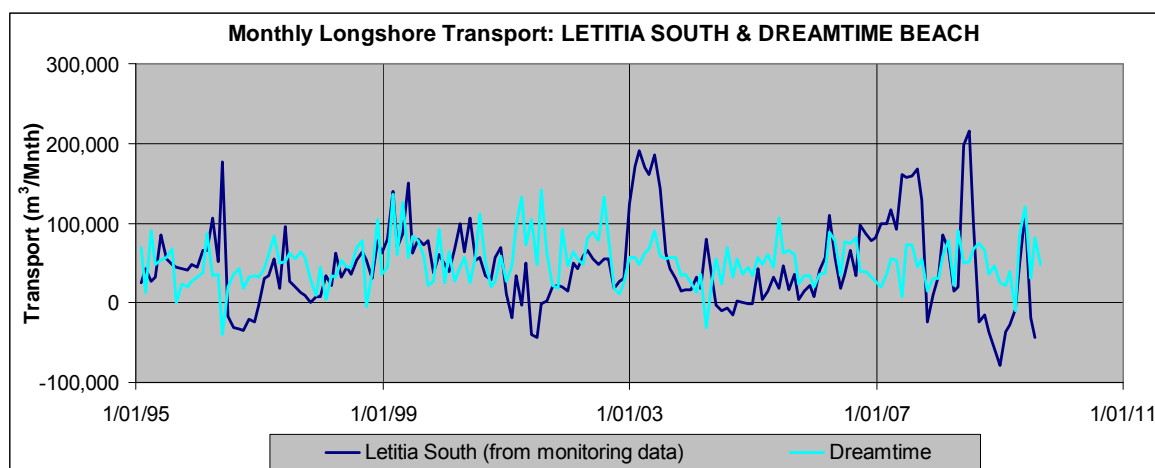

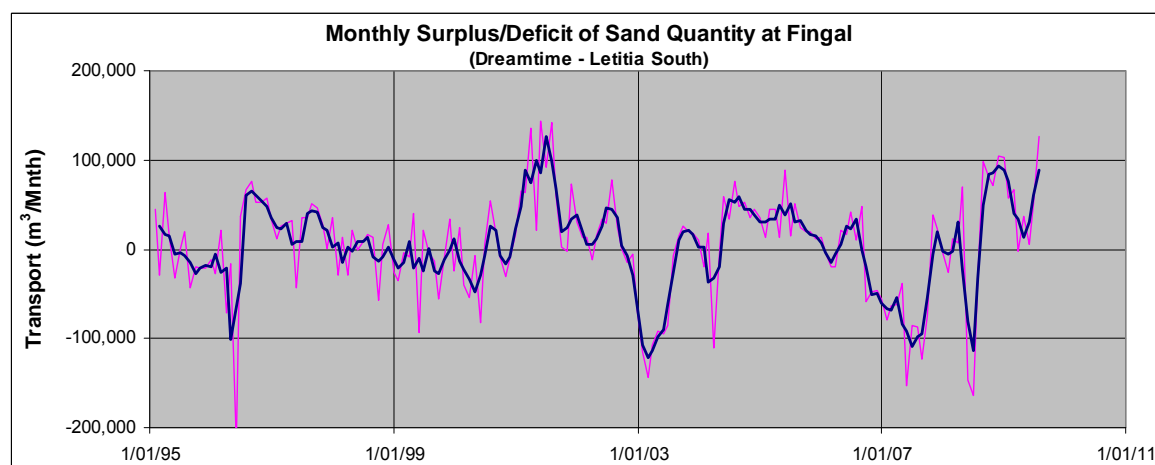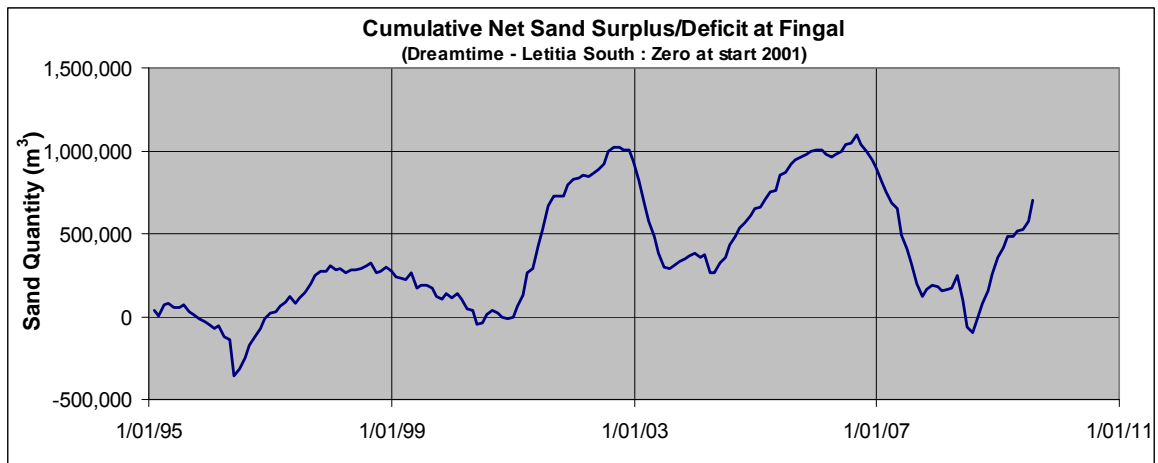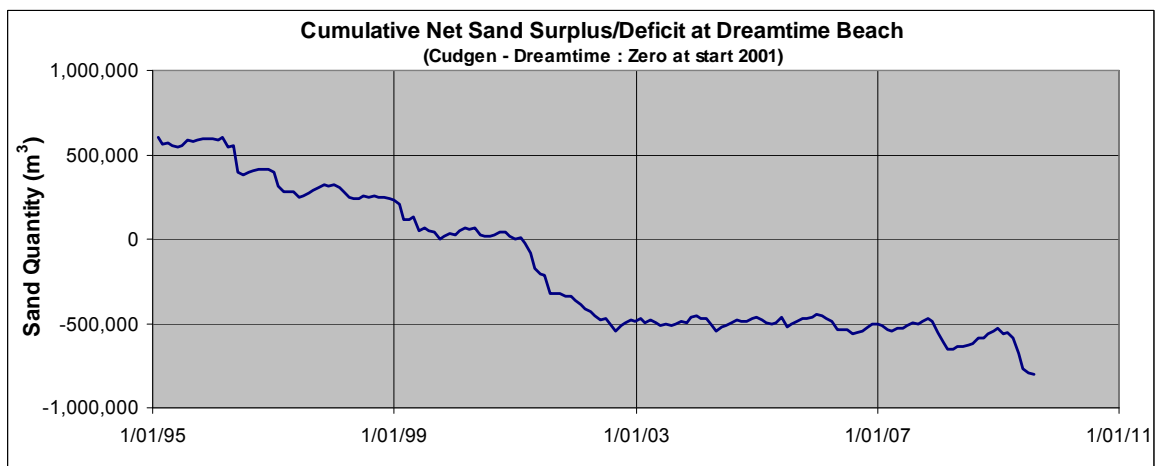**Figure 7-16 Monthly transport rates at Dreamtime Beach & Letitia South**

Figure 7-17 Monthly difference in transport: Dreamtime minus Letitia South

Figure 7-18   Cumulative difference in transport: Dreamtime minus Letitia Sth



Figure 7-19   Calculated cumulative change at Dreamtime Beach

8 DISCUSSION AND RECOMMENDATIONS

8.1 Longshore Sand Transport

It is apparent that the monthly rate of longshore sand transport into Letitia Spit past Fingal has varied substantially over the period since 1995. This is illustrated in Figure 8-1. However, the average annual transport there has been relatively uniform when assessed over several years, calculated at 562,000m^3/yr for 1995 to 2009 and 553,000m^3/yr from 2001 to 2009, within 1-2% of the assessed long term context average annual net transport rate of about 550,000m^3/yr through the regional coastal system. The monthly temporal pattern of transport appears to be subject to strong 'slug' like behaviour that cannot be calculated using conventional sand transport formulae. The average annual transport at Letitia South for the 3-year period July 2003 to June 2006 was only 297,000m^3/yr, while large slugs of transport occurred in early 2003 and in 2007 to early 2008. The average annual rate of transport for the period January 2007 to July 2008 was about 1,200,000m^3/yr, whereas it was essentially zero over the subsequent year August 2008 to July 2009.
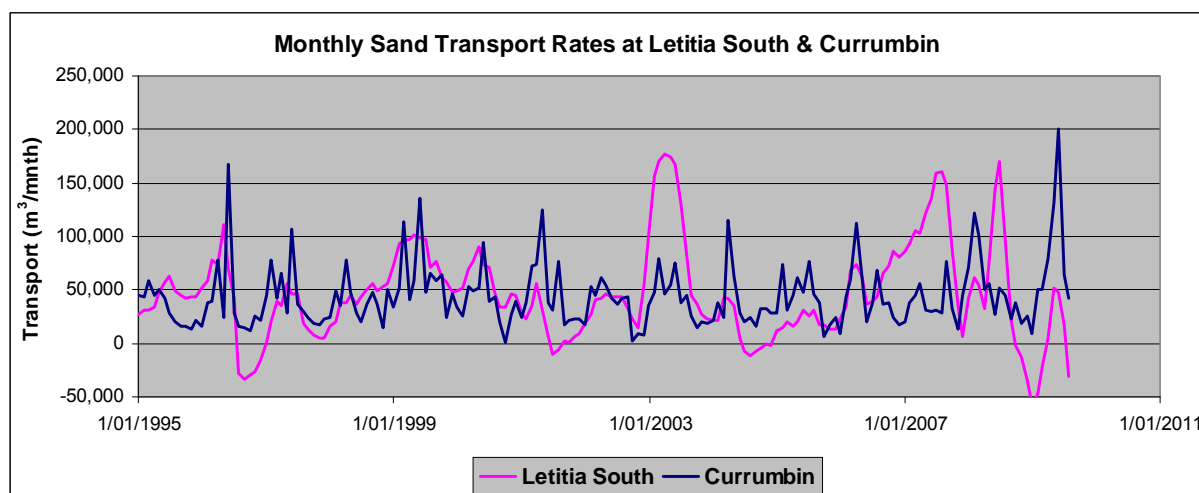
Figure 8-1   Calculated monthly transport at Currumbin and Letitia South

The rate of transport along Letitia Spit has been substantially affected by the sand bypass system activities through changes in the shoreline alignment (Figure 5-16). Rates of transport into Letitia North, approximately 1,000m south of the southern training wall, increased from about 600,000m^3/yr for 1995 to 2000 to 752,000m^3/yr for 2001 to 2009. The shoreline re-alignment that has occurred suggests that the sand bypassing operations have been a dominant contributor to this increase.

The slug transport in 2003 and 2007-08 appears to be the result of periodic strong inputs of sand to Letitia Spit from Dreamtime Beach, identified as occurring late in 2002 and during 2005-06 (Figure 7-18). This has affected the transport of sand to the sand bypass system and led to a higher rate of delivery of sand to Queensland.

This contrasts significantly with the temporal pattern at Currumbin, which is generally more uniform. However, it is subject to occasional high transport associated with larger waves from more easterly directions, as occurred during early 2009, reaching 130,000 and 200,000 m^3 in the single months of April and May 2009 respectively. This relatively short period of high transport increased the average

BMT WBM

annual net rate from about 506,000 m^3/yr for 1995 to 2008 to 527,000 m^3/yr for 1995 to 2009, with 735,000 m^3 being transported there in the single year August 2008 to August 2009.

Because the net sand transport to the north at Currumbin is less than that coming into Letitia Spit at Fingal, there is an overall net gain of sand, determined from the surveys to be about 0.51 million m^3 since the start of 1995, equivalent to an annual rate of 35,000m^3/yr, the difference in the assessed transport rates over that period.

The natural longshore transport into Letitia Spit from Dreamtime Beach appears to have been unusually high over the period, particularly during 2001 and 2002 (Figure 7-15), averaging about 596,000m^3/yr over 1995 to 2009, but as high as 810,000m^3/yr in 2001-02. However, the only source of sand transport information there is theoretical calculation from wave data and this location is probably the least reliable and accurate for such calculations. Nevertheless, it matches quite well the cumulative rate determined independently for Letitia South up to 2001 and again coincides with the cumulative Letitia South rate at October 2008, although the temporal pattern is different (Figure 7-15).

These results are reasonably consistent with the processes that have been observed. However, it would be expected that the transport rates at Dreamtime Beach would on average be lower in the future than the recent period in order to maintain the long term average rates.

8.2   Natural Bypassing and LTA Trends

8.2.1   Longer Term Trends

It is apparent from the assessment results outlined in Chapter 6 and 7 that both the natural bypassing and the monthly/annual components of the LTA have been significantly influenced by:

- Natural variability of the longshore transport processes; and
- The sand bypass system activities.

It has been adopted that the natural bypassing at the NSW/Qld border does not include the sand bypass system discharge at Duranbah. That is, the calculations are based on the assumption that this discharge is effectively all directed to Queensland.

The natural bypassing (Figure 8-2) has been reduced by both the Stage 1 initial dredging and the sand bypass system activities. An average annual natural bypassing rate of 322,000m^3/yr has been determined for the period 1995 to 2000 associated with the increase that occurred following completion of the Stage 1a dredging and subsequent reduction again during the Stage 1b and pre-commissioning dredging. It has subsequently reduced to an average of 40,500m^3/yr for the period 2001 to 2009 as a result of the sand bypassing operations, though it has varied significantly in a cyclical manner. The longer term trend is shown in Figure 8-2 as a 12 month running mean (yellow line).
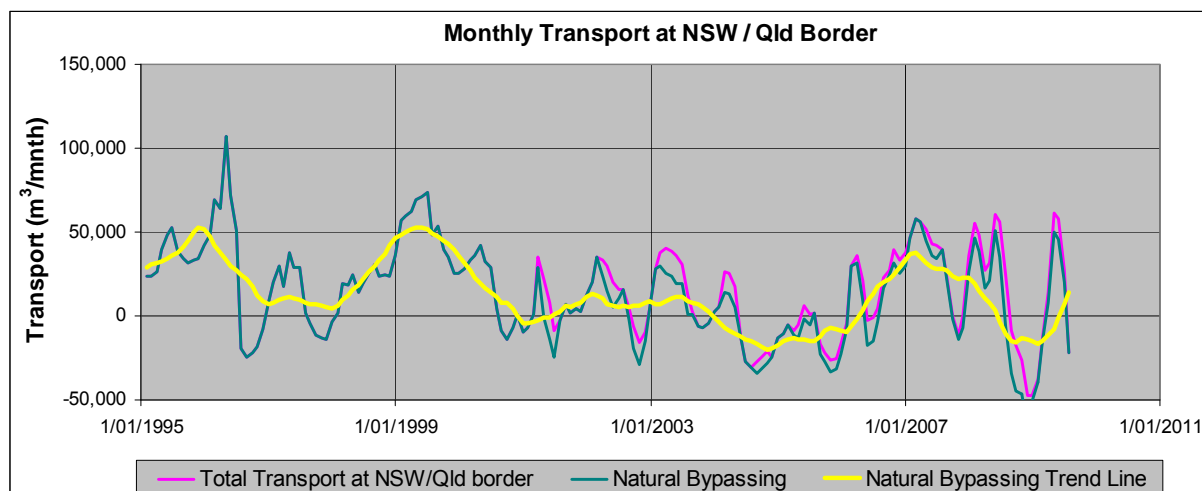
Figure 8-2   Trend of natural bypassing

The average annual components of the LTA have also varied significantly (Figure 8-3). They have increased from about 162,000m^3/yr (Equation 1b) (157,000m^3/yr using Equation 2c) for the period 1995 to 2000 to approximately 507,000m^3/yr to 512,000m^3/yr for the period 2001 to 2009, following commencement of sand bypassing operations, for the two methods.
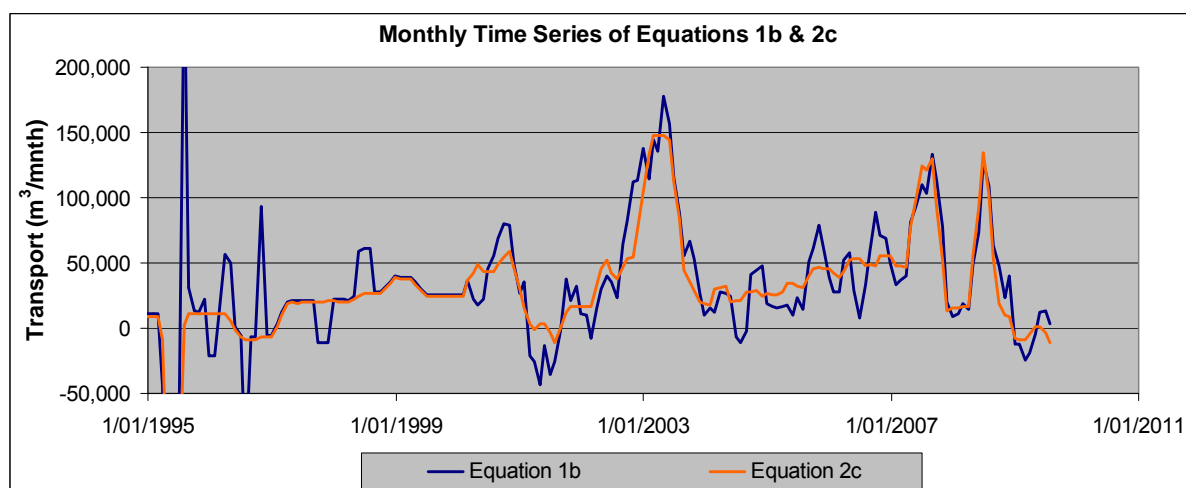
Figure 8-3   Time series of monthly values of Equations 1b & 2c

8.2.2 Trends Since Commencement of Sand Bypassing

Cumulative trends in the various rates of sand transport, pumping and dredging and natural bypassing since 2001 are shown in Figure 8-4. The equivalent cumulative average rate trends are shown in Figure 8-5. It can be seen that the pumping and dredging are relatively consistent in their steadily decreasing trends over time, whereas the various sand transport rates surged initially in 2003 and again during 2007-08, but then have trended back towards their longer term average rates. Despite considerable differences between the jetty system pumping and the Letitia South transport up to mid 2007, the pumping trend has averaged only marginally higher than the Letitia South transport by 2009. The natural bypassing trend has oscillated over time. Future reassessments of the LTA will be guided to a large extent by the continuing pattern of these trends.

The LTA rate since 2001 of approximately 509,000m^3/yr from Equation 1b is somewhat low while the rate of 513,000m^3 from Equation 2c is closely consistent in the context of the assessed average annual net longshore transport into Letitia South of 553,000 m^3/yr and the natural bypassing of about 40,500 m^3/yr for the same period. In the context of a long term average annual net longshore transport through the coastal system of 550,000m^3/yr, as assessed in Section 7.3, the average LTA rate from Equation 1b of 509,000m^3/yr corresponds closely to that natural bypassing rate.
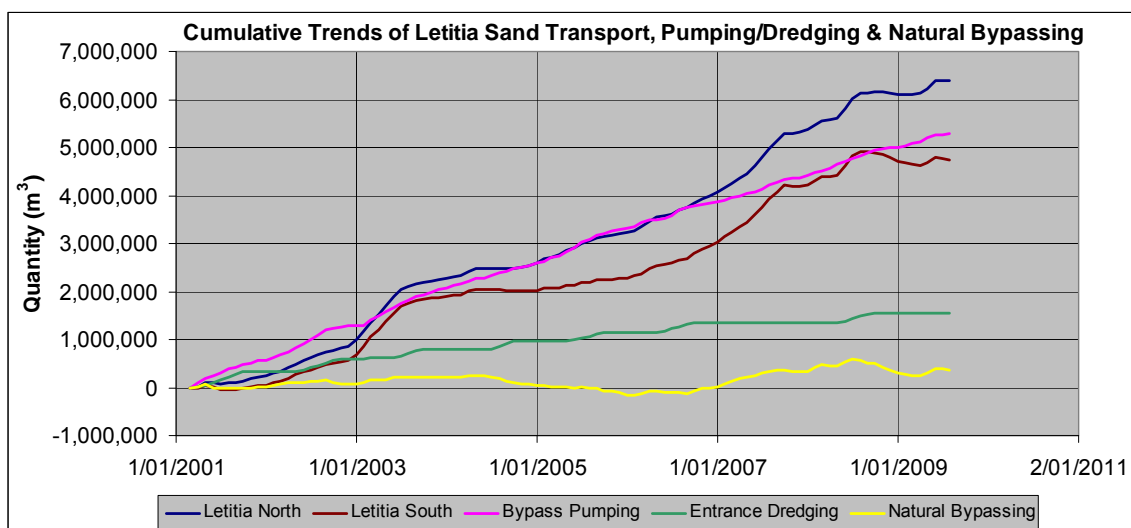
Figure 8-4   Cumulative sand transport, pumping/dredging and natural bypassing since 2001
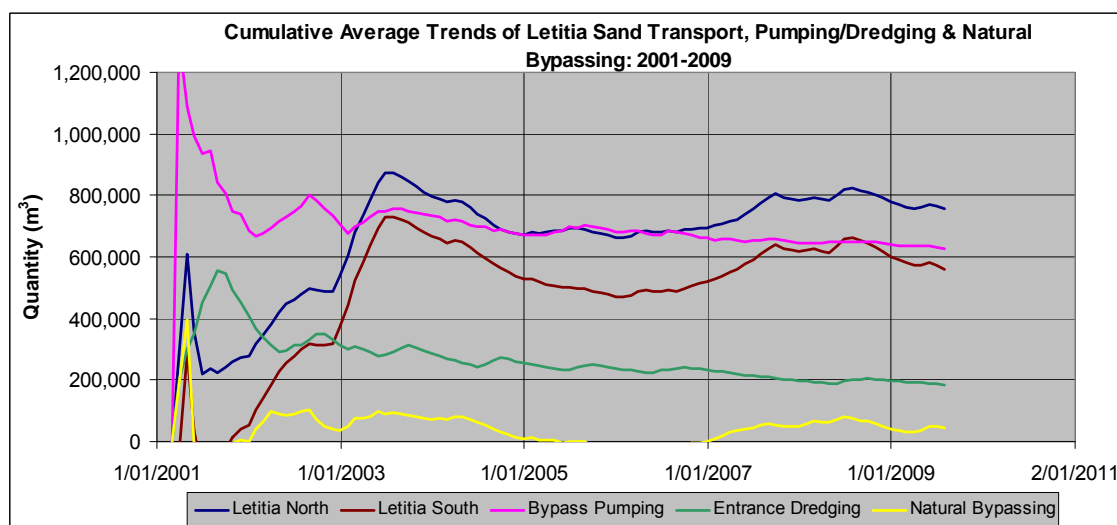
Figure 8-5   Cumulative average sand transport, pumping/dredging and natural bypassing

The temporal pattern of natural bypassing is shown in Figure 8-6, together with the transport into Letitia North. It is evident that the natural bypassing may be controlled to at or below zero except during sustained periods of higher transport that occur unpredictably from time to time, particularly when 'slugs' pass through the system, being only partially intercepted by the bypass pumping and dredging. Thus, the natural bypassing will unavoidably average more than zero over time. The LTA will be less than the rate of 550,000m^3/yr to the extent of the average annual natural bypassing, which is dependent on the capacity of the bypass system operations to intercept and deliver the incoming transport. The cumulative average trend of Equation 1b since 2001 is shown in Figure 8-7, indicating a prevailing fluctuating trend since 2003 around a rate somewhat above 500,000m^3/yr.
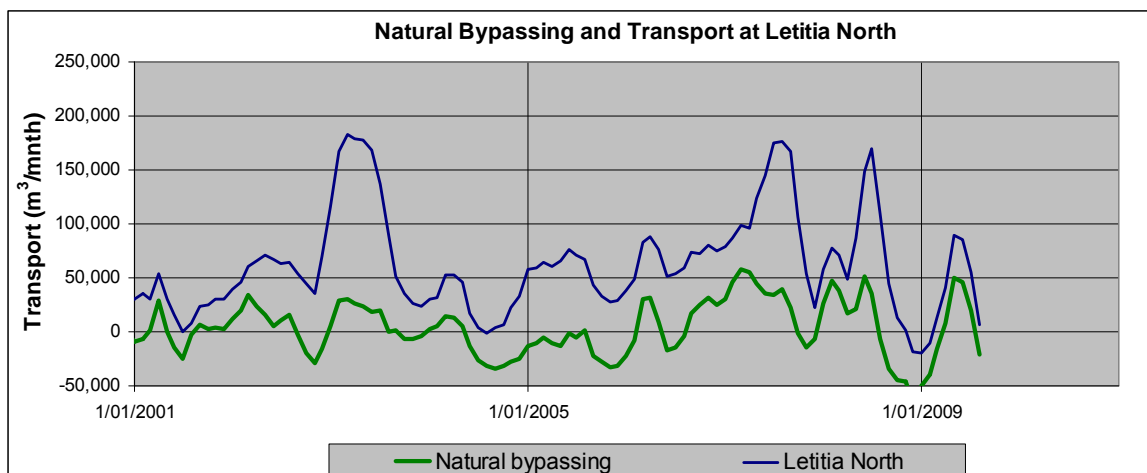
Figure 8-6   Natural bypassing and Letitia North transport since 2001
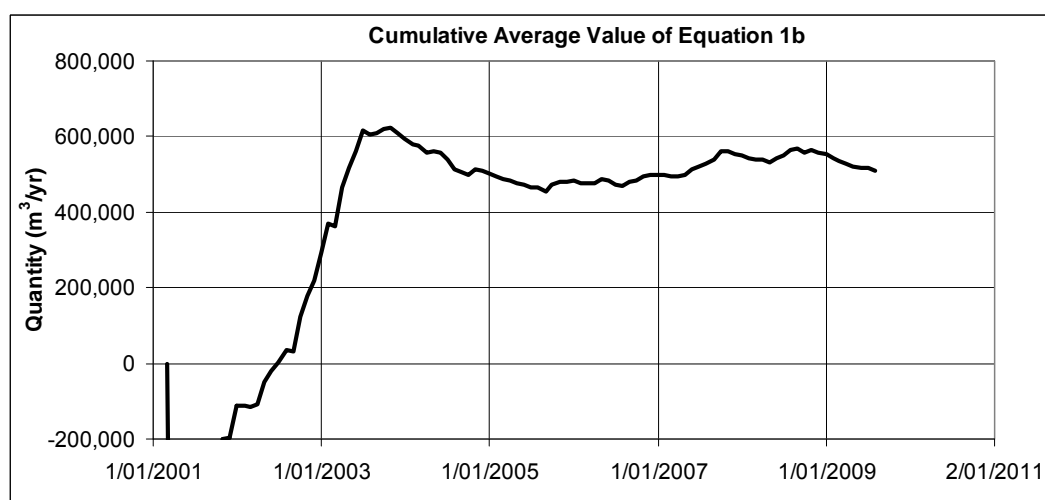
Figure 8-7   Cumulative average rate of Equation 1b since 2001

8.3   Re-assessing the LTA

8.3.1   General Considerations

The LTA must be based on its definition under the legislation. Its determination is dependent on the assessment of the natural bypassing of sand to Queensland (among other factors), which in turn is dependent on sand bypassing system operations. While the quantity of sand pumping at the jetty may have exceeded the LTA over the period of bypassing since 2001, the leakage through the jetty system to the entrance has caused a requirement for entrance dredging to meet the NSW objectives. This has been associated with a net loss of sand from NSW of about 2.48 million m^3 and an associated excess delivery to Queensland of about 2.65 million m^3 since 2001. It is noted that this includes the Supplementary Increment quantity of about 1.66 million m^3.

Because of the high variability of the sand supply along Letitia Spit and the significant and complex influence on the coastline response of the relatively high bypassing rate required to cater for the Supplementary Increment over the initial 6 years of system operation and changes in dredging frequency required to help maintain navigation conditions, there remains significant variability and uncertainty in the trends of behaviour on which the LTA may be based. The analysis undertaken

indicates an LTA rate somewhat higher than that adopted initially in the DOA at about 510,000m^3/yr. Only after a period of operations in which the annual sand delivery conforms more consistently to that rate will a more reliable LTA assessment for this bypassing system, which accounts for the system efficiency and the requirement for dredging to maintain the river entrance channel, be feasible.

At present, all of the analysis undertaken herein indicates:

- The long term average annual longshore sand transport along the beach system is approximately 550,000m^3/yr;

- There is a leakage of sand through the jetty system that leads to a requirement for entrance dredging as part of the bypassing operations;

- Not all of the leakage of sand to the entrance needs to be dredged to maintain the entrance channel and the balance passes through as the natural bypassing;

- Significant leakages of sand and natural bypassing occur predominantly in association with high transport during storm events or 'slugs' of transport along Letitia Spit that are not intercepted by the bypassing;

- The appropriate LTA rate depends on the rate at which the jetty system intercepts the longshore transport and the entrance channel dredging required to meet the channel depth criterion in determining the natural bypassing rate, as assessed in Section 8.3.2 below.

8.3.2 Jetty System Interception of the Longshore Transport

The reduction in the natural bypassing over the period 2001 to 2009 has been achieved by pumping and dredging substantially more than the net rate of longshore sand supply, including bypassing of the Supplementary Increment of about 1.66 million m^3 over the period 2001 to 2006. The total bypass pumping and dredging rates have been as follows to date:

- Average annual rate of 894,000 m^3/yr for March 2001 to December 2006 inclusive, approximately the period including the Supplementary Increment;

- Average annual rate of 813,000 m^3/yr for March 2001 to August 2009 inclusive; and

- Reduced average annual rate of 630,000m^3/yr for January 2007 to August 2009 inclusive.

All of these rates are significantly higher than the assessed LTA and yet there is still significant natural bypassing when slugs of transport pass through the system. The rates of sand transport for the period since the start of 2007 following completion of the Supplementary Increment, assessed from the monthly time series of transport rates derived from Equations 3a to 3f, have been as follows:

Letitia North	900,000 m^3/yr
South Wall	253,000 m^3/yr
North Wall	137,000 m^3/yr
Across NSW/Qld border (total)	244,000 m^3/yr
Natural bypassing	136,000 m^3/yr
Snapper Rocks	800,000 m^3/yr

For the same period since January 2007, the average sand pumping rate at the jetty system was 553,000m^3/yr, the Letitia North compartment accumulated approximately 241,000m^3 and about 200,000m^3 were dredged from the entrance.

An estimate of the proportion of the longshore transport intercepted by the jetty system has been made on the basis of the longer term cumulative ratio of the leakage, taken to be the transport past the south wall, to the transport into the Letitia North compartment. The leakage rate expressed as a percentage of the transport into Letitia North is shown in Figure 8-8. This indicates that, overall to date, about 30% of the transport into Letitia North will leak through the system.

As well, an estimate of the amount of dredging required to maintain the entrance channel as a percentage of the transport of sand into the channel past the south wall has been made, as shown in Figure 8-9. This suggests that the proportion of the leakage sand that needs to be dredged to maintain the navigational requirement of the channel has been about 60-100 %, trending down since 2007 and averaging about 80% by 2009. The natural bypassing would be thus approximately 20% of the leakage through the jetty system.
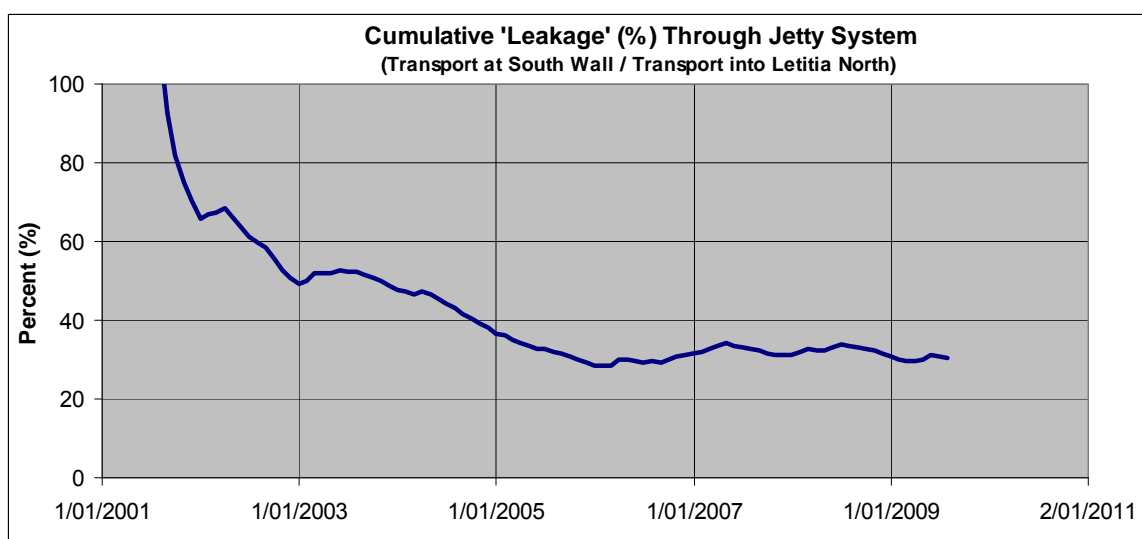
Figure 8-8   Trend of % leakage through jetty system
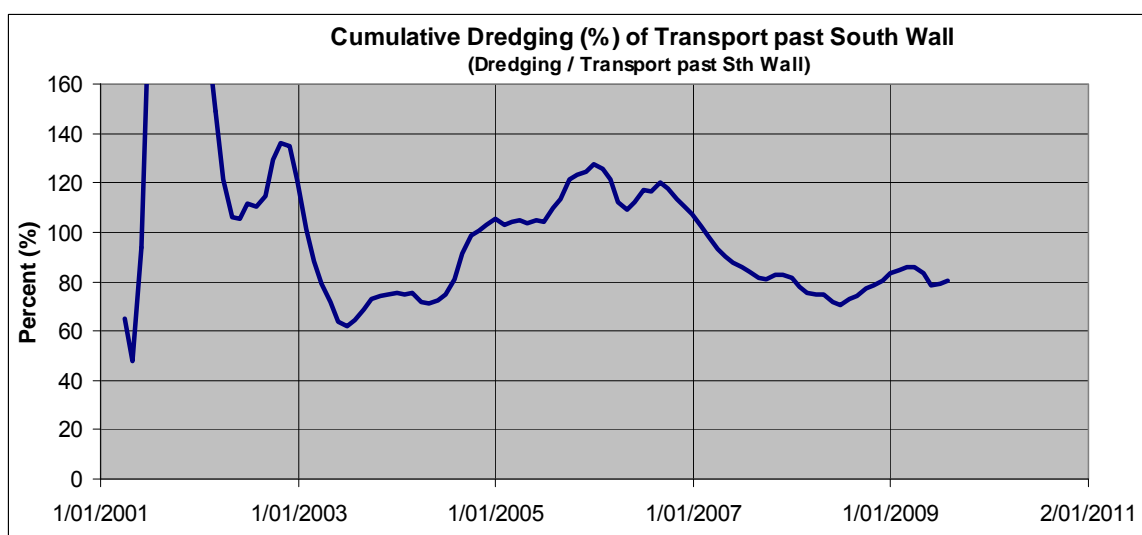
Figure 8-9   Trend of % dredging of sand leakage

BMT WBM

8.3.3   LTA Rate Discussion and Recommendation

The LTA rate will depend on both the prevailing average annual net sand transport through the coastal system and the jetty pumping/entrance dredging rates required to satisfy the channel depth criterion. The average annual net sand transport through the coastal system has been assessed herein at most probably about 550,000m^3/yr, but possibly as high as about 553,000m^3/yr based on the Letitia South rates to date.

Based on the trends derived in Section 8.3.2, for a sustainable long term average situation, the leakage through the jetty system is likely to be about 30% of the net sand transport, approximately 165,000m^3/yr. This corresponds to an effective jetty pumping rate of 385,000m^3/yr. Adopting a dredging need of 80% of the transport past the south wall, the dredging required would be 132,000m^3/yr and the natural bypassing 33,000m^3/yr.

However, this analysis of natural bypassing is highly sensitive to the proportion of the transport past the south wall that needs to be dredged. For example, should that proportion be 75%, as is quite feasibly interpreted from Figure 8-9, the natural bypassing would be 41,250m^3/yr, close to the average since 2001.

That is, based on this approach, the LTA rate would be in the range 509,000 to 517,000m^3/yr compared with 509,000 to 513,000m^3/yr derived directly from the data for the period 2001-2009. This is within a surprisingly a small range, given the potential and actual high variability of the processes and the uncertainties inherent in the assessment.

It is considered appropriate to give greater weighting to the result derived directly from the survey data (Equation 1b) of 509,000m^3/yr. Accordingly, a reassessed LTA rate of 510,000m^3/yr has been adopted.

The proportion of the LTA that would be pumped compared with that dredged could vary substantially, depending on the ability of the jetty pumping system to intercept the longshore transport. For optimum utilisation of the jetty system infrastructure, the operational target jetty pumping rate should be as high as possible, up to the LTA rate. Nevertheless, some dredging to achieve suitable conditions in the entrance channel will most probably be needed because the jetty system will not achieve a 100% interception rate. The average annual increments to the total sand delivery, being the pumping plus channel dredging, need to match the LTA over the longer term, while catering also for temporal variability.

Careful ongoing monitoring and review of the operations are needed to assess progressively how the system operations are trending and, in particular, the development of a longer term pattern of dredging and its influence on the natural bypassing rates and the trend towards the situation in which the LTA is being delivered in the longer term.

The monitoring to date has been comprehensive and invaluable as a data source for this reassessment of the LTA. The identification of a minor leakage of sand to deeper water beyond the 20m limit of the calculation compartments in the vicinity of the entrance suggests that there would be considerable value gained over the future longer term in extending at least some of the surveys along that area somewhat further offshore.

9 REFERENCES

Allen, M.S. and Callaghan, J. 1999. *Extreme Wave Conditions in the South Queensland Coastal Region.* 14th Australasian Coastal and Ocean Conference, Perth, April 1999.

Andrews M. and Nielsen C. (2001). *Numerical modelling of the Gold Coast Seaway.* Proc. 15th Australasian Coastal and Ocean Engineering Conference, Gold Coast, September 2001. 469-473.

Boswood P., Victory S. and Lawson S. (2001). *Placement Strategy and Monitoring of the Tweed River Entrance Sand Bypassing Project Nourishment Works.* Proc. 15th Australasian Coastal and Ocean Engineering Conference, Gold Coast, September 2001. 253-258.

BMT WBM (2008). *Tweed River Entrance Sand Bypassing – Erosion of Letitia Spit.* Report for NSW Dept of Lands, R.B16998.001.01, July 2008.

Callaghan D.P. (2005). *Issues at the Frontiers of Coastal Morphodynamics Modelling.* PhD thesis, Division of Civil Engineering, University of Queensland, August 2005.

Delft Hydraulics Laboratory, 1970. *Gold Coast Queensland Australia – Coastal Erosion and Related Problems.* Report 257. Prepared for the Queensland Government. 1970.

Goodwin I.D. (2005). *A mid-shelf mean wave direction climatology for south-eastern Australia and its relationship to the El Nino Southern Oscillation since 1878 AD.* International Journal of Climatology, 25, 1715-1729.

Hyder Consulting, Patterson Britton Partners and WBM Oceanics Australia (1997). *Tweed River Entrance Sand Bypassing Project Permanent Bypassing System, Environmental Impact Statement/Impact Assessment Study.* Prepared for the NSW Dept Land & Water Conservation and Qld Dept of Environment, June 1997.

Gordon A.D., Lord D.B. and Nolan M.W. (1978). *Byron Bay – Hastings Point Erosion Study.* NSW Dept Public Works, Coastal Engineering Branch Report, PWD 78026.

Kampius, J.W. (1991) *Alongshore Sediment Transport Rate.* Journal of Waterway, Port, Coastal and Ocean Engineering, Vol 117, No. 6. pp624-640.

King, D. (2006) *Dependence of the CERC Formula K Coefficient on Grain Size.* Coastal Engineering 2006. pp 3381-3390.

Kulmar M., Lord D. and Sanderson B. (2005). *Future Directions for Wave Data Collection in New South Wales.* Proc. 17th Australasian Coastal and Ocean Engineering Conference, Coasts and Ports, Adelaide.

Macdonald H.V. and Patterson D.C. (1984). *Beach Response to Coastal Works, Gold Coast, Australia.* Proc. 19th Coastal Engineering Conference Proceedings, Houston, Texas, ASCE, September 1984.

Pattearson C.C. and Patterson D.C. (1983). *Gold Coast Longshore Transport.* Proc. 6th Aust conf. On Coastal Engineering, Gold Coast.

Patterson, D.C. (1999) *Longshore Transport Modelling for Tweed River Entrance Sand Bypassing project.* Coasts & Ports '99, 14th Australasian Coastal and Ocean Engineering Conference and the 17th Australasian Port and Harbour Conference, Perth, April 1999.

Patterson D C (2007a). *Sand Transport and Shoreline Evolution, Northern Gold Coast, Australia.* Journal of Coastal Research SI50, ICS2007, Gold Coast, 2007.

Patterson D C (2007b). *Comparison of Recorded Brisbane and Byron Wave Climates and Implications for Calculation of Longshore Sand Transport in the Region.* 18th Australasian Conference on Coastal and Ocean Engineering, Coasts and Ports 2007, Melbourne, July 2007.

Public Works Department (1978). *Byron Bay – Hastings Point Erosion Study.* Report No. PWD 78026, November 1978.

Public Works Department, NSW, 1980, *Dreamtime Beach Coastal Engineering Advice*, prepared by the Coastal Engineering Branch, PWD, Report DPW 80006.

Roelvink J.A. and Murray R.J. (1992). *Gold Coast Queensland Australia – Southern Gold Coast Littoral Sand Supply.* Report H85 prepared by Delft Hydraulics Laboratory for the Qld. Govt.

Rosati, J., Walton, T., Bodge, K. (2006) *Coastal Engineering Manual: Longshore Sediment Transport.* Coastal and Hydraulics Laboratory – Engineering Research and Development Center Waterways Experiment Station – Vicksburg Mississippi.

Smith, E., Ping, W. and Zhang, J. (2003). *Evaluation of the CERC Formula Using Large Scale Model Data.* Engineering Research and Development Center Waterways Experiment Station – Vicksburg Mississippi.

Wang P., Ebersole B.A> and Smith E.R. (2002). *Longshore Sand Transport – Initial Results from Large-Scale Sediment Transport Facility.* US Army Corps of Engineers, ERDC/CHL CHETN-II-46, March 2002.

WBM (2000). *Byron Shire Coastline Hazard Definition Study.* Report for Byron Shire Council.

WBM (2003). *Ballina Shire Coastline Hazard Definition Study.* Report for Ballina Shire Council.

BMT WBM Brisbane   Level 8, 200 Creek Street Brisbane 4000
                        PO Box 203 Spring Hill QLD 4004
                        Tel +61 7 3831 6744   Fax +61 7 3832 3627
                        Email   wbm@wbmpl.com.au
                        Web   www.wbmpl.com.au

BMT WBM Denver   14 Inverness Drive East, #B132
                        Englewood Denver Colorado 80112 USA
                        Tel +1 303 792 9814   Fax +1 303 792 9742
                        Email   wbmdenver@wbmpl.com.au
                        Web   www.wbmpl.com.au

BMT WBM Mackay   Suite 1, 138 Wood Street Mackay 4740
                        PO Box 4447 Mackay QLD 4740
                        Tel +61 7 4953 5144   Fax +61 7 4953 5132
                        Email   wbmmackay@wbmpl.com.au
                        Web   www.wbmpl.com.au

BMT WBM Melbourne   Level 5, 99 King Street Melbourne 3000
                        PO Box 604 Collins Street West VIC 8007
                        Tel +61 3 8620 6100   Fax +61 3 8620 6105
                        Email   wbmmelbourne@wbmpl.com.au
                        Web   www.wbmpl.com.au

BMT WBM Newcastle   126 Belford Street Broadmeadow 2292
                        PO Box 266 Broadmeadow NSW 2292
                        Tel +61 2 4940 8882   Fax +61 2 4940 8887
                        Email   wbmnewcastle@wbmpl.com.au
                        Web   www.wbmpl.com.au

BMT WBM Perth   1 Brodie Hall Drive Technology Park Bentley 6102
                        Tel +61 8 9328 2029   Fax +61 8 9486 7588
                        Email   wbmperth@wbmpl.com.au
                        Web   www.wbmpl.com.au

BMT WBM Sydney   Level 1, 256-258 Norton Street Leichhardt 2040
                        PO Box 194 Leichhardt NSW 2040
                        Tel +61 2 9713 4836   Fax +61 2 9713 4890
                        Email   wbmsydney@wbmpl.com.au
                        Web   www.wbmpl.com.au

BMT WBM Vancouver   1190 Melville Street #700 Vancouver
                        British Columbia V6E 3W1 Canada
                        Tel +1 604 683 5777   Fax +1 604 608 3232
                        Email   wbmvancouver@wbmpl.com.au
                        Web   www.wbmpl.com.au