Reassessment of Long-term Average Annual Net Sand Transport Rate 2020

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BMT Commercial Australia Pty Ltd Level 5, 348 Edward Street Brisbane Qld 4000 Australia PO Box 203, Spring Hill 4004 Tel: + 61 7 3831 6744 Fax: + 61 7 3832 3627 ABN 54 010 830 421 www.bmt.org	**Document:**	R.A10169.001.03.docx
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	Project Manager:	Ian Teakle
	Author:	Ian Teakle
	Client:	Tweed Sand Bypassing
	Client Contact:	Matthew Harry
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Synopsis: **This report describes the results of the re-assessment of the Long-term Average (LTA) sand transport rate at Letitia Spit to January 2020. The re-assessment strategy includes analysis of wave-induced sand transport rates and interpretation of the results of the surveys quantifying quantities of sand in various compartments of the system.**

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Executive Summary

Background

The Long-Term Average (LTA) is the quantity of sand defined in the Tweed River Entrance Sand Bypassing Project Deed of Agreement and required to be bypassed over the longer term by use of the Tweed Sand Bypassing (TSB) jetty mounted pumping system and entrance dredging.

An updated reassessment of the LTA sand transport rate for the TSB project has been undertaken to extend the previous 2015 reassessment to the beginning of 2020, using the same methodology. 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 sand bypassing system is operated.

The assessment strategy adopted makes maximum use of the considerable survey data obtained from the monitoring program implemented over the period from 1993 to 2020, including the period of Stage 1 initial entrance dredging that commenced in 1995, and 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. This 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 updated. This necessarily required calculation of a reference sand transport rate at Currumbin, at the northern end of the monitoring survey compartments, being less subject to complexities in wave propagation and sand transport processes than other locations. The previously utilised SWAN wave propagation parameters and sand transport calculation procedure was adopted. The Queens sand transport relationship was utilised, with the same coefficients as calibrated in the previous analysis.

The analysis is undertaken with a monthly timestep based on interpolating the surveyed sand quantities and integrating the monthly sand transport rates. 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.

Survey Trends

The intention of the Tweed Sand Bypassing LTA objective has been to re-instate the natural sand supply from Letitia Spit to the Gold Coast. The survey trends indicate that the trend of reducing sand volumes for NSW compartments since jetty pumping commenced in 2001 had ceased by 2015 and has since increased by around 0.5M m^3 to a total net 3.5M m^3 loss since 1993. Sand volume increases along the Qld compartments have also reached a maximum around 2015 and have since stabilised at a total net 5.0M m^3 gain since 1993. It therefore appears as though the system response has broadly stabilised from the initial transient response to commencement of bypassing and the 2001 to 2007 supplementary increment period.

LTA and Sand Transport Rates

The component monthly LTA values for the period of the operations and monitoring analysed varied significantly over time, depending on the rates of sand transport and the bypassing rates and methods implemented. Understanding how the LTA quantity varies over both the long term and short term helps inform the operational requirements to satisfy the Deed of Agreement. Over the past 5 years the net longshore sand transport rates have been lower than the long-term trend due to a less energetic wave climate.

The analysis undertaken indicates that the long-term average annual longshore sand transport past Fingal over the period 1995 to 2019 is approximately 546,000 m^3/yr, which has significantly reduced from the previous estimate of 575,000 m^3/yr. The corresponding average rate at Currumbin is assessed to be only 494,000 m^3/yr, which is also a slight reduction from the previous estimate of 503,000 m^3/yr. The long-term discrepancy between Fingal and Currumbin transport rates, which is derived solely from the net sand volume increase within the coastal compartment between Fingal and Currumbin over this period, has been noted in previous assessments and while still evident, it has reversed since 2015.

The LTA averaged 497,000 m^3/yr for the bypassing period 2001 to 2019, which is slightly higher than the previous assessment. While average annual net longshore transport into Letitia Spit has reduced, the natural bypassing trend has also substantially reduced since 2015. A lower LTA of 480,000 m3/yr is derived by averaging over the period from 2007 to 2019, which doesn't include the supplementary increment (2001 to 2006).

There is a leakage of sand through the jetty system, determined through the LTA analysis to be about 25% of the Letitia Spit longshore transport. This leakage is in part deposited in the entrance compartment and is in part passed northwards as natural bypassing. The natural bypassing rate had previously trended upwards during the period from 2009 to 2015 when there was no entrance dredging. Since 2015, in total, there has been 410,000 m^3 dredged from the Tweed River entrance and a noticeable reduction has been observed in the long-term trend rate of natural bypassing. The 2001 to 2015 natural bypassing trend rate had increased to around 100,000 m^3/yr but has reduced to 56,000 m^3/yr, averaged over the period from 2001 to 2019. The average annual rate of entrance dredging over the period from 2001 to 2019 was 109,000 m^3/yr.

Recommendations

Despite the recently below trend longshore transport and the re-commencement of entrance dredging, the assessed LTA rate has actually remained relatively stable since the 2015 re-assessment. The 2020 re-assessment LTA best estimate is 490,000 m^3/yr (±20,000 m^3/yr), comprised of bypass pumping at around 400,000 m^3/yr and bypass dredging of around 90,000 m^3/yr. These LTA components are based on the re-assessed long-term transport into Letitia Spit of approximately 550,000 m^3/yr and a natural bypassing rate of approximately 60,000 m^3/yr.

Climate change has the potential to drive long-term impacts on longshore sediment transport supply into Letitia Spit. At the same time, future Sea Level Rise projections are likely to create additional demand for sand supply to maintain existing levels of amenity along the Gold Coast beaches. The Tweed Sand Bypassing project will operate into the future in the context of these evolving climate change pressures.

The monitoring to date has been comprehensive and invaluable as a data source for this reassessment of the LTA and should be continued at the present level of detail and frequency in order to maintain suitable and sufficient accuracy and reliability for future reassessments.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

1.1.1 Overview

BMT has been commissioned to undertake an updated reassessment of the Long-term Average (LTA) sand transport rate to 2020 for the Tweed Sand Bypassing Project. This has been completed using the same strategy and analysis parameters as for the previous 2015 and earlier 2009 reassessments. 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 2020 reassessment, the sand bypassing system has been in operation since April 2001, with over 19 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. In the first six annual periods, a higher rate of bypassing was implemented to include the Supplementary Increment as required. Since 2007, the rate of bypassing has operated broadly in line with the requirement to match the LTA quantity.

This report sets out the results of the reassessment to the start of 2020, including discussion of the strategy and updated information on the coastal processes relating to the LTA and natural bypassing from NSW to Qld. Discussion of the key issues and uncertainties in the analyses are presented.

1.1.2 Project History

The Tweed Sand Bypassing Project (previously Tweed River Entrance Sand Bypassing Project – TRESBP) is a joint initiative of the New South Wales and Queensland state governments to maintain a navigable entrance to the Tweed River and provide an ongoing supply of sand to the southern Gold Coast beaches. The project has been ongoing for approaching 25 years, marked by the milestones in Table 1-1.

The Project officially commenced in 1995 with the Stage 1A dredging of 2.25M m^3 of sand from the Tweed River entrance and placement between Point Danger and Kirra, followed by a smaller scale Stage 1B dredging of 0.8M m^3 between 1997 and 1998. Stage 2 of the project was subsequently awarded as a Design and Construct contract to McConnell Dowell and commenced with entrance dredging in 2000 and commissioning of the sand bypassing jetty system in March 2001. Since then sand bypassing has continued through pumping supplemented by intermittent dredging campaigns.

Table 1-1 Tweed Sand Bypassing Project Milestones

Date	Project Milestone
1995-1996	TRESBP Stage 1A dredging
1997-1998	TRESBP Stage 1B dredging
2000-ongoing	TRESBP Stage 2.
March 2001	TRESBP Stage 2 jetty commissioned.

Over the Project duration the sand bypassing operations have progressed through a number of distinct operational “epochs”, which are referred to in this (and previous) LTA assessments and reporting. These epochs and previous LTA reports are summarised in Table 1-2.

Table 1-2 Tweed Sand Bypassing Project Epochs

Project Epoch / LTA report	Overview
1995-2000	TRESBP Stage 1A/1B dredging.
2001-2007	TRESBP Stage 2 jetty commissioned. Supplementary increment period.
2001-2009	Stage 2 period of high total bypassing (pumped and dredged) primarily due to supplementary increment.
2011	First LTA report (BMT WBM, 2011), covering period from 1995 to 2009.
2009-2015	Reduced rate of jetty bypassing and no entrance dredging. Period between first and second LTA reports.
2016	Second LTA report (BMT WBM, 2015), extending analysis period from 1995 to 2015.
2016-2019	Period between second and third (this) LTA reports. Entrance dredging re-instated.
2020	Third LTA report (this report), extending analysis from 1995 to 2019.

1.1.3 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 is the quantity of sand required to be bypassed over the longer term by use of the TSB jetty mounted pumping system and entrance dredging. 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 and the requirement to bypass the LTA is achieved through annual bypassing of the LTA as defined above as best assessed for, and during, the annual period.

While the LTA may be adopted as the target quantity for TSB sand transport at the beginning of the annual operational period, it is the actual varying quantities as above that become the operational target for transporting by the pumping and dredging system during the year.

Furthermore, 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.

Neither of the transport rates that define the LTA 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.

The 1995 Deed of Agreement specified that re-assessment of the LTA should happen at 10 year intervals, or more frequently. This report represents the third re-assessment of the LTA (Table 1-2).

1.2 Study Scope

The aim of the study is to reassess the Long-term Average Annual Net Sand Transport Rate (LTA) in the most comprehensive and meaningful way feasible to the extended date of January 2020, taking maximum advantage of the data and knowledge now available. More broadly, the study also aims to advance the present status of knowledge of the sand transport processes relating to the LTA for application to ongoing management of the bypassing system.

This latest LTA reassessment study covers the Tweed Sand Bypassing Project area as defined in the Exhibit 10 (Placement) and Exhibit 11 (Removal) figures, shown in Figure 1-1 and Figure 1-2 respectively. The study considers the Project period from prior to Stage 1A in 1995 to the end of the 2019 calendar year.

The study outcomes thus include detailed analysis of the LTA component processes as defined in the Deed of Agreement 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 are identified within the limits of feasible accuracy.

Further, the study seeks to provide information on prevailing trends in the processes and LTA to assist in future management of the system.

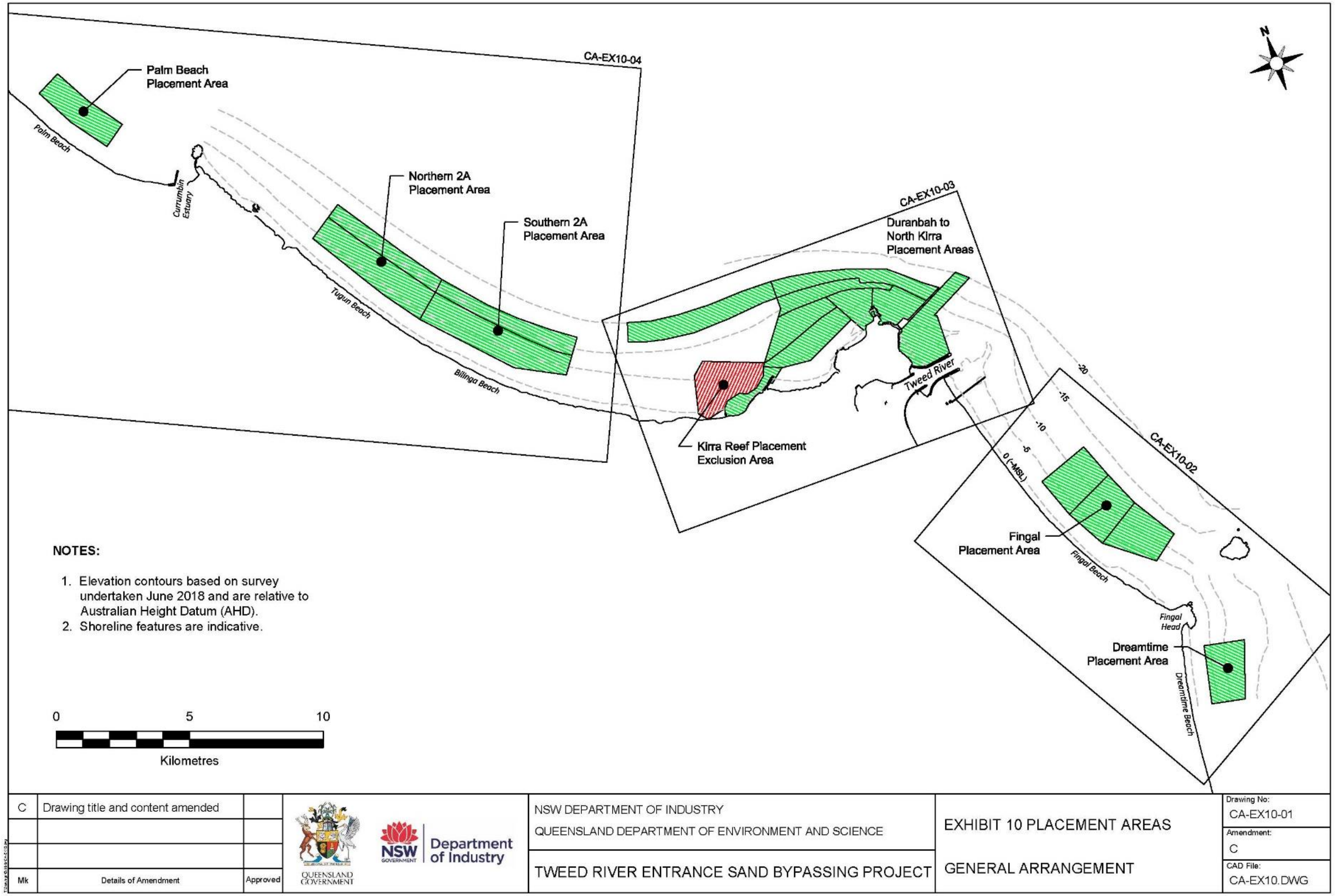


Figure 1-1 Tweed Sand Bypassing Placement Areas (Exhibit 10)

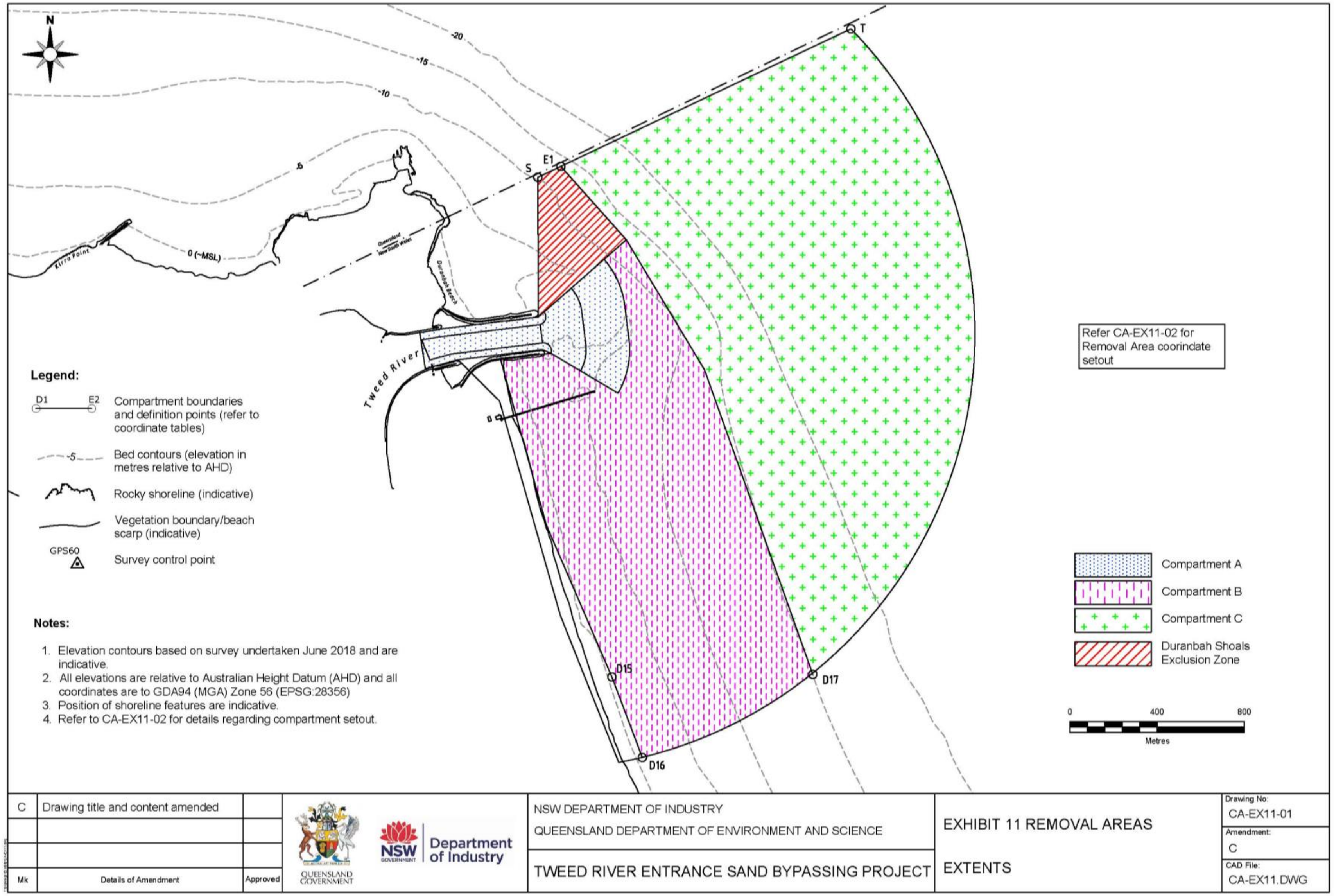


Figure 1-2 Tweed Sand Bypassing Removal Areas (Exhibit 11)

1.3 LTA Reassessment Strategy

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 included provision also for an initial 6 year period of Supplementary Increment to be delivered to compensate for accumulation of sand in the New South Wales compartment 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 was considered in the previous LTA reassessment to 2009 (BMT WBM 2011). By 2020, the sand bypass jetty system has been operating for 19 years and some 13 years post supplementary increment.

The LTA reassessment strategy pursued in this study is the same as that implemented in the previous reassessments. It is based on time series (monthly/annual) analysis of the LTA components (refer Section 1.3.1) over the 2001-2020 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 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. Accordingly, this study is based on applying a consistent LTA calculation methodology from 1993 to present day, as described below.

1.3.1 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 plus Duranbah (Figure 1-3) 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/offshore supply (1b)**

* Pumping/Dredging (total) is the amount removed from NSW compartments and transferred to Queensland or Duranbah, i.e. not including backpassing quantities.

** Net Quantity Change is total change in the New South Wales compartments including Duranbah.

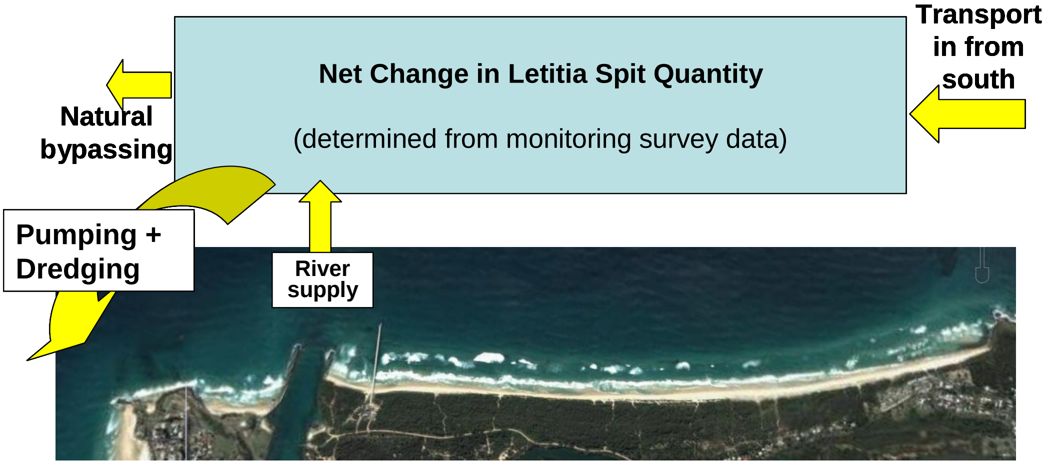


Figure 1-3 Conceptual sand budget for Letitia Spit

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), that is 1 km south of the Tweed River entrance southern training wall, and importantly satisfies the "*…absence of any artificial actions to influence it*" requirement.

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.

1.3.2 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. 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 1-4, together with adjustment for the fact that not all of the transport across the NSW/Qld border is 'natural bypassing' but results from sand bypassed to Duranbah, 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)

* ΔQ (Qld) is the total volume change in the Queensland compartments (does not include Duranbah).

** Sand Pumping/Dredging (total) is the amount removed from NSW compartments and transferred to Queensland or Duranbah, i.e. not including backpassing quantities.

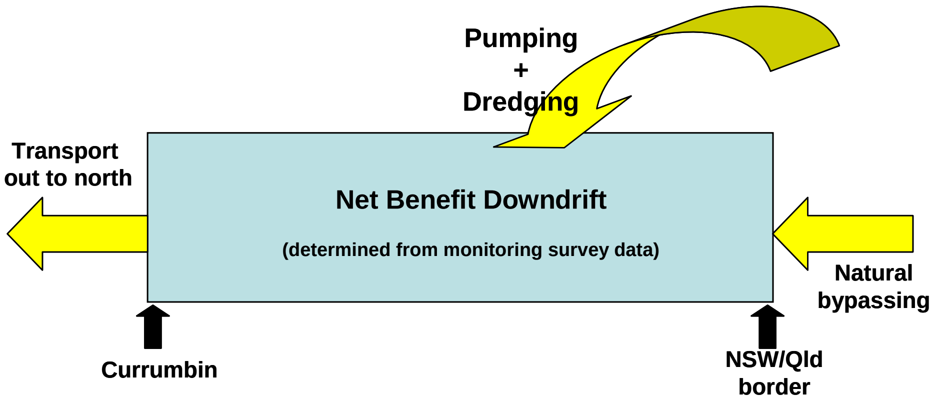


Figure 1-4 Conceptual quantification of natural bypassing

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)

***** Sand Pumping/Dredging(Qld) is the amount removed from NSW compartments and transferred to Queensland, excluding amount placed at Duranbah or any backpassing quantities.

For this analysis, the net sand transport out to the north at Currumbin over the years covered by the monitoring is needed. It varies continuously with the incident wave conditions and 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 2. Longshore sand transport (LST) rates calculated for Currumbin are described in Chapter 3. The LTA rates derived from the data using Equation 1b and from calculated LST rates are presented in Chapter 4.

Analysis of natural bypassing rates across the NSW/Qld border is presented in Chapter 5.

1.3.3 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
- Analysis of the incremental rates into each of the survey compartments along the entire study area based on sand budget considerations.

The incremental LST rates derived from sand budget considerations, utilising the surveyed quantities together with known dredging and pumping rates and the calculated LST rates at Currumbin, are based on the conceptual considerations illustrated in Figure 1-5. The LST rates for Letitia Spit and the entrance area are calculated from sand budget components as shown in Figure 1-6. These calculations are performed on a monthly timestep by interpolating volume change quantities derived from less frequent (approximately 6-monthly) surveys.

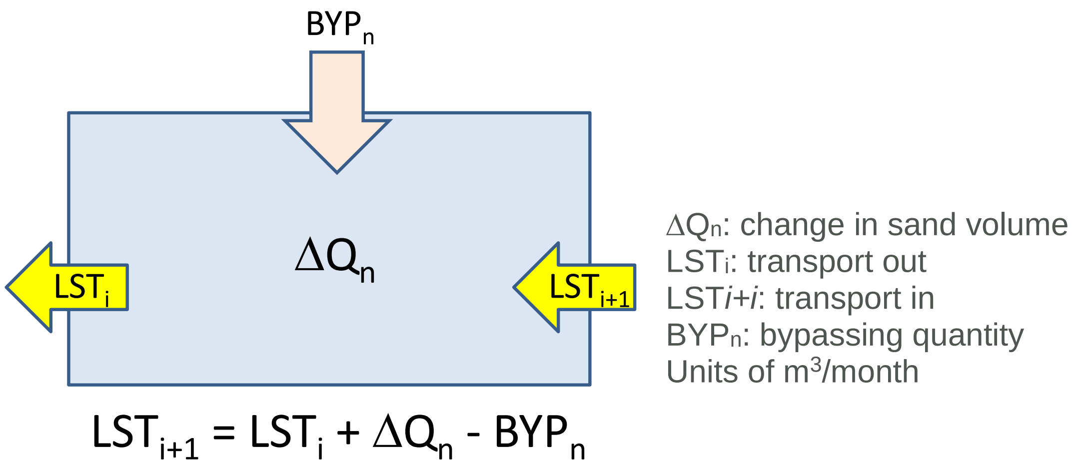


Figure 1-5 Conceptual sand budget for LST calculations

The LST rates derived in this manner are inclusive of all longshore transport processes, including the cross-embayment pathway which is active within the southern Gold Coast embayment (Jacobs, 2019).

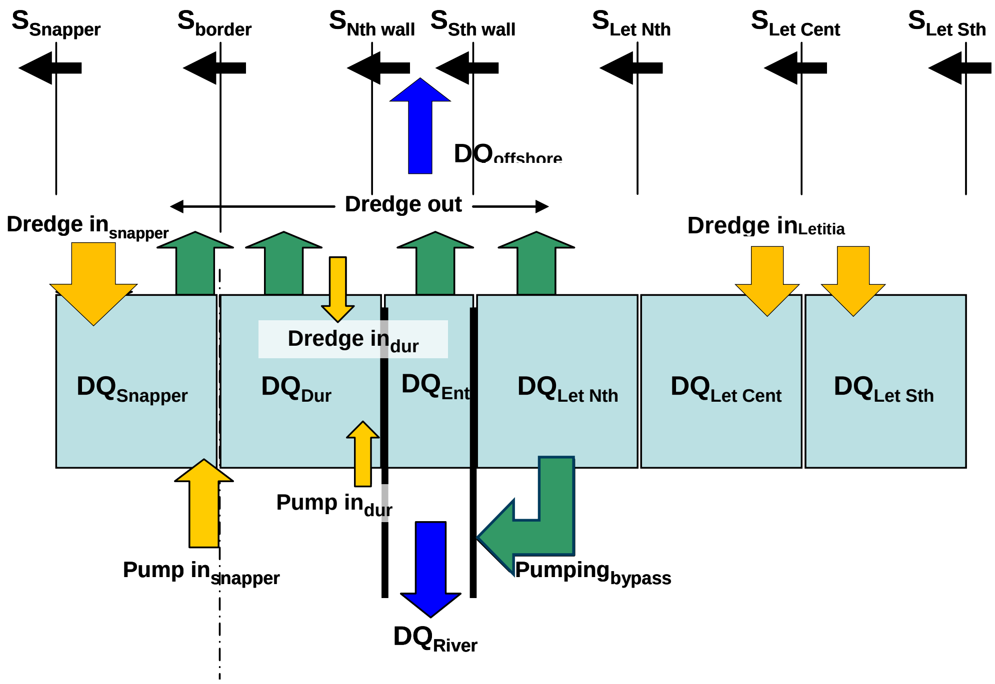


Figure 1-6 Conceptual sand budget for Letitia transport calculations

The Letitia Spit rates of transport have been affected to varying degrees by the bypass 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.

1.3.4 Bypassing and Dredging rates

The history of bypassing and dredging rates since January 2000 is shown in Figure 1-7. The years from 2001 to 2007 included the Supplementary Increment above the LTA and transfer of sand to Queensland was undertaken through a combination of pumping and entrance compartment dredging. There was no dredging of the entrance from late-2008 to mid-2016, however 3 separate dredging campaigns have been undertaken since 2016 in order to manage the volume of sand accumulating in the entrance compartment. The 2019 dredge campaign was also the first to undertake backpassing of sand from the entrance compartment to placement areas along Letitia Spit.

1.3.5 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 (Level 1 certification):

- 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.

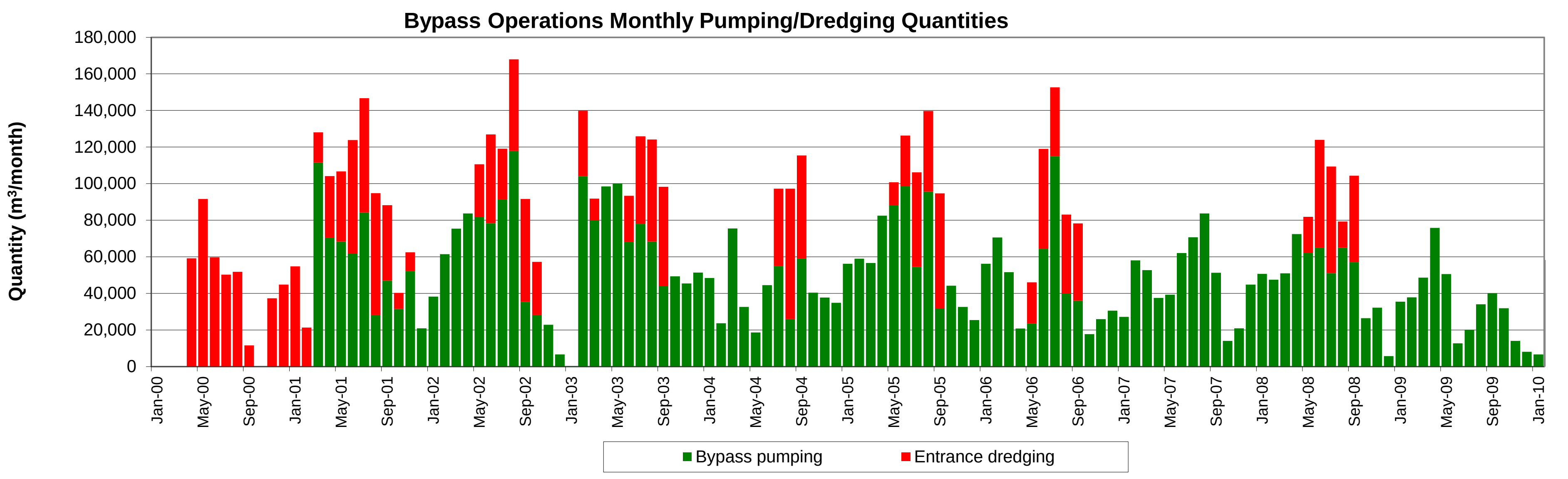
The LTA may be estimated directly from the survey data and sand bypass operations (pumping and dredging) quantities via Equation 1b. As such, the potential error in the LTA is subject only to the errors in the quantities derived from the surveys and bypassing system. Considerable design control has been 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 (*O*±0.15 m according to survey contract) 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. As of the 2020 re-assessment, the LTA estimate is based on sand budget analysis over a 27-year timeframe and the potential error attributable to survey inaccuracy is estimated to be less than ±5%.

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, mainly by applying a smoothing of change trends. This smoothing is only significant at the monthly analysis timescale and is not expected to have a significant bearing on the cumulative LTA estimate.

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. The 2020 LTA re-assessment has assumed that the rate of loss of sand to deep water has continued at the same rate as previously assessed in 2015.

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, at the northern end of the study area (Figure 1-1), 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 including the 2009/15 LTA reassessments (BMT WBM 2011; 2016) has shown the longer term annual average net transport to be about 500,000 m^3/yr or possibly up to 550,000 m^3/yr. The methodology used in the previous LTA reassessment has been applied again in this extension of the reassessment to 2020.



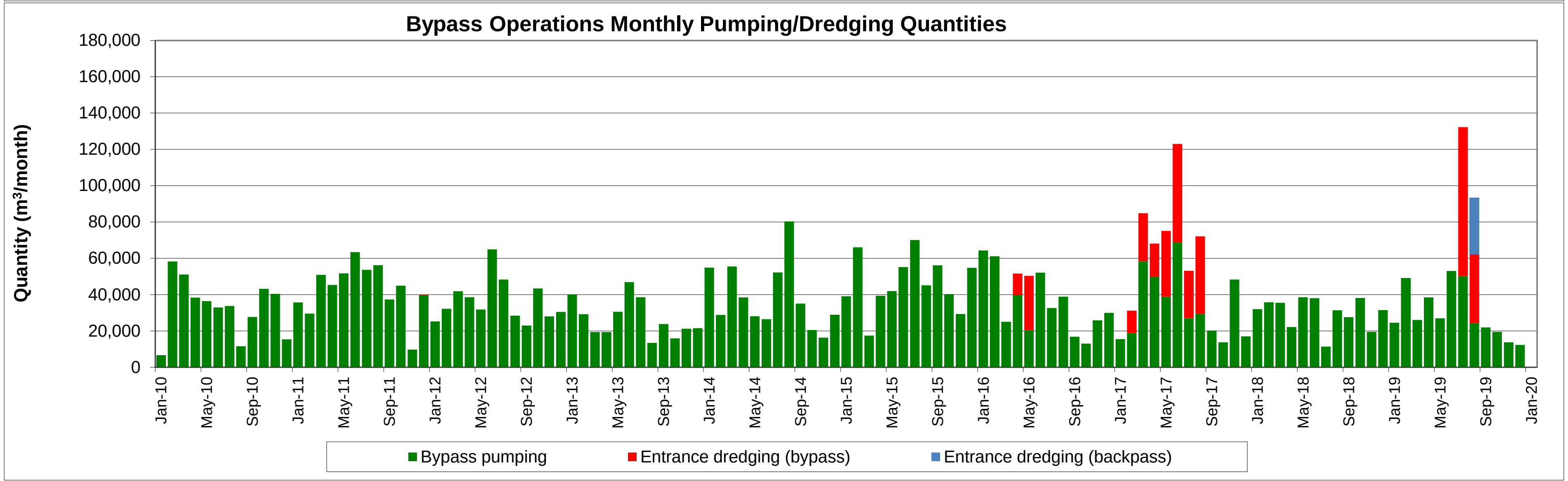


Figure 1-7 Bypass pumping and entrance channel dredging monthly rates

2 Sand Quantity Changes Derived from Surveys

2.1 Monitoring Program Surveys

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

The surveys have been carried out regularly, at least once per year, and analysed by Tweed Sand Bypassing 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 dates up to June 2020, within the various analysis compartments outlined in Section 2.2.

2.2 Surveyed Quantities

2.2.1 Analysis Compartments

Sand quantity analyses have been undertaken by Tweed Sand Bypassing to determine progressive changes within various compartments within the overall study region from Fingal to Currumbin. Those compartments are shown in Figure 2-1 and have been used in the present study either separately or in combination for the purpose of LTA and sand transport calculations.

Additionally, surveys have been undertaken of the quantities of sand within the Tweed River to identify changes associated with movement of sand to or from the river reaches. Those surveys that comprehensively cover the whole system (Figure 2-2), including the entrance area, extend over the period since February 2000, showing a gradual reduction (export) of sand. Allowance has been made for channel maintenance dredging within the Tweed River compartments, such that any quantities removed by dredging are not included as a quantity being naturally exported to the offshore littoral system.

Further, review of the surveyed quantity changes over the longer term of the data identifies a slight movement of sand to deeper water beyond 20 m depth offshore from the river entrance that is estimated to have been about 18,000 m^3/yr for the period 1993 to 2000, 12,300 m^3/yr from 2000 to 2005 and only about 5,000 m^3/yr from 2005 to date (refer Table 1-2 for project epoch context). The reducing trend since 2000 is likely related to a reduction in natural bypassing of the entrance as a result of the jetty system. While relatively minor (~*O*1% of net LST), 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.

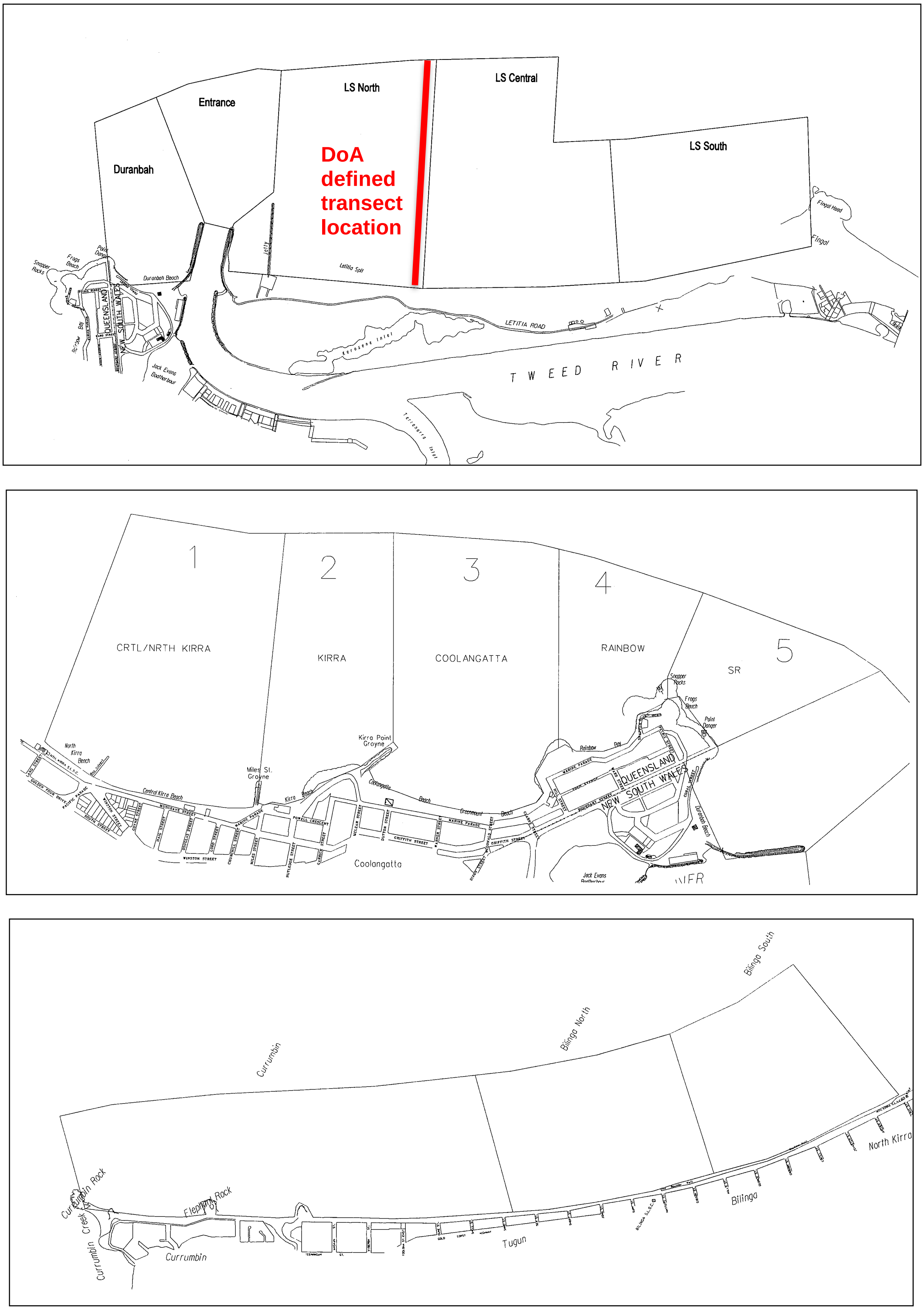


Figure 2-1 Sand quantity calculation compartments

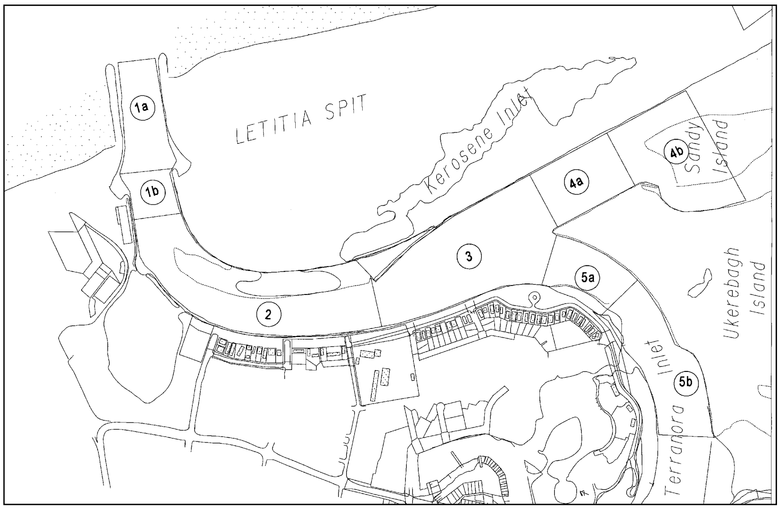


Figure 2-2 Survey compartments within Tweed River

2.2.2 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, as described above; 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 from the baseline survey of 1993 to January 2020 are shown in Figure 2-3 to Figure 2-7 for the individual compartments. The smoothing of the monthly trends with respect to the surveyed quantities is evident. The long-term trends in volume changes are now clearly evident.

Letitia Spit

There has been an overall reduction in volumes along Letitia Spit since the baseline survey of 1993, with key trends summarised below:

- An initial decrease by about 1.25M m^3 to 2008 at Letitia North followed by recovery and stabilisation back to a net loss of between 0.8 and 1M m^3 over the period from 2009 to 2020,
- A progressive loss of sand at Letitia Central after 2001 to about 1.5M m^3 by 2014, which has stabilised and reversed to a slow accretionary trend over the past 3 years,
- A loss of about 0.3M m^3 at Letitia South prior to bypassing in 2001 followed by slow fluctuations with the lowest volume occurring around 2013 followed by a strong recovery of 0.5M m^3 to around 2001 levels by 2019; comparing these trends to those of Letitia Central/North indicates that the

Letitia South volumes are related more to sand supply past Fingal than the behaviour of the up-drift compartments along Letitia Spit.

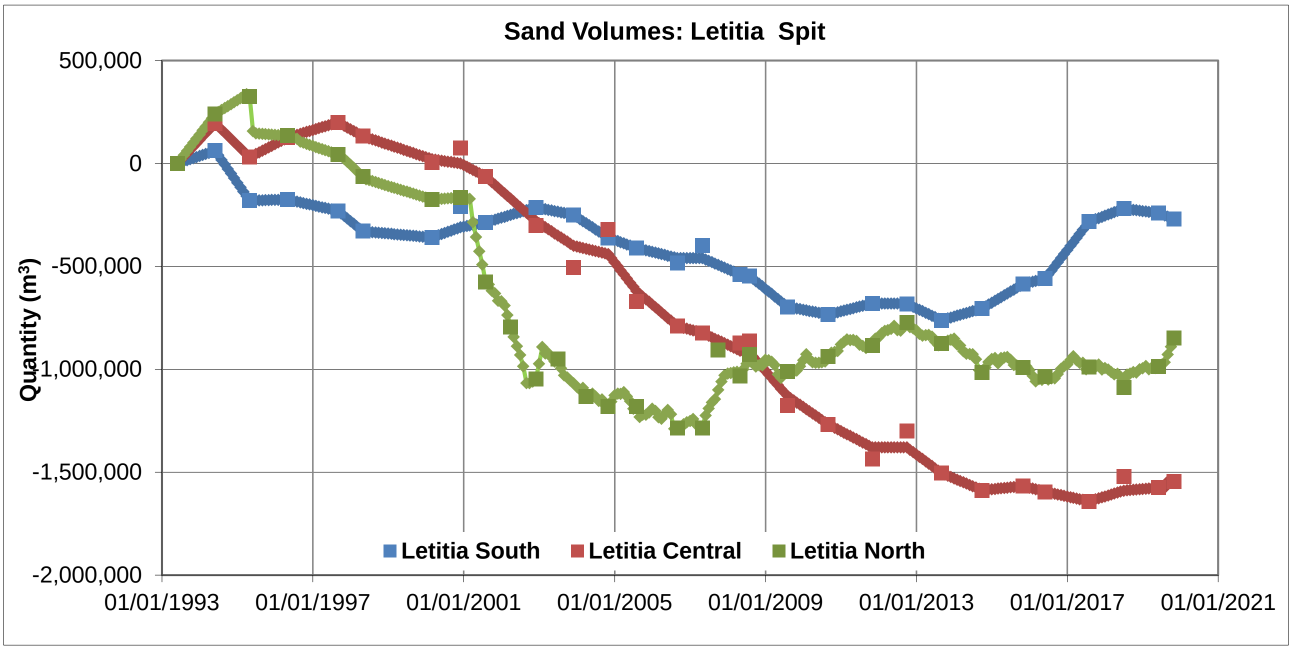


Figure 2-3 Sand volume changes along Letitia Spit

Tweed River and Entrance

- The significant reductions in entrance compartment sand volume associated with dredging within the compartment during 1995 to 1997 were followed by significant re-accumulation prior to bypassing.
- Subsequently since bypassing commenced in 2001 and particularly while entrance dredging did not occur from 2009 to 2016 the sand volume within the entrance compartment has steadily increased back to 1993 levels (0.6M m^3 above 2001 levels) by 2017.
- Reductions associated with recent entrance dredging campaigns are evident since 2017, however total volumes remain close to 1993 levels.
- Sand volumes in the River compartments have exhibited a slowly reducing trend since around 2003 and are presently around 0.3M m^3 below 1993 levels.

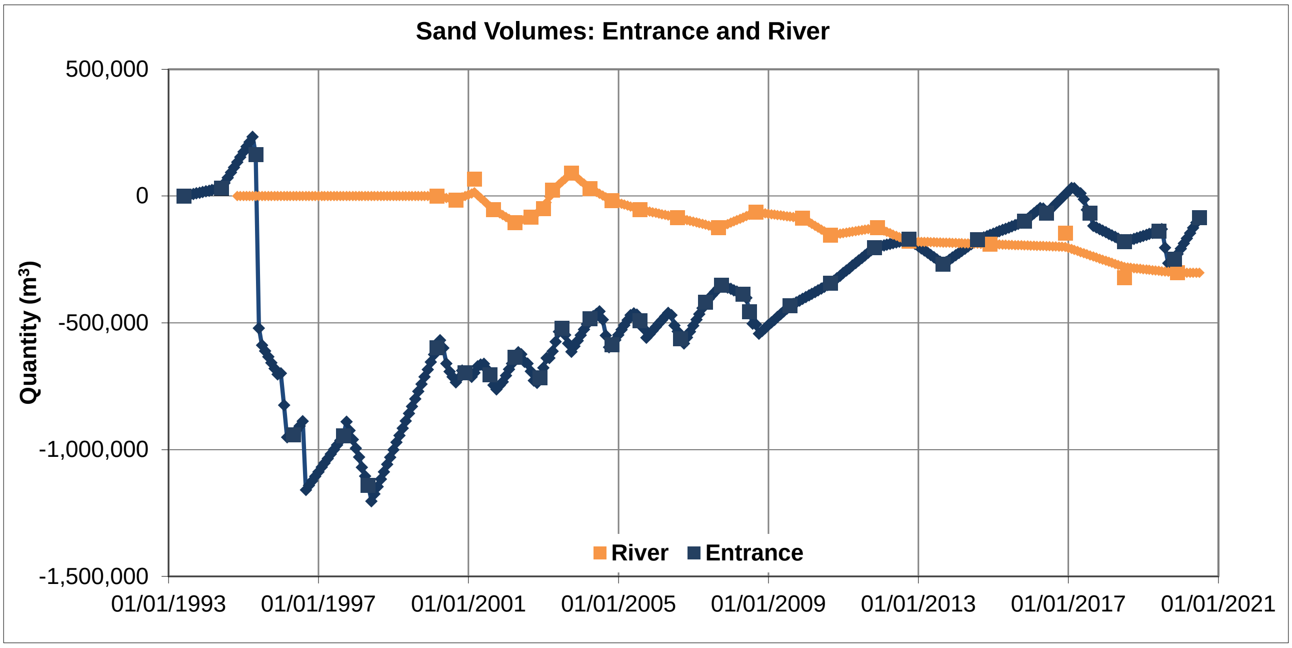


Figure 2-4 Sand volume changes at the River entrance

Point Danger

The Duranbah compartment is included in NSW, while Snapper Rocks East is the southernmost compartment in Queensland. The following trends have been evident:

- The significant reductions in Duranbah compartment sand volume associated with dredging within the compartment during 1995 to 1997 were followed by rapid re-accumulation prior to bypassing.
- Volumes at Duranbah reduced again following commencement of Stage 2 dredging in 2000.
- Duranbah volumes have achieved a “dynamic” stability since around 2005.
- An overall negligible change in volume at Snapper East, following an initial slight increase prior to commencement of bypassing in 2001, a gradual decrease to 2012 and a stable trend since.

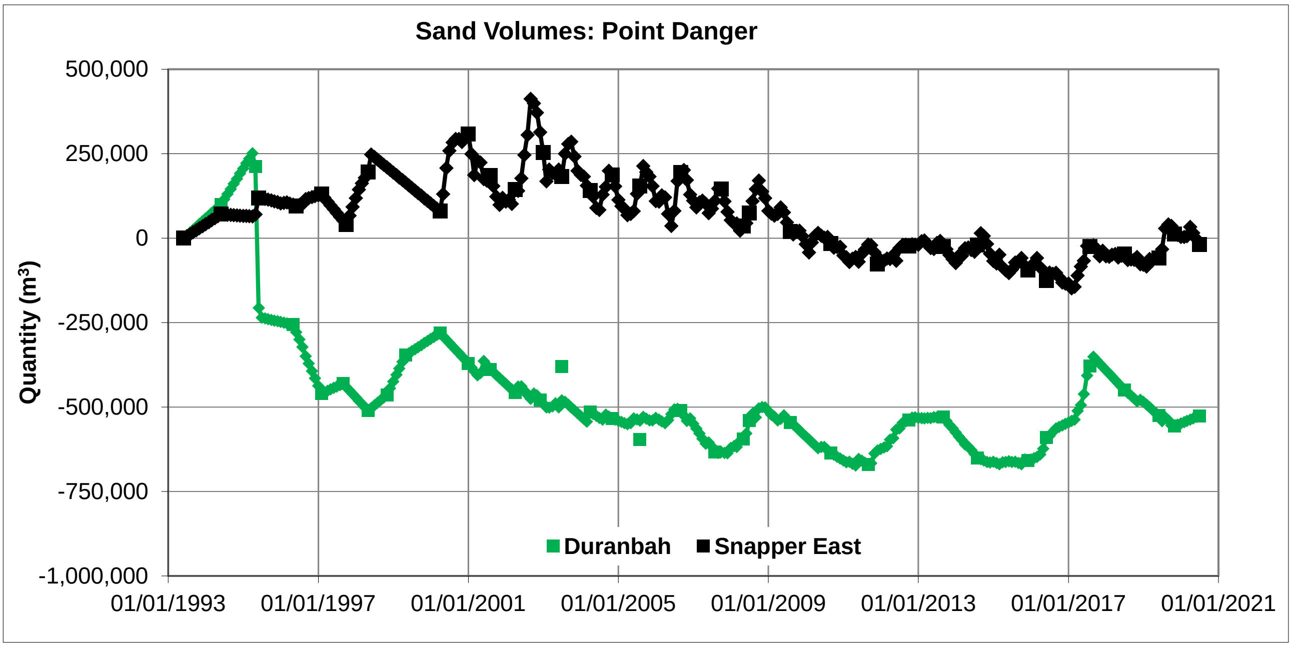


Figure 2-5 Sand volume changes at Duranbah and Snapper Rocks East

Rainbow Bay to Kirra

The compartments from Rainbow Bay to Kirra are immediately north (downdrift) of the pumping system outlet at Snapper Rocks east and have been the main recipients of dredged sand placement. The volume trends in these compartments have therefore responded to the changing operations of the Tweed Sand Bypassing project from Stage 1 onwards:

- Substantial sediment volume gains associated with the Stage 1A dredge placement commencing in 1995.
- An initial rapid increase of about 1M m^3 at Rainbow-Coolangatta from 2001 to 2003 (following Stage 2 commissioing), followed by a steady reduction to 2017 and a more recent slight rebound there such that the net change from 2001 to 2015 is a loss of about 0.3M m^3, representing a net gain of about 0.7M m^3 since 1993.
- Reversal of the initial gains of sand after 2001 at Kirra and North Kirra, resulting in a small 0.1M m^3 reduction since 2001 at Kirra and a residual net change of 1M m^3 at North Kirra.

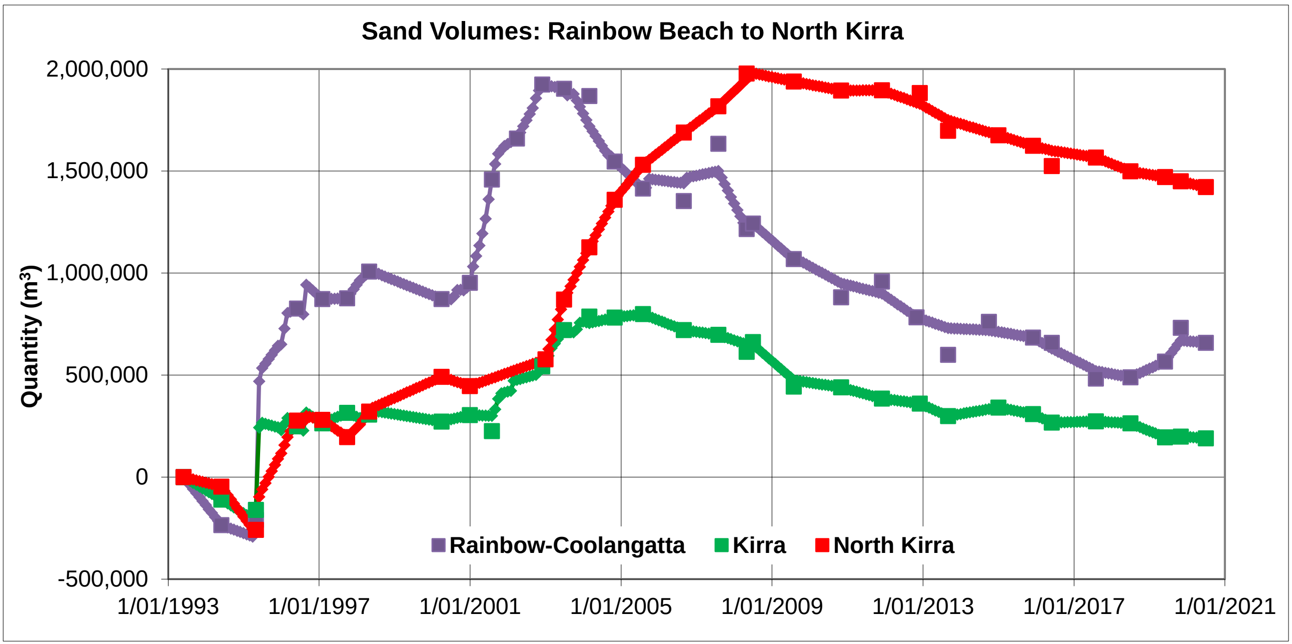


Figure 2-6 Sand volume changes Rainbow bay to North Kirra

Bilinga to Currumbin

The Gold Coast beaches from Bilinga to Currumbin have generally not received much in the way of direct sand placement from the Tweed Sand Bypassing project, however the compartment volumes have responded to the re-instated sand supply:

- Increases at South Bilinga evident from 2001 and stabilised by 2015 at around 1.4M m^3 above the 1993 volume.
- Accretionary response at North Bilinga evident from 2004 and stabilised by 2015 at around 0.9M m^3 above the 1993 volume.
- Accretionary response at Currumbin evident from 2008 rand stabilised by 2015 at around 0.7M m3 above the 1993 volume.

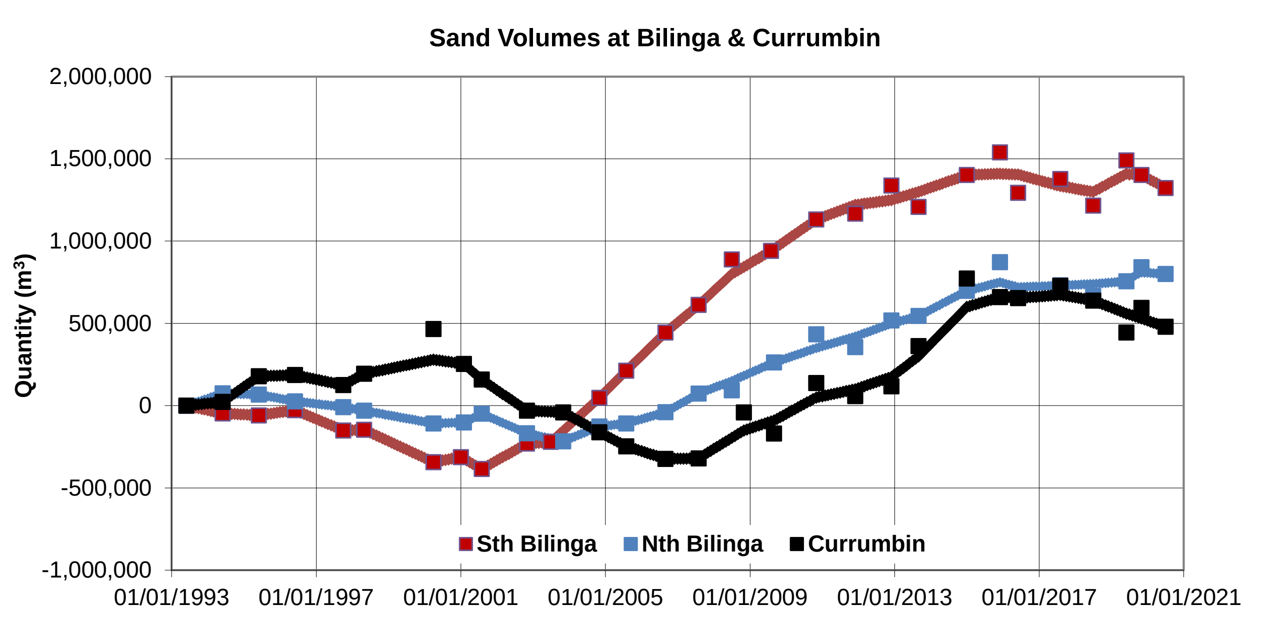


Figure 2-7 Sand volume changes Bilinga South to Currumbin

2.2.3 Loss to Deep Water

Provision has been made in the sand budget analysis for a small but ongoing 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. The ongoing rate of sand loss to deep water has not been re-evaluated in the 2020 LTA re-assessment as the regular surveys do not extend further offshore than the 20m depth contour. Due to its small relative magnitude, any inaccuracy in this quantity is not expected to significantly alter the LTA quantity estimate.

2.2.4 NSW & Queensland Totals

The results of this analysis from the baseline survey of 1993 to January 2020 are shown in Figure 2-10 for the combined NSW compartments (top) and Queensland compartments (bottom).

The resulting total cumulative quantity changes since 1993 are shown in Figure 2-8. This figure illustrates the progressive reduction of a net quantity of approximately 3.47M m^3 from Letitia Spit and the entrance/river areas (including Duranbah) and a corresponding gain of about 5.02M m^3 to Gold Coast beaches. Notably, there is a 1.54M m^3 overall gain of sand volume in the study area from Fingal to Currumbin.

The progressively reducing trend in NSW and increasing trend in Queensland was clearly evident from 2001 and particularly through the Supplementary Increment period from 2001 to 2007. The rates of change can be seen to moderate with the reduced rate of bypassing from around 2009. Both the NSW and Queensland absolute change quantities have now reduced from peak levels which occurred around 2014/15, which is evidence that the system response to the introduction of bypassing has now reached a level of stability.

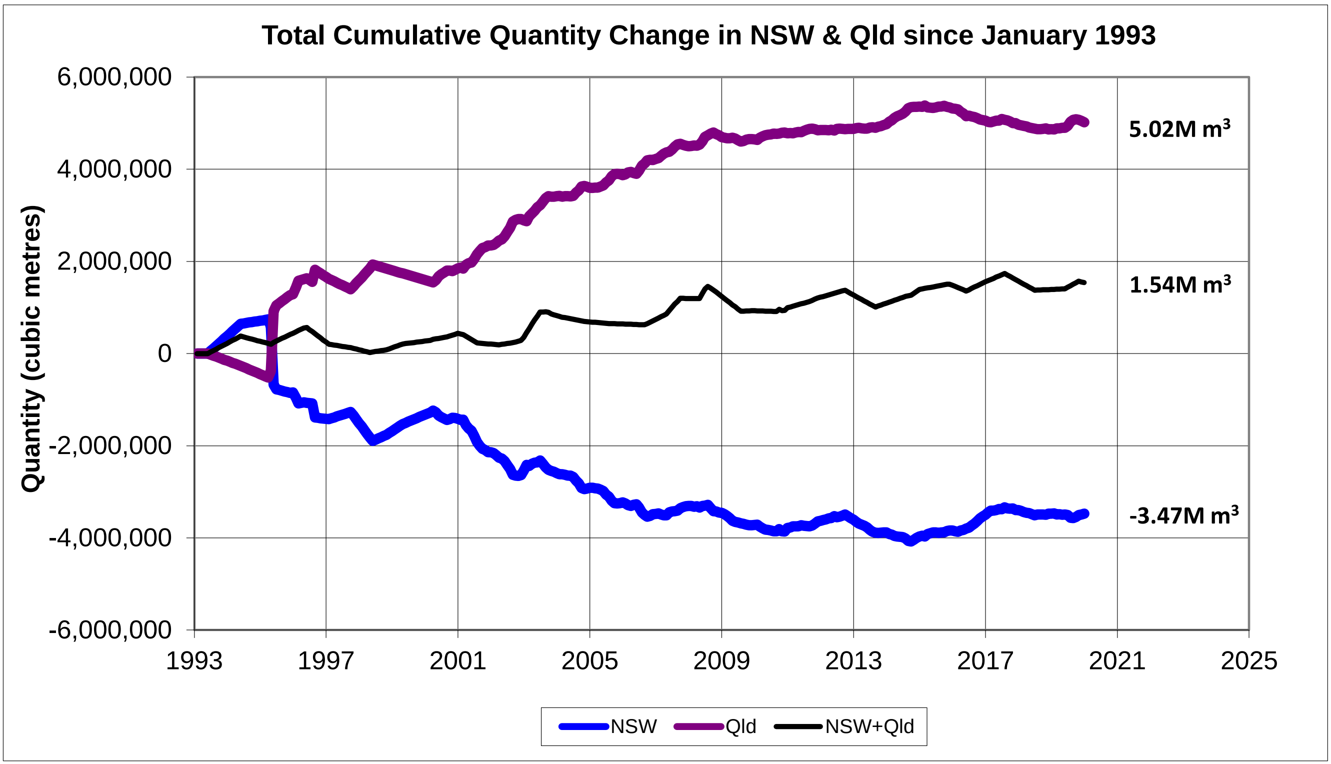


Figure 2-8 Cumulative total change in sand quantities in NSW & Qld since 1993

The alongshore distributions of sand quantity changes for various dates since 1993 are shown in Figure 2-9 and again reflects the significantly greater retention of sand in Queensland than is depleted from NSW.

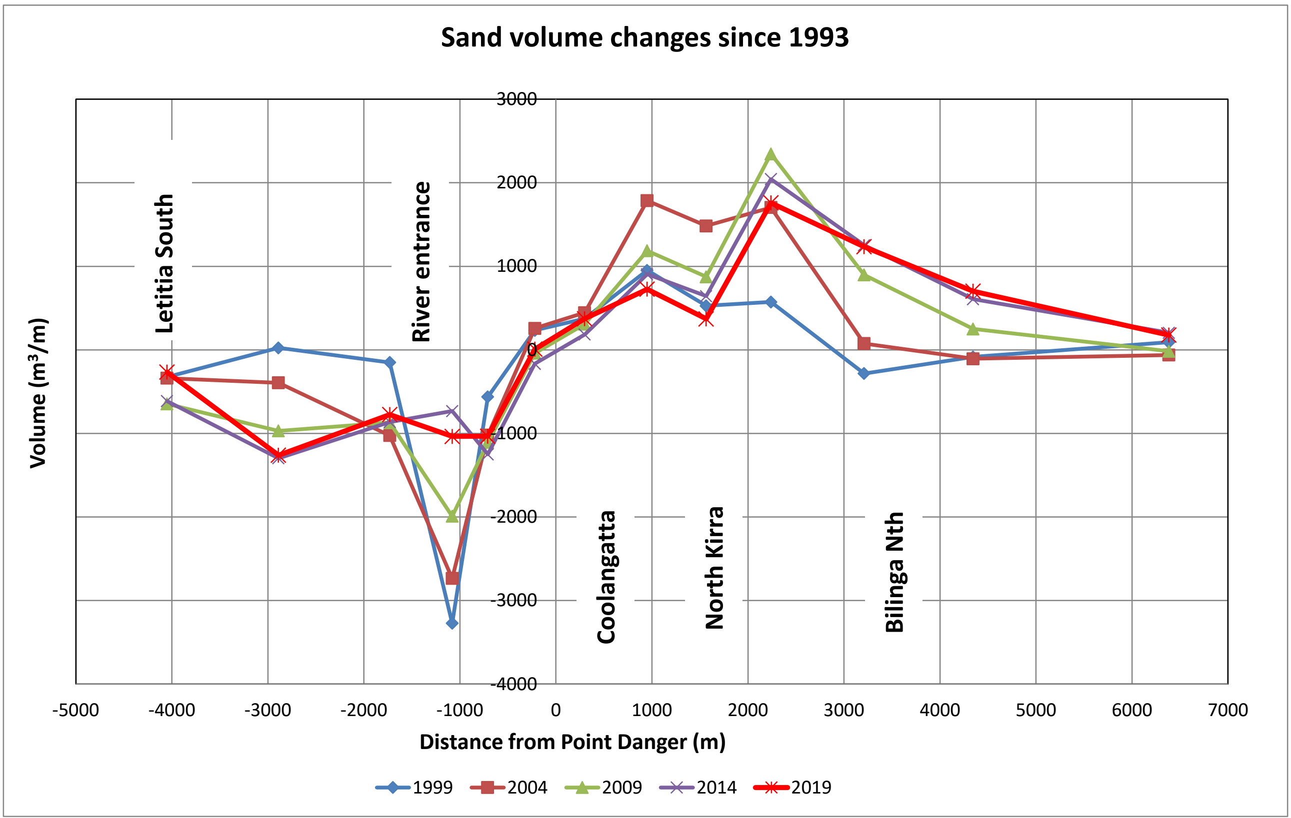


Figure 2-9 Alongshore distribution of change in sand quantities in NSW & Qld since 1993

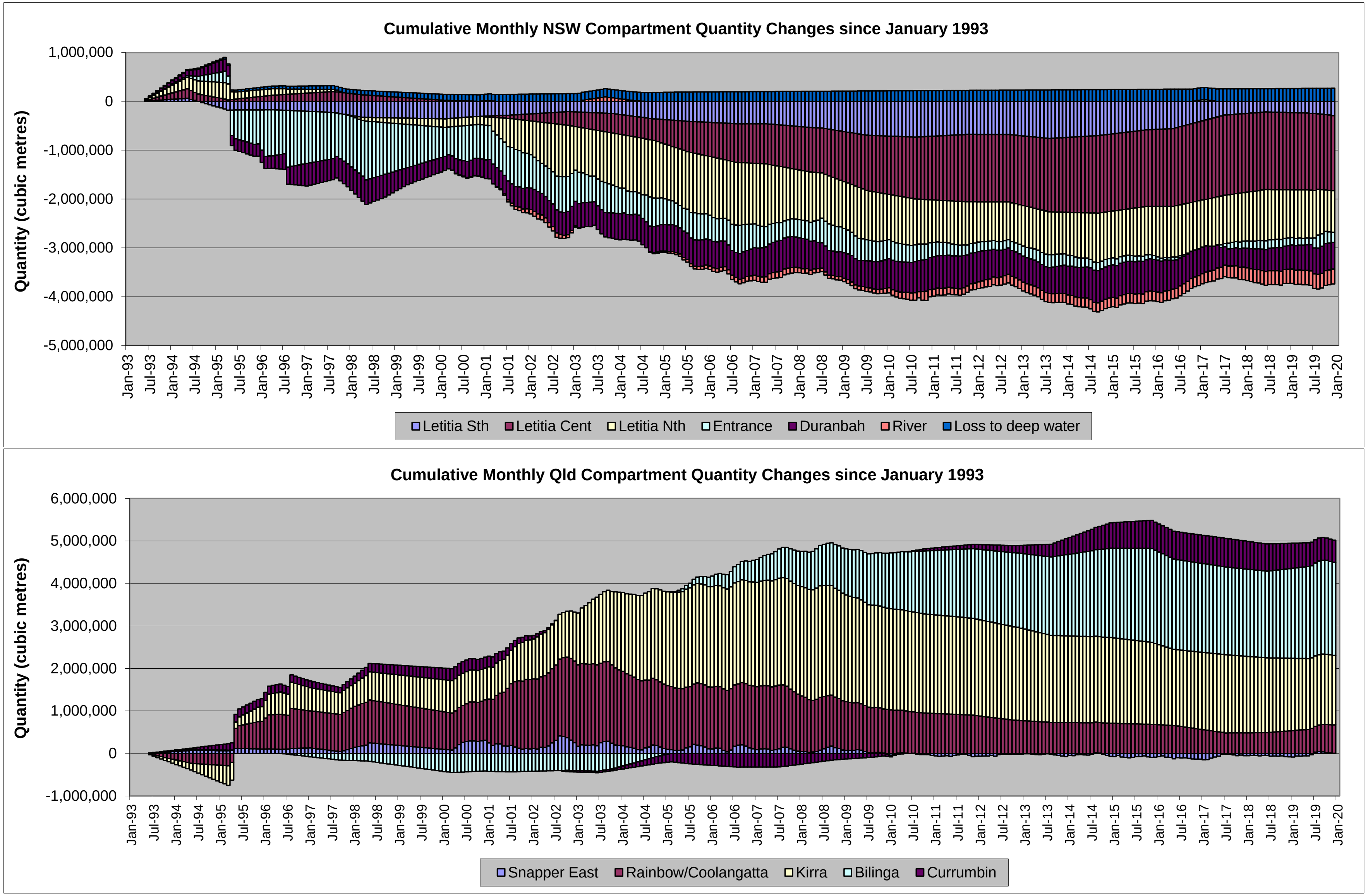


Figure 2-10 Cumulative monthly compartment quantity changes in NSW (top) and Qld (bottom)

2.2.5 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.

Scrutiny of the sequential time series of sand volumes derived from the surveys is undertaken to ensure there are no anomalous individual surveys. As well, the volume trends are checked and smoothed as appropriate (where short-term fluctuations are evident) to minimise any impacts on the monthly transport rates derived. 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 such that any errors in any survey will be offset over time.

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. The compartment volume data show 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.

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.

3 Longshore Sand Transport Rates

3.1 Background

A LST rate of 500,000 m^3/yr was adopted as the most reasonable best estimate for the initial design of the TRESB system and was used in the Deed of Agreement as the LTA rate, with provision for progressive re-assessment following additional data collection and experience with the sand bypass operations.

The first LTA reassessment (BMT WBM 2011) represents the most comprehensive analysis of LST rates to 2009, providing:

- Time series rates at Currumbin calculated directly from the recorded Tweed directional wave data, from which monthly and annual average rates were derived;
- Monthly and average annual rates at Snapper Rocks (Point Danger), the Qld/NSW border and along Letitia Spit, derived from the Currumbin rates together with surveyed compartment sand volume changes using the methodology illustrated schematically in Figure 1-5;
- Monthly and annual rates calculated at a location about 1,000 m south of the river entrance directly from the recorded Tweed directional wave data.

Reference is made to BMT WBM (2011) for a detailed description of the wave climate and the SWAN wave propagation model(s), validation and analysis used in that study and incorporated again in this reassessment.

Directional wave recording undertaken at the Tweed Waverider location since 1995 represents the longest available comprehensive data set for the region. 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 deep water conditions, but is directly applicable as the basis for LST calculations at both Letitia Spit and, via transformations based on SWAN propagation modelling, at Currumbin.

The previous BMT WBM (2011; 2016) reassessments reviewed both CERC formula (US Army Corps of Engineers 1984, 2002; Smith et al 2003) and the 'Queens' formula (Kamphuis, 1991) for deriving theoretical LST rates at Currumbin and along Letitia Spit. The review concluded that both of these formulations are mathematically very similar and yield essentially the same results when they are "calibrated" to available site-specific information regarding transport rates (BMT WBM, 2011). The 'Queens' formula (reproduced below) has been adopted as the consistent methodology for application in this (and previous) LTA re-assessments.

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_q = Coefficient typically (approx 1.33 for m^3/s or 41x10^4 for m^3/yr)

H_b = Breaking significant wave height

T_p = Spectral peak energy period

C_g = Wave group velocity

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 (constant value)

D_{50} = Median sediment grain size

3.2 LST Rates to 2020

The wave data record and the compartment sand volumes have now been extended to 2020, facilitating extension of the previous work to cover the period 1996 to 2020. This utilises the Tweed recorded data as the basis of theoretical calculations at Currumbin and Letitia Spit, together with the Queens formulation with the same calibration of coefficients as those applied previously.

The calculated Currumbin monthly rates are shown in Figure 3-1, with the annual and progressive trend rates since 1995 shown in Figure 3-2. It has been assumed that the shoreline alignment at Currumbin remains unchanged from that adopted previously. The long-term average rate for the period January 1995 to December 2019 is 494,000 m^3/year, which has reduced by around 2% since the 2015 assessment due to a sustained period of below trend annual transport from 2013 to 2019.

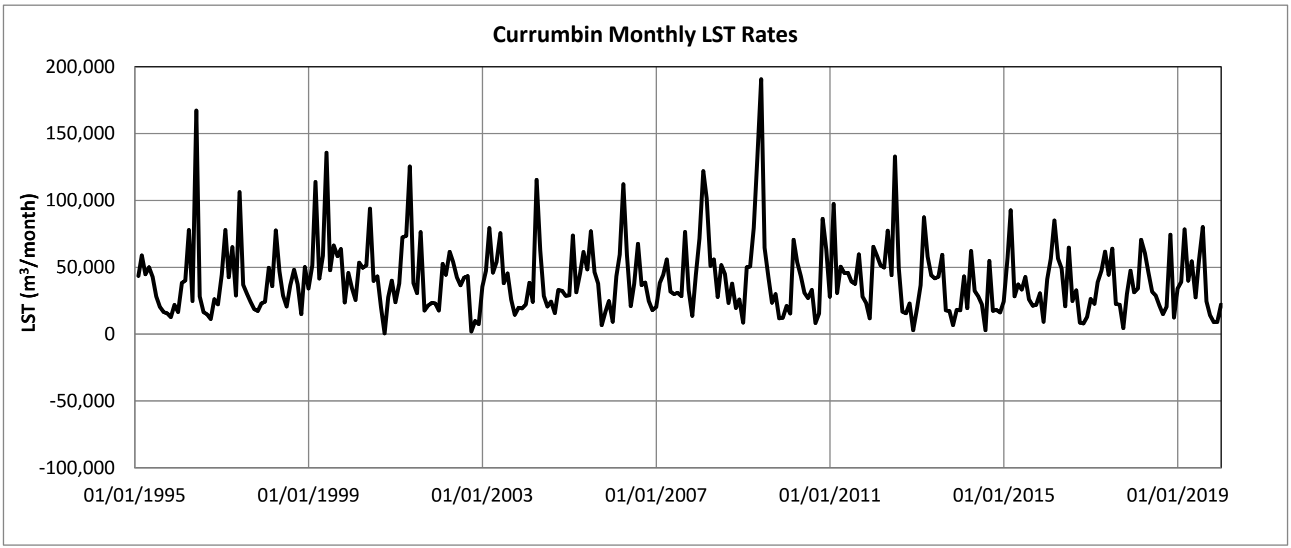


Figure 3-1 Monthly LST rates at Currumbin (+ve northwards)

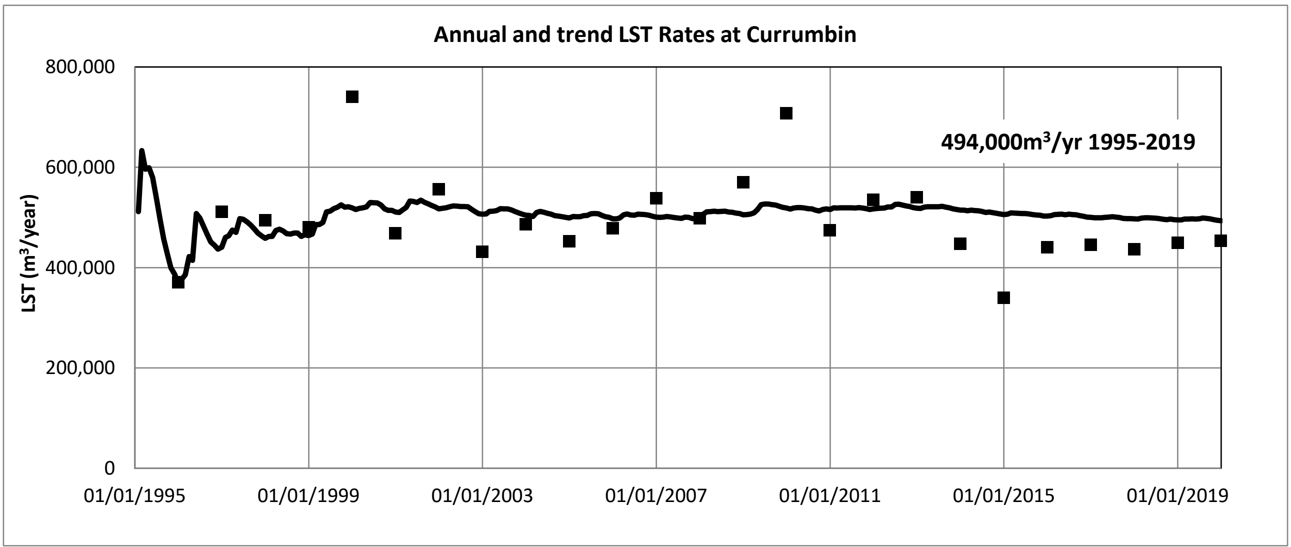


Figure 3-2 Annual and long-term trend LST rates at Currumbin

LST at Letitia Spit 1,000 m south of the entrance was calculated theoretically directly from the Tweed wave data. Previous LTA assessments had adopted a Letitia Spit shoreline alignment of -18 degrees for the period from 2001-2015 (BMT WBM, 2011; 2016), which accounted for the short-term project impacts on the shoreline at this location. Since 2015 the shoreline retreat along Letitia Spit appears to have stabilised. Based on a review of recent Letitia Spit survey data, the shoreline alignment 1,000 m south of the Tweed River entrance has been re-derived at -15 degrees for the period from 2015-2019, which approximately matches the pre-2001 alignment.

LST at Letitia Spit 1,000 m south of the entrance calculated theoretically directly from the Tweed wave data are shown in Figure 3-3 and Figure 3-4 as monthly and annual rates respectively. The long-term trend rate since 1995 of 570,000 m^3/yr has reduced by 4% since the 2015 assessment, due mainly to the recent below trend annual transport (as also seen at Currumbin).

While the theoretical calculations at the two location use the same input wave timeseries from the Tweed offshore waverider buoy, the different wave transformation and shoreline orientation of these two locations results in different LST timeseries.

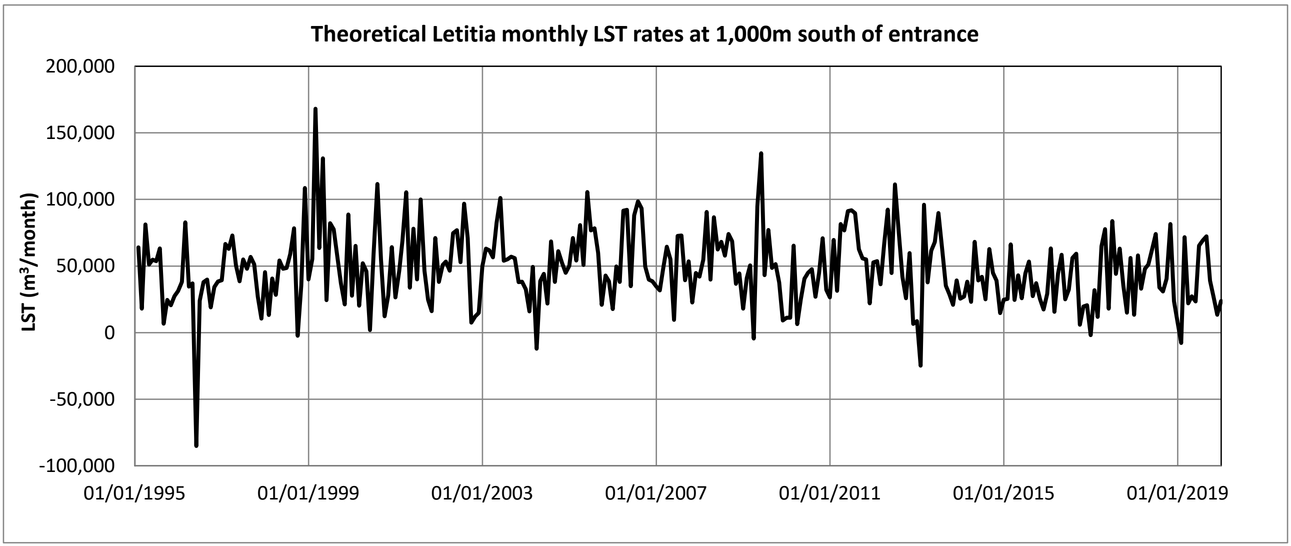


Figure 3-3 Monthly LST rates at Letitia Spit at 1,000 m south of river entrance

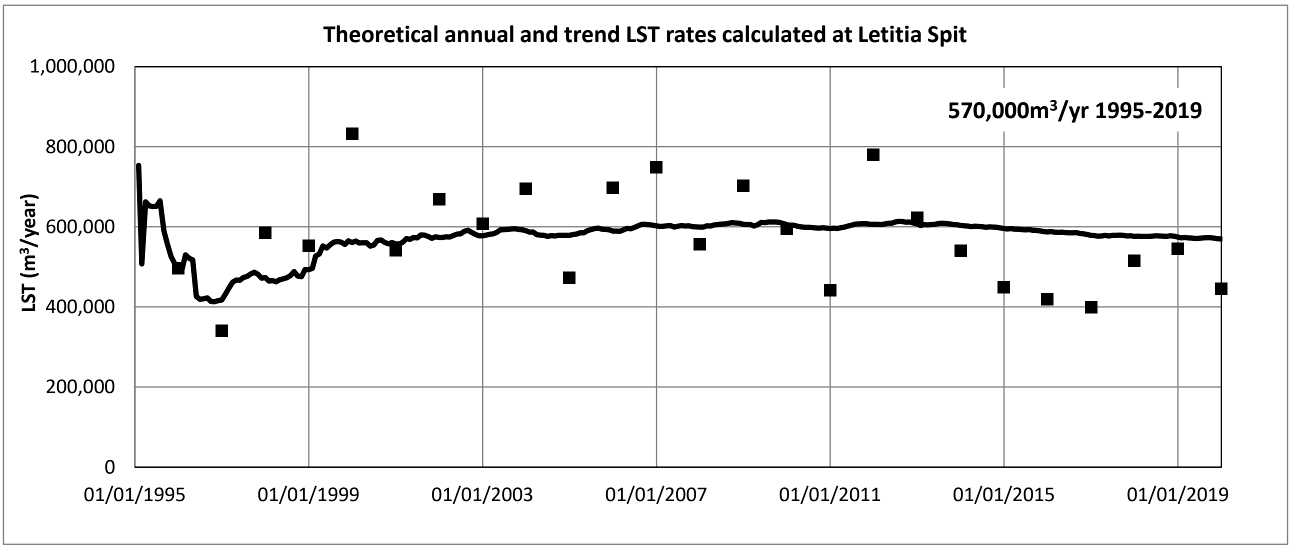


Figure 3-4 Annual & trend LST rates at Letitia Spit at 1,000 m south of river entrance

The LST rate derived at Currumbin using the Tweed offshore buoy was reviewed against calculations based on the Brisbane (Point Lookout) buoy data transformed to Currumbin and used in the 'Queens' formula. The Currumbin monthly LST rates derived from Brisbane and Tweed buoy datasets shown in Figure 3-5 are similar. The average transport derived using the Brisbane Buoy transformed data is approximately 9% higher than the Tweed derived average.

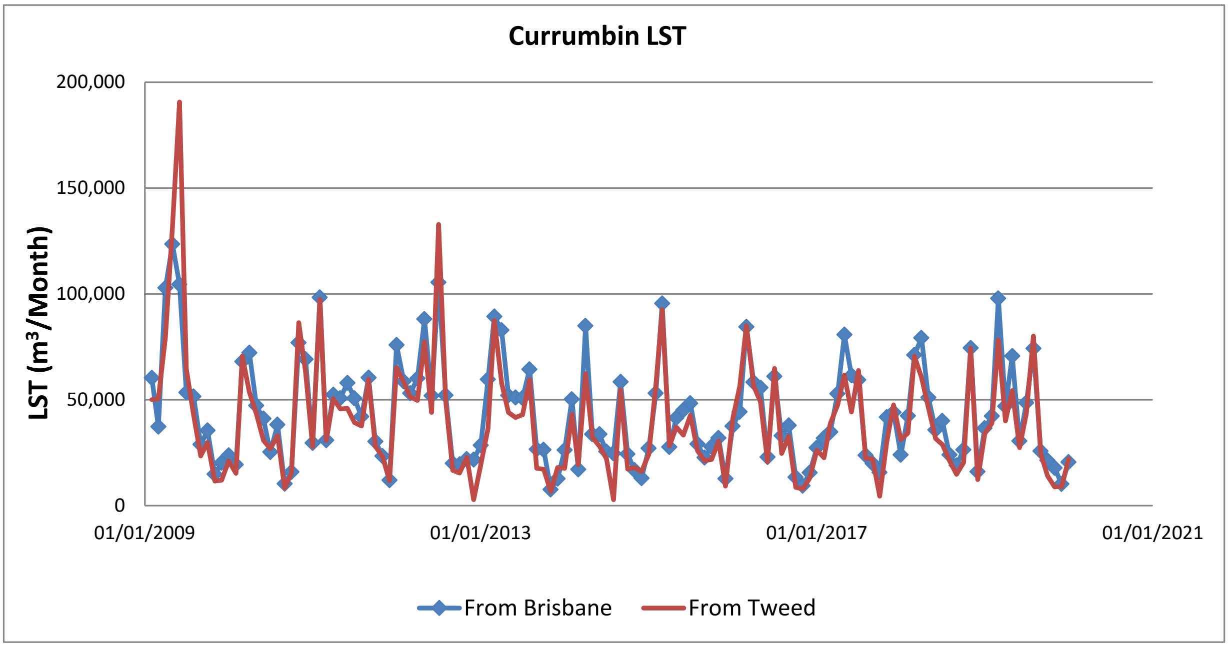


Figure 3-5 Queens formula LST derived from Brisbane Buoy and Tweed Buoy wave data

It is notable that for the 7-years from 2013 to 2019, the theoretically derived LST has been below the long-term trend at both Currumbin and Letitia Spit. In order to understand how LST trends were correlated with offshore wave climate the first LTA reassessment (BMT WBM, 2011) analysed the offshore wave climate using a deep water wave energy parameter ($g^{0.6}H_o^{2.4}\ T_p^{0.2}$) and an energy-weighted direction.

Figure 3-6 compares these parameters since 2009 and shows that the 2013 low annual net northward transport could be explained due to the below-trend energy-weighted wave direction while the subsequent years 2014-2019 were below-trend in terms of incoming wave energy.

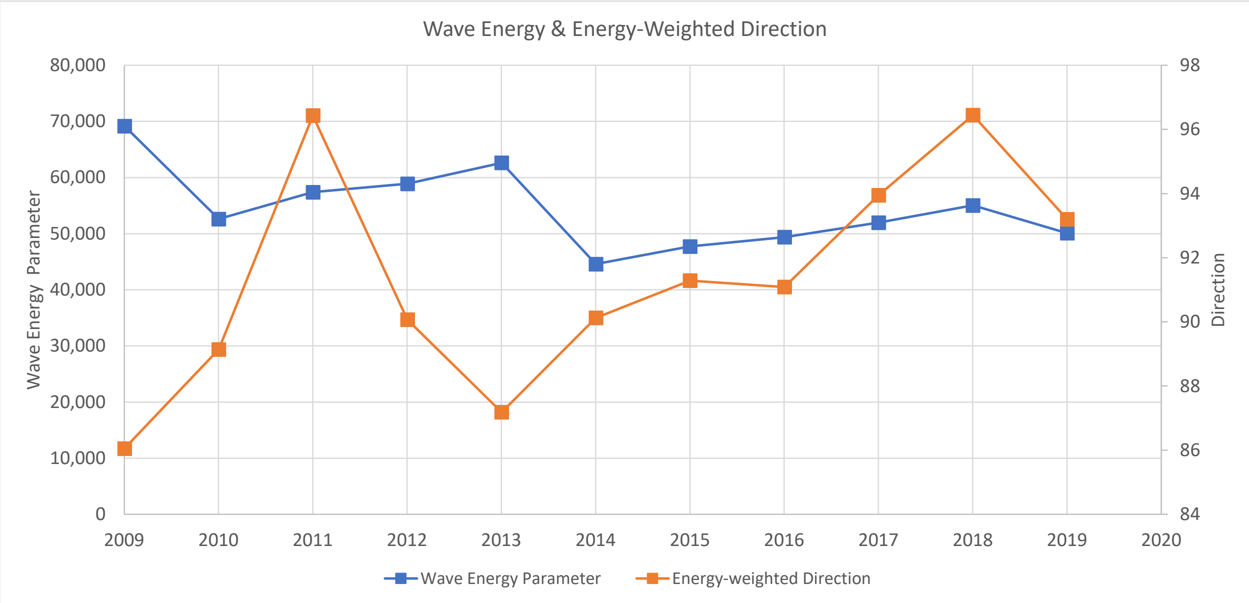


Figure 3-6 Wave energy parameter and energy-weighted direction

3.2.1 Rates Derived from Survey Data

The monthly net sand transport rates at the various locations along the southern Gold Coast and Letitia Spit and at Snapper Rocks have been derived using the methodology illustrated schematically in Figure 1-5 and Figure 1-6.

Based on the Currumbin rates, the LST for various locations along the Queensland lower Gold Coast have been determined using the method illustrated in Figure 1-5, as shown in Figure 3-7 as monthly rates and in Figure 3-8 as annual rates. The relatively high rates of transport past Point Danger during 2001 to 2003 following commencement of bypassing, with the additional make-up quantities pumped at that time are evident. Also evident are the relatively high rates of transport along the whole lower Gold Coast since 2003. These are associated with the effects of greater than equilibrium quantities of sand in the littoral system there resulting from the over-bypassing undertaken during 2001-2006.

The more recent pattern from 2015-2019 has been for below-trend annual transport along the entire coastline form Letitia Spit to Currumbin, as discussed above.

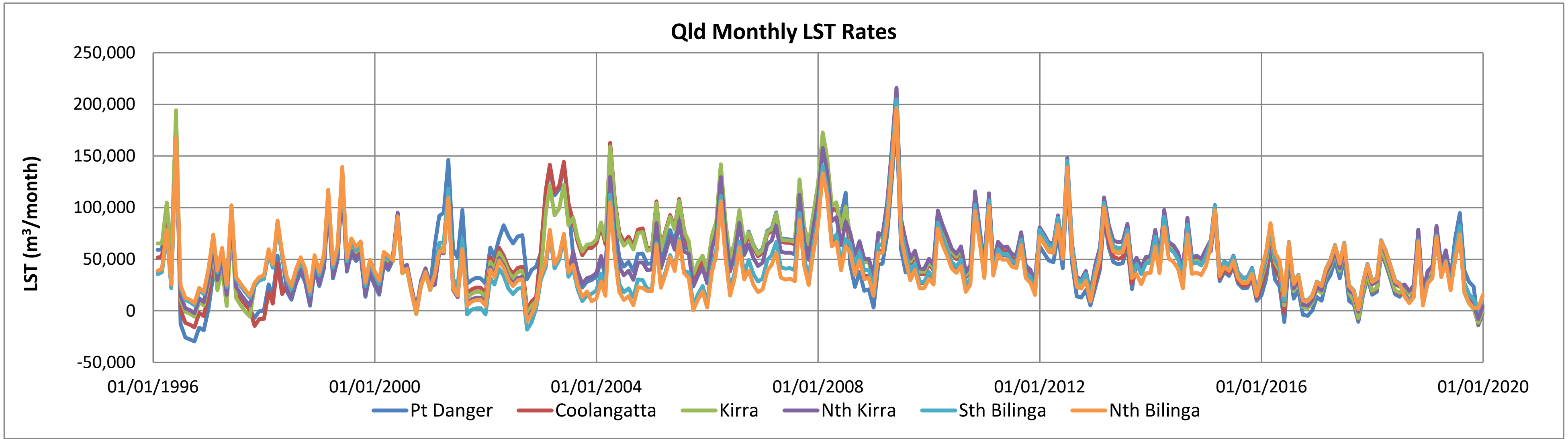


Figure 3-7 Monthly LST rates at lower Gold Coast: Pt Danger to North Bilinga

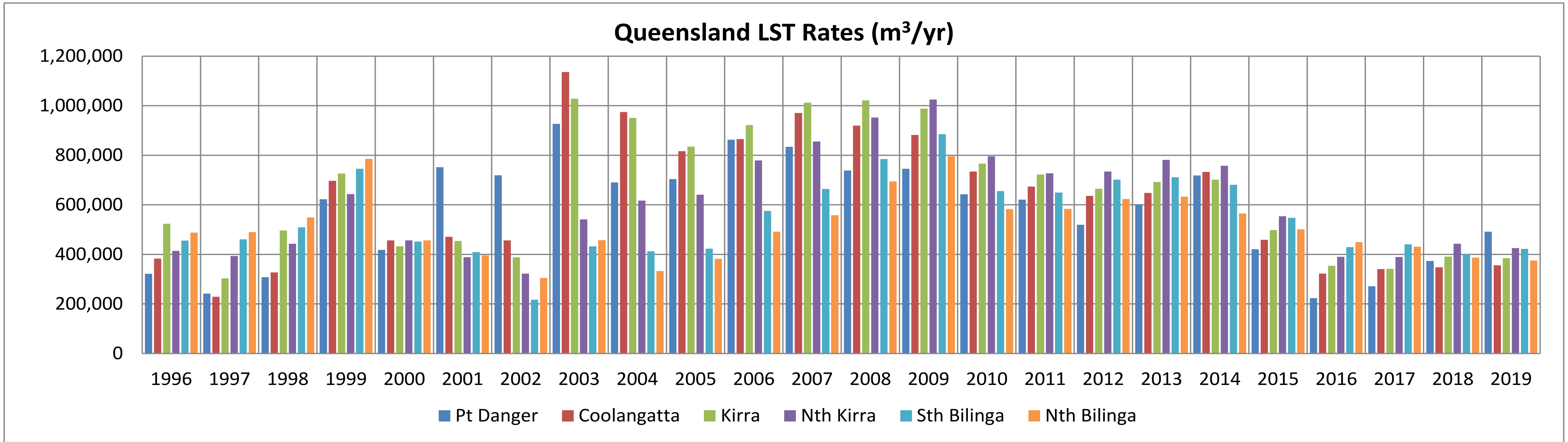


Figure 3-8 Annual and long-term trend LST rates: Pt Danger to North Bilinga

The LST rates derived for Snapper Rocks at Point Danger, at the Qld/NSW border and along Letitia Spit are illustrated in Figure 3-9 and listed in Table 3-1.

Locations south of the training walls at Letitia North and Letitia Central show significantly higher average annual net transport rates after sand bypass operations commenced in 2001 than had prevailed prior to that time. There was an induced increase in transport particularly at Letitia North as a result of the sand bypass system operations altering the shoreline alignment due to drawback at the jetty.

The derived LST rate at Letitia South for the period 1995 – 2019 is 546,400 m^3/yr, about 11% higher than the calculated rate of 494,000 m^3/yr for the same period at Currumbin. This longshore transport differential from Letitia Spit to Currumbin is evident from a net accumulation of approximately 1.3M m^3 since 1995 within the overall Letitia Spit to Currumbin coastal system.

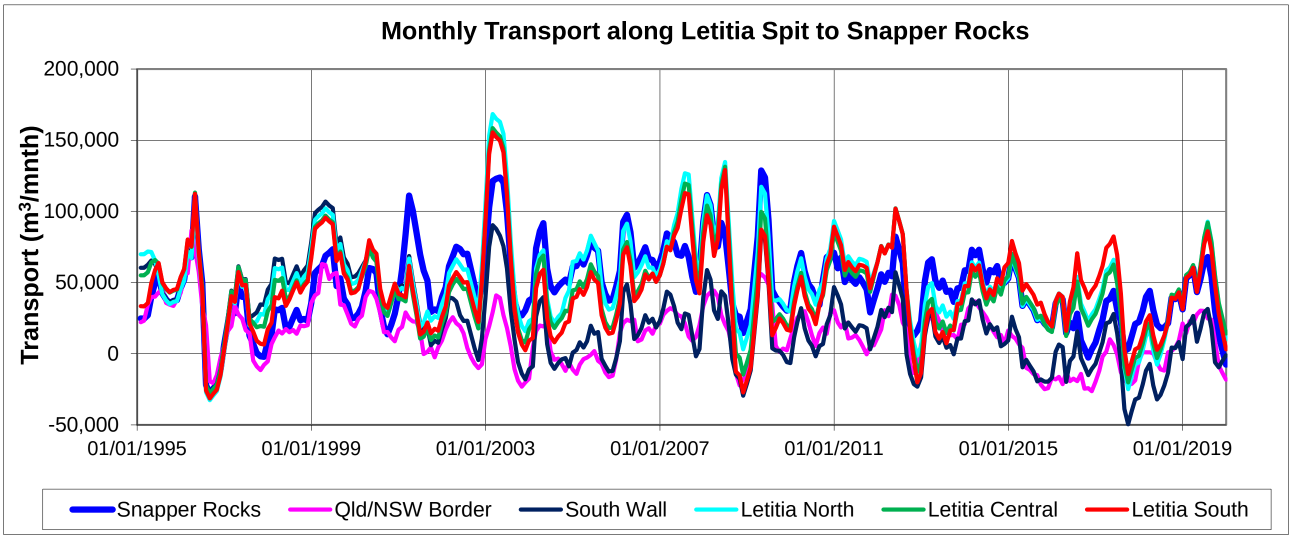


Figure 3-9 Monthly net transport along Letitia Spit

Table 3-1 Calculated transport at Letitia Spit

Period of Calculation*	Average Annual Net Transport at Various Letitia Locations (m^3/yr)					
	Snapper	North Wall	Sth Wall	Letitia Nth	Letitia Cnt	Letitia Sth
1995 to 2000	393,700	306,400	626,400	591,700	575,500	539,900
1995 to 2009	622,400	141,300	396,900	691,500	606,600	565,500
1995 to 2019	568,800	99,200	270,400	620,800	554,400	546,400
2001 to 2009	775,000	31,300	243,900	758,000	627,400	582,500
2001 to 2019	624,100	33,700	158,000	629,900	547,700	548,500
2009 to 2019	511,700	48,400	97,300	528,900	477,800	506,600

* Refer to Table 1-2 for further description of Tweed Sand Bypassing project epochs.

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

On the basis that the southern boundary of Letitia North (Figure 2-1) is located approximately at the location 1,000 m 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 listed in Table 3-2 and illustrated in Figure 3-10.

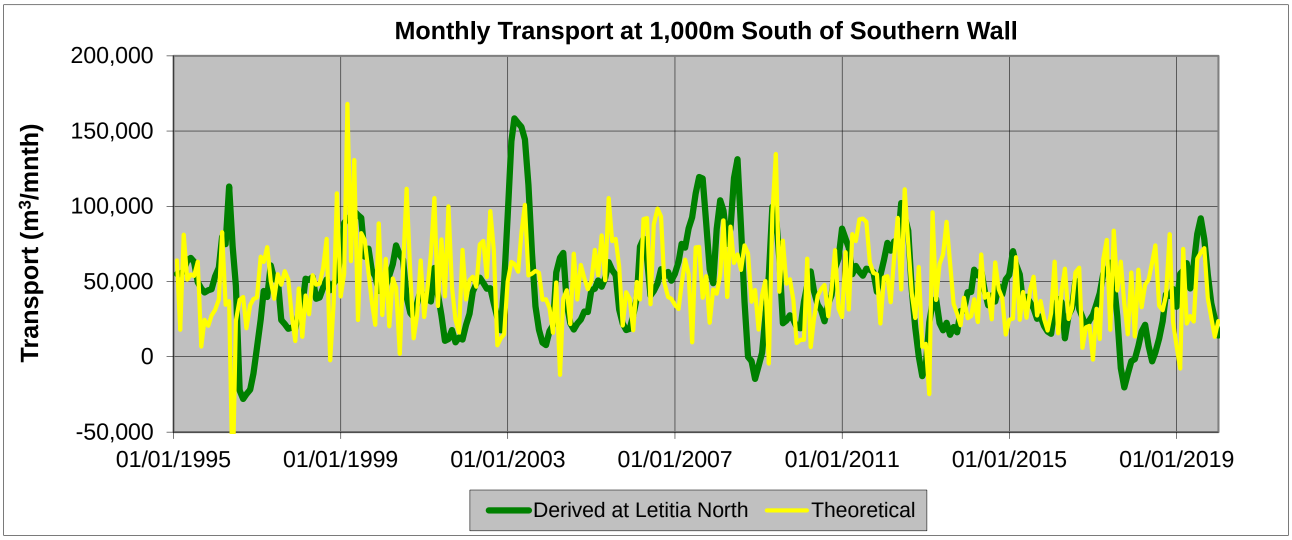


Figure 3-10 Monthly net transport 1,000 m south of southern training wall

Table 3-2 Transport rates 1,000 m South of Walls

Period of Calculation*	Annual Average Net Transport at 1,000m south of walls (m^3/yr)	
	Derived from Surveys & Currumbin Transport**	Theoretical from Waves
1995 to 2000	591,700	557,900
1995 to 2009	691,500	606,100
1995 to 2019	620,800	570,000
2001 to 2009	758,000	638,300
2001 to 2019	629,900	573,800
2009 to 2019	528,900	522,900

* Refer to Table 1-2 for further description of Tweed Sand Bypassing project epochs.

** Derived transport corresponds to Letitia North in Table 3-1

The Letitia Spit transport rates derived from survey data analysis and theoretical Currumbin transport exhibit some notable differences from the theoretically derived transport. The average annual transport rate of 570,000 m^3/yr calculated theoretically at Letitia Spit directly from the Tweed wave data at 1,000 m south of the entrance over the period 1995 to 2019 is significantly less than the 620,800 m^3/yr for Letitia North in Table 3-1. This result suggests that the shoreline alignment adjustment made in the theoretical calculation of Letitia Spit transport was not quite sufficient to

BMT

account for the project-related increase in transport at this location during the period from 2001 to 2015.

Periods of 'slug ' like transport are also evident in the derived rates along Letitia Spit shown in Figure 3-11 and Figure 3-12. While errors in individual survey datasets could contribute to this type of behaviour in the derived transport rates, there is independent evidence (Silva et al. 2020) to corroborate 'slug' like transport variability around Fingal headland into the Letitia South compartment.

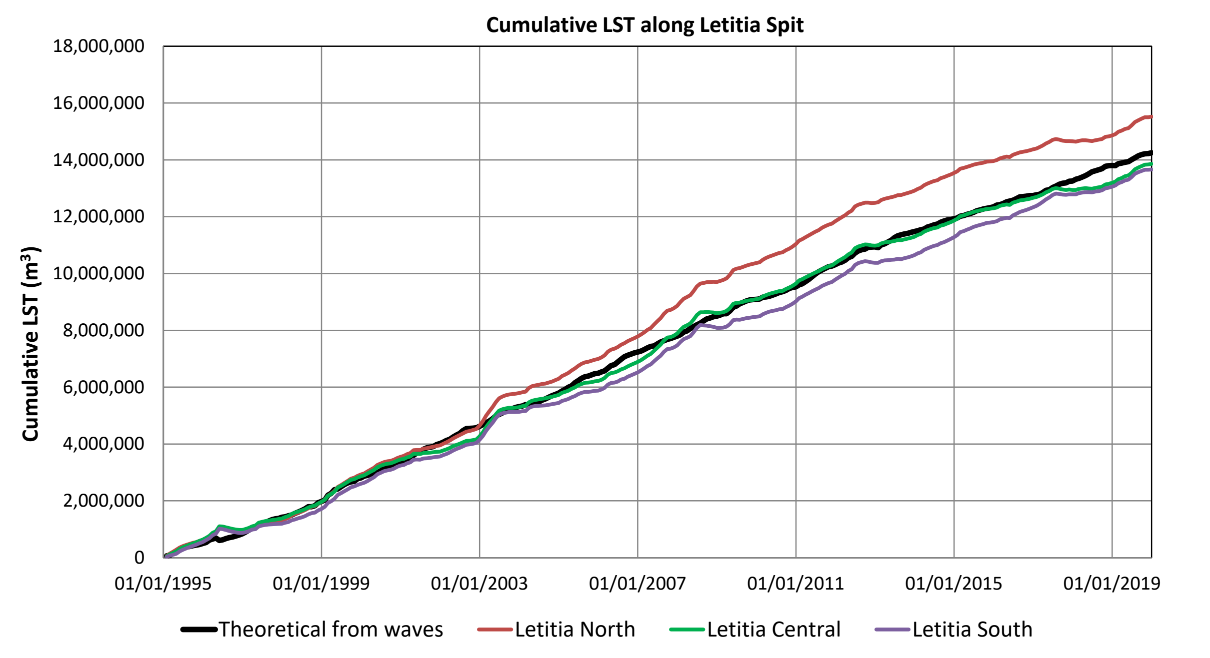


Figure 3-11 Cumulative sand transport at Letitia Spit. Theoretical is from Queen's formula applied to Letitia Spit, other rates have been derived from survey.

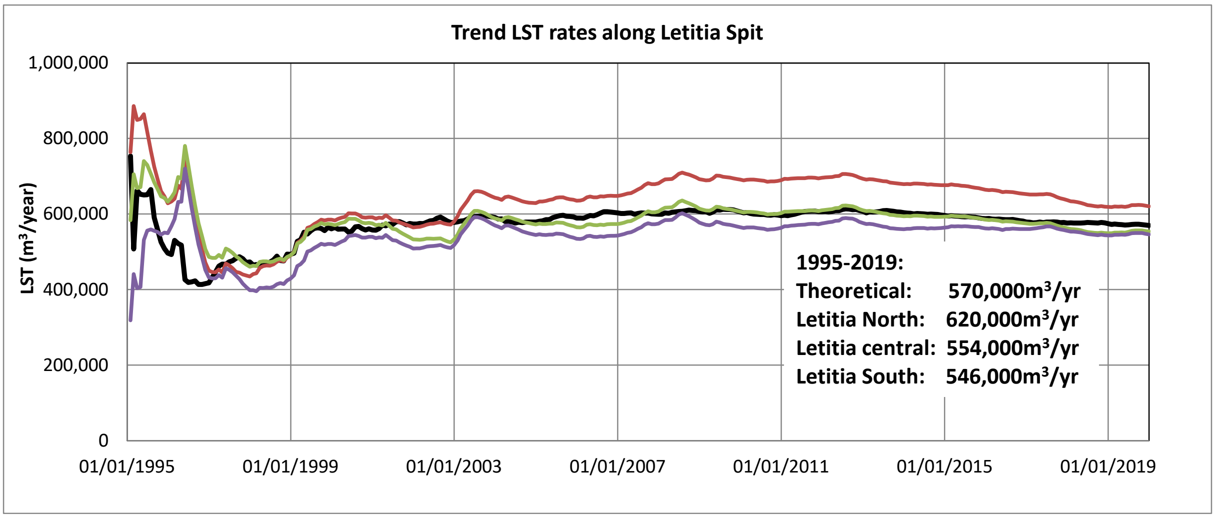


Figure 3-12 LST trends at Letitia Spit Theoretical is from Queen's formula applied to Letitia Spit, other rates have been derived from survey.

4 LTA and Natural Bypassing rates

4.1 LTA from Equation 1b based on survey data

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 from 2001 to 2006. 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'*.

The LTA is affected by the bypassing itself in terms of the natural bypassing that is acceptable while maintaining suitable entrance channel conditions. As such, the LTA calculations have been based on behaviour since bypassing commenced in 2001.

It is clear that, at the specified location one kilometre south of the southern training wall (Figure 2-1), the 'natural' sand transport patterns have been influenced since 2001 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 based on the seemingly de-coupled volume trends in the Letitia South compartment that the natural transport rate nearer to Fingal has been influenced much less or not at all by the sand bypassing operations. However, the Letitia South compartment volumes are evidently influenced by a "slug" delivery mechanism around Fingal headland and as such the sand delivery trends into Letitia Spit exhibit significant temporal variability.

To maintain consistency with previous LTA assessments, Equation 1b has been applied with respect to the whole length of Letitia Spit to the southern limit of the surveys (Letitia South compartment). The derived monthly LTA increments are shown in Figure 4-1. The average annual rate of these values since 2001 indicates the LTA based on the actual behaviour over the 19 years of sand bypassing operations up to 2020. 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. The annual rate comparison is shown in Figure 4-3.

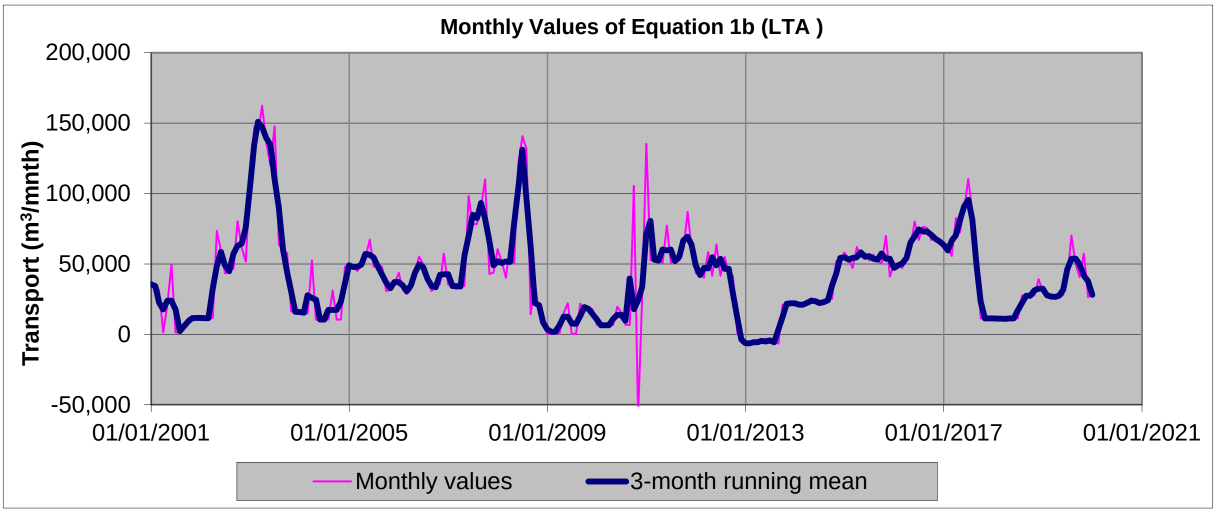


Figure 4-1 Monthly analysis of Equation 1b (LTA)

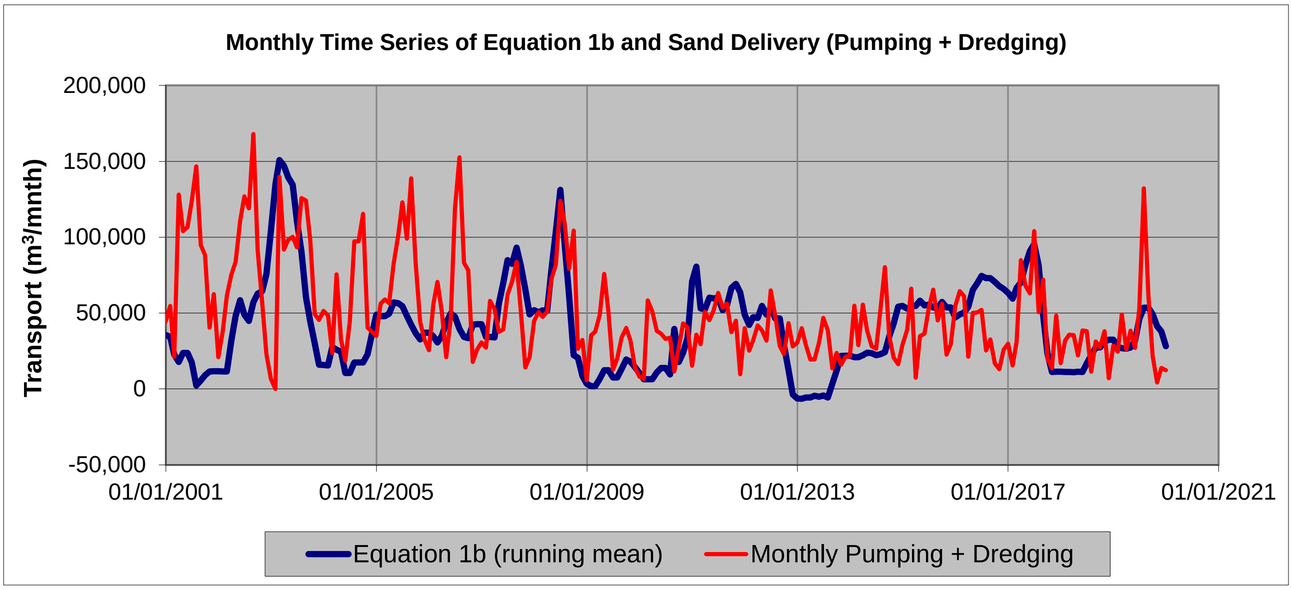


Figure 4-2 Monthly time series of Equation 1b and sand delivery undertaken

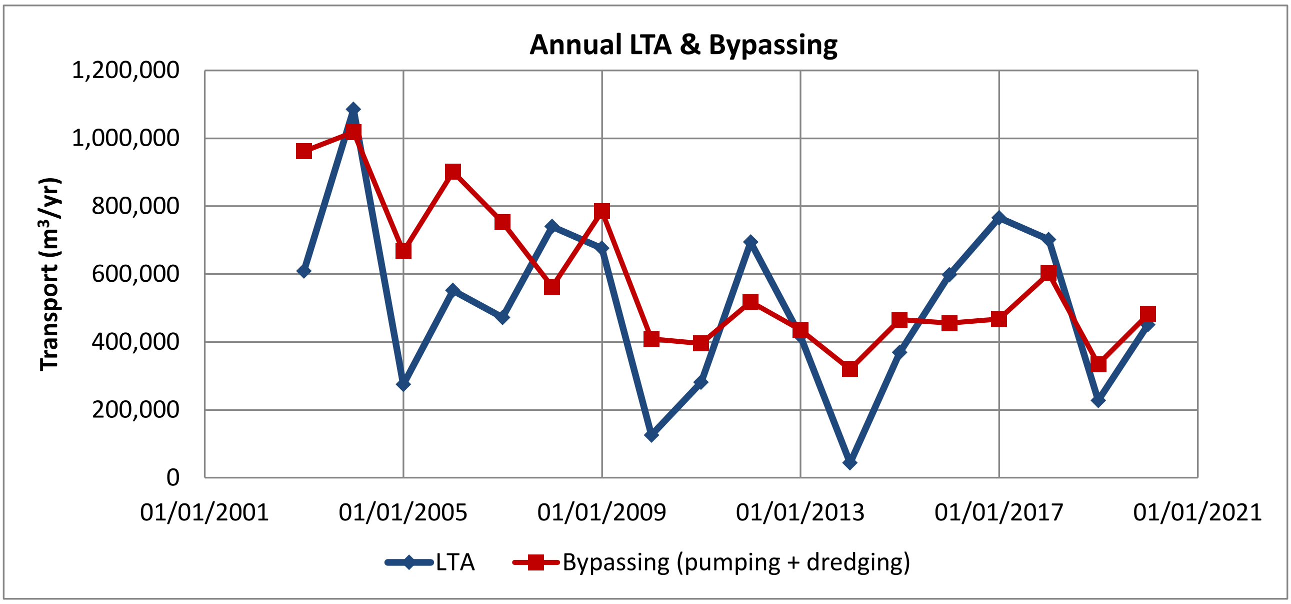


Figure 4-3 Annual time series of LTA from Equation 1b and total bypassing

The average annual LTA rate thus derived using Equation 1b for the period from January 2001 to January 2020, covering the period of sand bypass operations, is 497,000 m^3/yr. This is about 19,000 m^3/yr more than the previous reassessment (Table 4-1), which reflects a period of above-trend LTA-annual increments for the three years from 2015 to 2017 inclusive. While likely due to a combination of both environmental and operational factors, the increased LTA during this period is consistent with a reduced rate of natural bypassing as a result of entrance dredging being re-commenced.

The LTA estimates (using Eq 1b) from the 2009, 2015 and 2020 re-assessment studies are summarised in Table 4-1. Notably the estimates have been within ±5% of the initial Deed of Agreement estimate of 500,000 m^3/yr.

Table 4-1 Summary of LTA estimates from previous assessments

Reference	LTA Eq 1b (m^3/yr)	Calculation period
1995 Deed of Agreement	500,000	–
2009 LTA Re-assessment (BMT WBM, 2011)	509,000	2001 to August 2009
2015 LTA Re-assessment (BMT WBM, 2016)	478,000	2001 to July 2015
2020 LTA Re-assessment (this report)	497,000	2001 to January 2020

LTA cumulative trend rates for both periods from 2001 to 2020 (see above) and from 2007 to 2020 (480,000 m^3/yr), following cessation of the supplementary bypassing, have been determined, as shown in Figure 4-4. As discussed above, the LTA is a metric which can be influenced by the project operations in so much as these operations (pumping and dredging) can modify the quantity of natural bypassing that occurs. The total rate of bypassing during the supplementary increment period was by design significantly higher than the rate of natural transport into Letitia Spit. This high rate of bypassing had the secondary effect of supressing the rate of natural bypassing, with the consequence that the LTA increments during this period were correspondingly inflated.

Since 2007 the total rate of bypassing has been more closely matched to the LTA and hence the latter exhibits a slightly lower value than the longer period. Increasing the balance of total mechanical bypassing due to dredging, has the potential to increase the LTA due to the secondary effect of reduced natural bypassing of the entrance. Given that entrance dredging only re-commenced in 2016/17 it is probable that the trend LTA may still be adjusting upwards in response to the altered pumping/dredging split. This is because the trend LTA reflects a discrete period of environmental conditions and bypassing operations and should therefore be interpreted in terms of the likely future context.

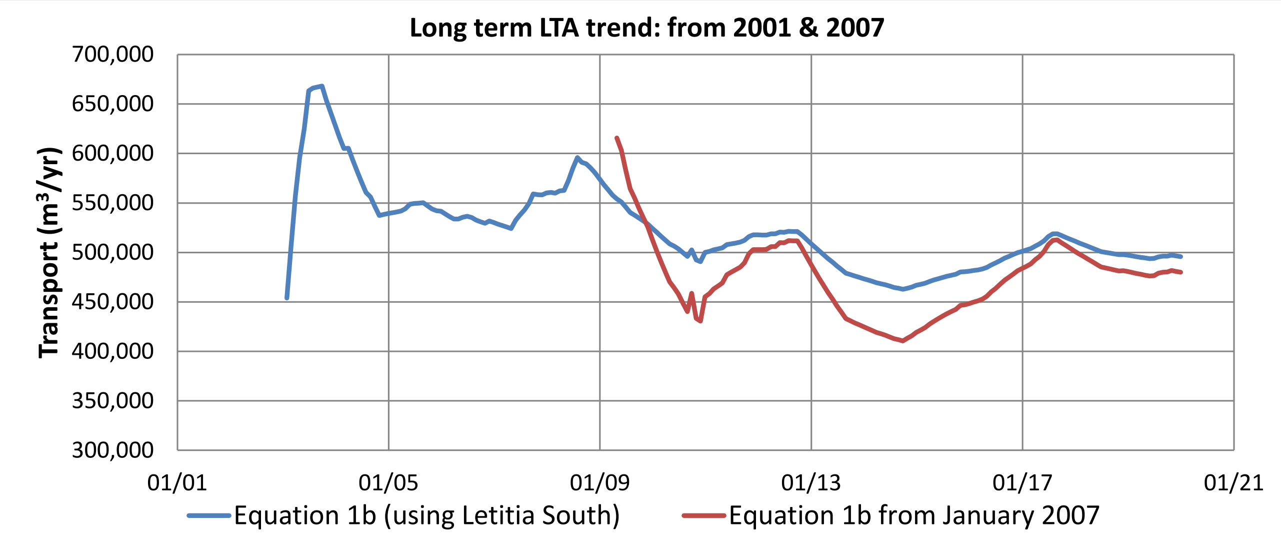


Figure 4-4 LTA trends from 2001 and 2007

4.2 Natural Bypassing 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 derived using the monthly net sand transport rates at Currumbin and the monthly quantity changes along the Queensland beach system. The natural bypassing is adopted as the transport across the border minus the contribution from the sand pumped to Duranbah in the bypassing operation. The time series results are shown in Figure 4-5.

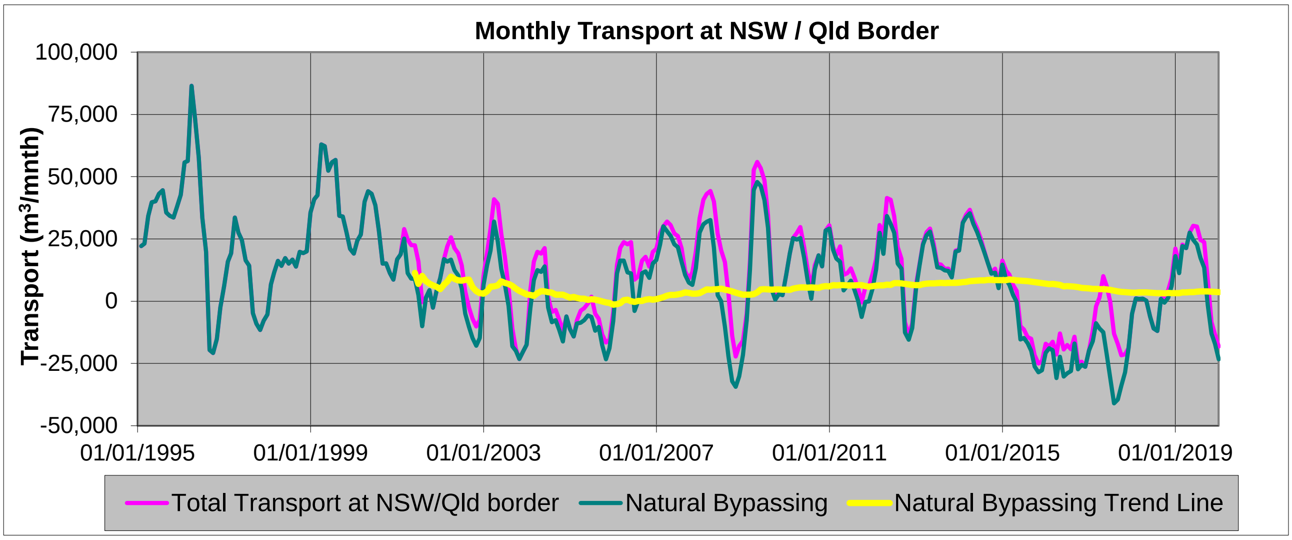


Figure 4-5 'Natural Bypassing' and total transport at NSW/Qld border (+ve northward)

These rates show a clear trend (refer yellow line) of marked reduction in natural bypassing after commencement of the sand bypass operations in 2001. Subsequently an increasing trend is evident from 2007 to 2015, associated with the reduced bypassing rate and increased leakage past the bypass system and entrance over that period. Since 2015, there has been an apparent decreasing trend as discussed below.

The average annual rate of total bypass pumping and dredging decreased since delivery of the "supplementary increment" was completed by 2008. Furthermore, no entrance dredging occurred from 2009 to 2016 and the natural bypassing rate would be expected to have increased as a result, as confirmed in Figure 4-6. Periodic entrance dredging has since recommenced with campaigns occurring in April to May 2016, March to August 2017 and July to August 2019 which have cumulatively removed 0.41M m^3 from the entrance compartment.

While short term periods of negative (southward) wave-driven transport at the NSW/QLD border are evident before 2015 (refer Figure 4-5), the period from 2015 to 2018 were a notable period of negative natural bypassing, to the extent that a significant reduction in the trend line was evident by 2019. The natural bypassing trend reversal in 2015 to 2018 is likely to be driven by multiple factors including wave climate (Section 3.2.2) and re-commencement of entrance dredging (Section 4.1). In particular, where dredge material is placed largely in the Duranbah compartment, as occurred in the 2017 campaign, the assumption that this quantity is effectively transferred to Queensland may not always hold. Some leakage of sand back into the entrance compartment is possible under certain wave conditions and would partly account for a negative natural bypassing rate.

The short-term fluctuations in estimated natural bypassing rates may also be related to individual survey errors. The period from 2015 to 2018 was notable in that it was the first sustained period of reducing sand quantity trend summed over the Queensland compartments since jetty pumping commenced in 2001 (Figure 2-10). To the extent that the 2015 peak in total Queensland sand volume could potentially have been over-estimated due to individual survey error, the recent natural bypassing trends may be in part a correction to earlier over-estimates.

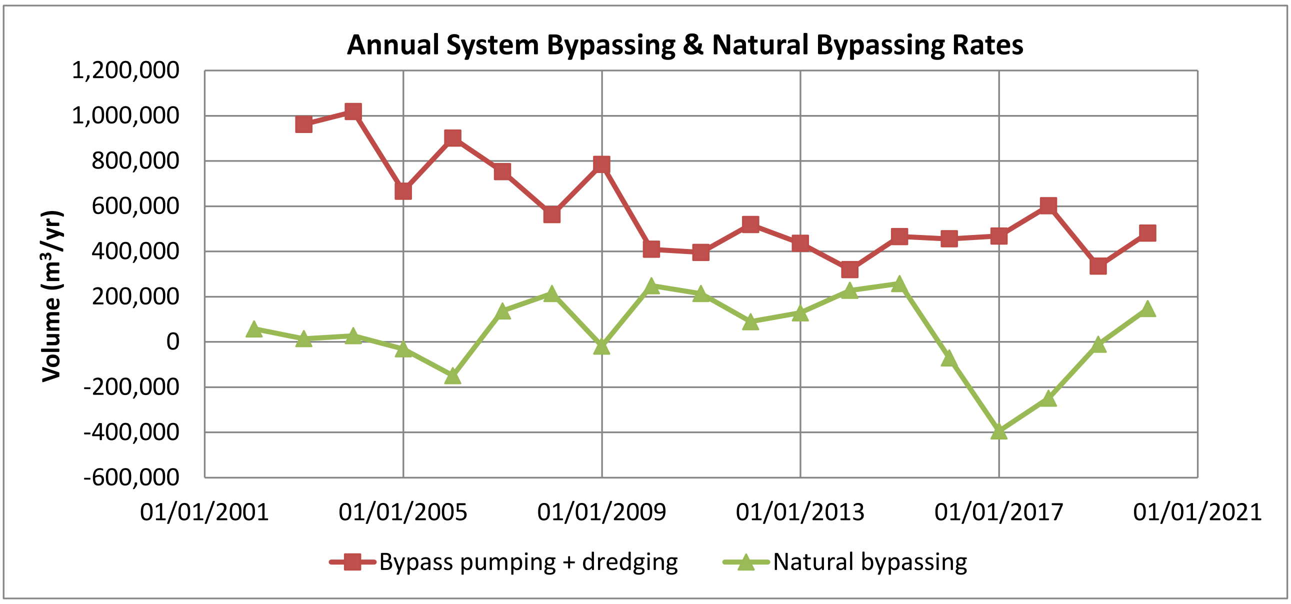


Figure 4-6 Annual time series of total system bypassing & natural bypassing

These results indicate the progressive sand transport rates at the border as listed in Table 4-2. This indicates the natural bypassing rate has averaged about 43,100 m^3/yr since bypassing commenced in 2001, and a slightly higher rate of about 45,800 m^3/yr since 2007. The cumulative trends of natural bypassing over the two periods 2001-2019 and 2007-2019 are illustrated in Figure 4-4. Of note is the significant reduction in the natural bypassing trend since 2015. As discussed above, the reduced natural bypassing trend is likely due to a combination of below trend wave energy and re-commencement of entrance dredging. A return to higher-energy wave climate may see the natural bypassing trend increase again in the future, while continuation of periodic entrance dredging campaigns to meet the entrance navigability objectives of the Project should help maintain lower natural bypassing rates.

Table 4-2 Calculated transport at NSW/Qld Border

Annual Average Net Transport at NSW/Qld Border (m^3/yr)		
Period of Calculation	**Natural Bypassing**	**Total Transport**
1995 to 2000	318,600	318,600
2001 to 2007	38,400	106,900
2001 to 2019	43,100	107,600
2008 to 2019	45,800	108,100

Refer Section 1.3.2 for definition of natural bypassing and total transport

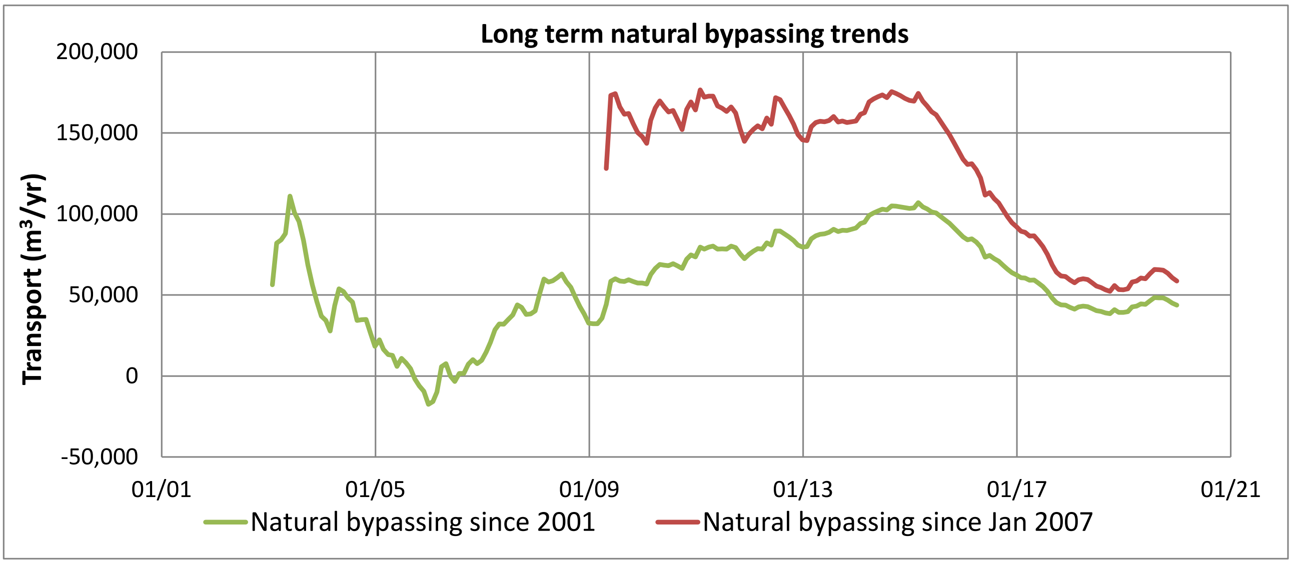


Figure 4-7 Natural Bypassing trends from 2001 and 2007

5 Discussion and Recommendations

5.1 Letitia Spit Quantities

It is evident from Figure 2-3 that the trend of reducing sand volumes along Letitia Spit, which has been ongoing since jetty pumping commenced in 2001, has now stabilised. Since the 2015 LTA re-assessment (BMT WBM, 2016) Letitia Spit sand volumes have recovered by around 0.5M m^3, though most of this is accounted for in the Letitia South compartment and may be located offshore rather than evident as shoreline accretion.

Reviewing the time history since 1993, the Letitia North compartment volume reached its minimum value back in 2007 at the end of the supplementary increment period, while the Letitia South minimum occurred around 2017. Letitia South compartment volumes also reached a minimum in 2013, however it is clear now that the variability seen at Letitia South is a result of slug delivery mechanisms around Fingal headland more so than recession induced by project operations.

The Letitia Central compartment volumes appear to have stabilised from 2015 onwards, however the reducing volume prior to 2015 was clearly linked to shoreline drawback due to commencement of jetty bypassing in 2001. The LTA assessment has up until now used the Letitia South derived transport as the basis for calculating the LTA, in order that the DoA requirement that it not include ‘any artificial actions to influence it’ is satisfied. It is recommended to also consider the Letitia Central derived transport in future LTA re-assessments as it may continue to satisfy the DoA requirement into the future.

5.2 Gold Coast Quantities

It is also appears that total sand volume increases along the Gold Coast compartments had reached a maximum in 2015 (Figure 2-8) and by 2020 have stabilised at around 5.0M m^3 above 1993 levels. Since completion of the supplementary increment period in 2007, there has been an ongoing redistribution of sand volumes out of the southern compartments and corresponding gains in the northern compartments. Rainbow-Coolangatta volumes reached a minimum in 2017 while North Kirra and Kirra compartments continue slow downward trends. Further north, the South Bilinga and North Bilinga compartments have remained relatively stable since around 2016 and Currumbin volumes have recently reduced. It appears likely that the distribution of sand volume through the southern Gold Coast embayment is now approaching a dynamic equilibrium with the renewed sand supply delivered by the Project.

As discussed in a study focussed on Currumbin (BMT WBM, 2018), Bilinga and Currumbin are more characteristic of the typical double-barred Gold Coast beaches than the southern embayment beaches from Point Danger to Kirra. The renewed sand supply to the northern beaches is expected to be distributed over the active profile and is therefore unlikely to result in substantial shoreline translation as seen at Kirra during the supplementary increment period.

5.3 Longshore Sand Transport

This study has re-calculated the average annual longshore sand transport into Letitia Spit as 546,000 m^3/yr for the 25 year period from January 1995 to December 2019. This quantity has reduced from the 574,000 m^3/yr calculated in the previous re-assessment study for the period 1995 to 2015 (BMT WBM, 2016).

The annual transport at Currumbin has similarly been re-calculated as 494,000 m^3/yr for the 1995 to 2019 period, which is also reduced slightly from the previous estimate of 503,000 m^3/yr (BMT WBM, 2016).

The implied transport gradient from Letitia to Currumbin has been previously highlighted and discussed (BMT WBM, 2016) and is calculated as a direct result of the net gain of sand volume in the Letitia South to Currumbin system. This net gain (NSW+Qld) has reached 1.54M m^3 over the 27 years since January 1993 (refer Figure 2-8) at an annual rate of 57,000 m^3/yr. This transport differential may reflect a multi-decadal increase in transport around Fingal Headland and/or reduced transport at Currumbin, however it would be expected to reduce in the longer term such that the long-term average of transport at Letitia is approximately balanced by the long-term average at Currumbin.

5.4 LTA and Bypassing

The LTA is defined as…

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

and is the Deed of Agreement quantity that should be bypassed over the longer term by the Tweed Sand Bypassing jetty mounted pumping system and entrance dredging. The calculated annual LST at Letitia South and Bypassing (pumping + dredging) are compared for the period 2001 to 2019 in Figure 5-1. The natural LST can be seen to vary strongly from year to year in a range from 270,000 m^3/yr in 2013 up to 990,000 m^3/yr in 2003. The high rate of bypassing during 2001 to 2007 includes the supplementary increment to the LTA. Since 2009 the rate of bypassing has remained in a range from 320,000 m^3 during the low transport year of 2013 up to 620,000 m^3 in 2017, a year which included a 217,000 m^3 entrance dredging campaign.

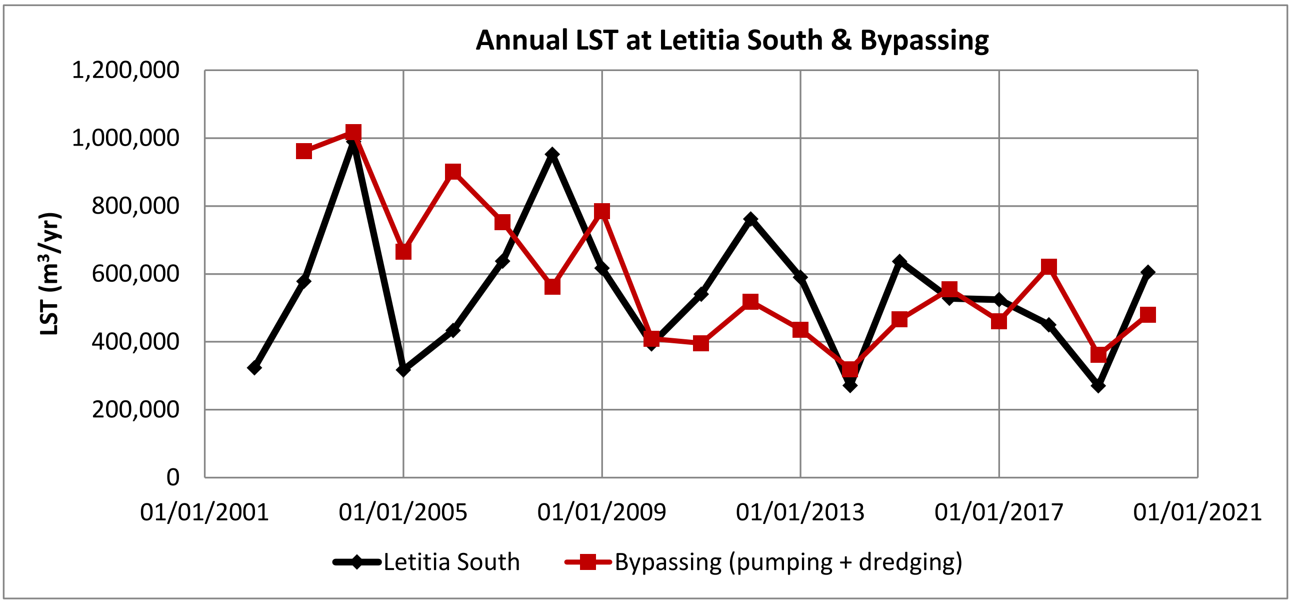


Figure 5-1 Calculated annual LST at Letitia South & bypassing since 2001

The monthly/annual components of the LTA account for the natural bypassing to Queensland. The natural bypassing quantity and LTA increments have been calculated since 2001, and are significantly influenced by both:

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

The cumulative trend rates of LST, LTA and natural bypassing quantities are shown in Figure 5-2 for the period since 2001. Also shown are the trend rates since 2007, following completion of the supplementary increment. While LST has trended downwards since the previous re-assessment was completed, the LTA has trended slightly higher as a result of a significant reduction in the natural bypassing trend. The period from 2009 to 2016 did not include any entrance dredging and consequently the natural bypassing trend rate increased during this period. Since 2016, there has been 0.41M m^3 of entrance dredging and this has likely contributed (in part) to the downward trend in natural bypassing.

Comparing the cumulative bypassing rate (comprising pumping plus dredging) with the cumulative LTA trend (Figure 5-3) demonstrates that the Deed of Agreement requirement has been successfully achieved over the 13 years from January 2007. The long-term trend value of LTA that has achieved this outcome is 497,000 m^3/yr since 2001, or the slightly lower value of 480,000 m^3/yr since 2007. Given that the larger value is inflated by inclusion of the supplementary increment and the lower value would have been reduced by the lack of entrance dredging activities from 2009 to 2016 it seems reasonable to retain the previous LTA best estimate of 490,000 m^3/yr (BMT WBM, 2016). This estimate implies a natural bypassing rate of 56,000 m^3/yr as being consistent with the Tweed Sand Bypassing entrance navigability objective. The entrance dredging requirements are considered further in the following section.

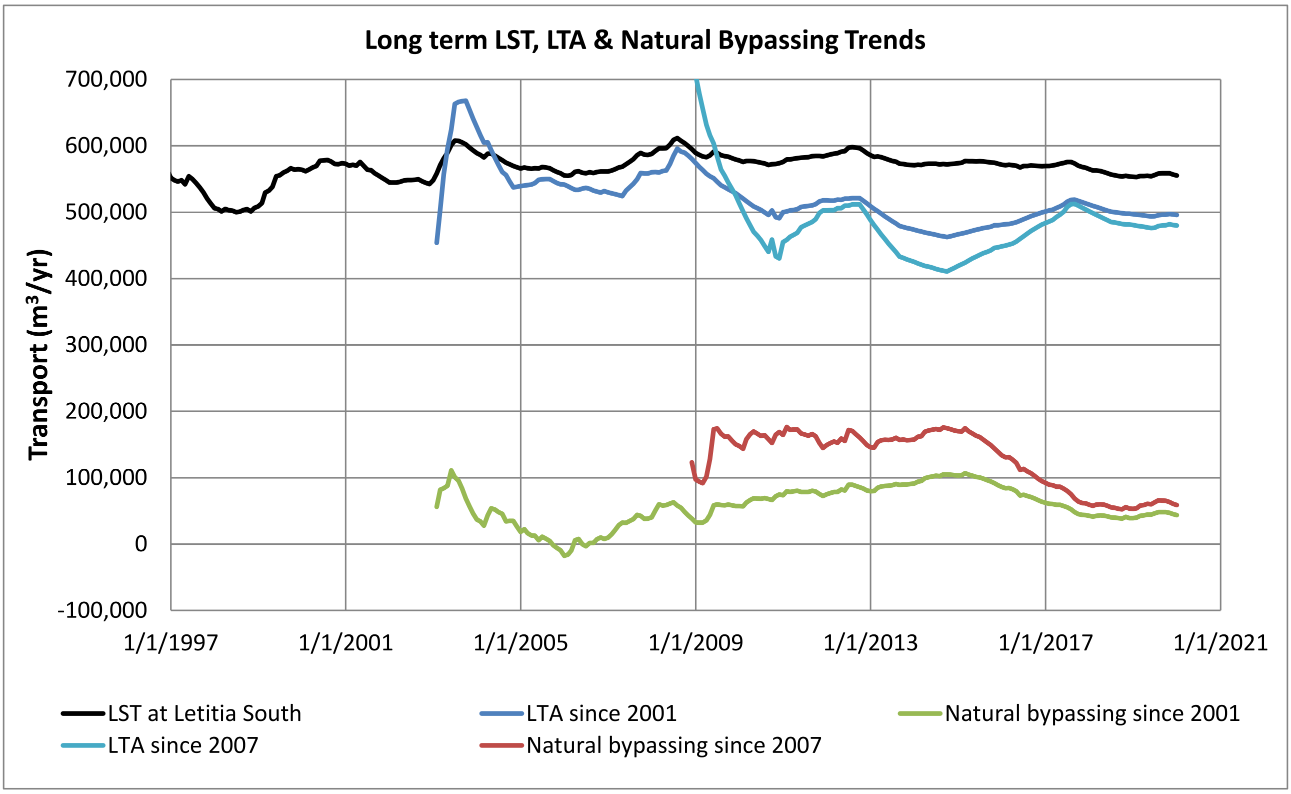


Figure 5-2 Cumulative Trend Rates of LST, LTA and Natural Bypassing

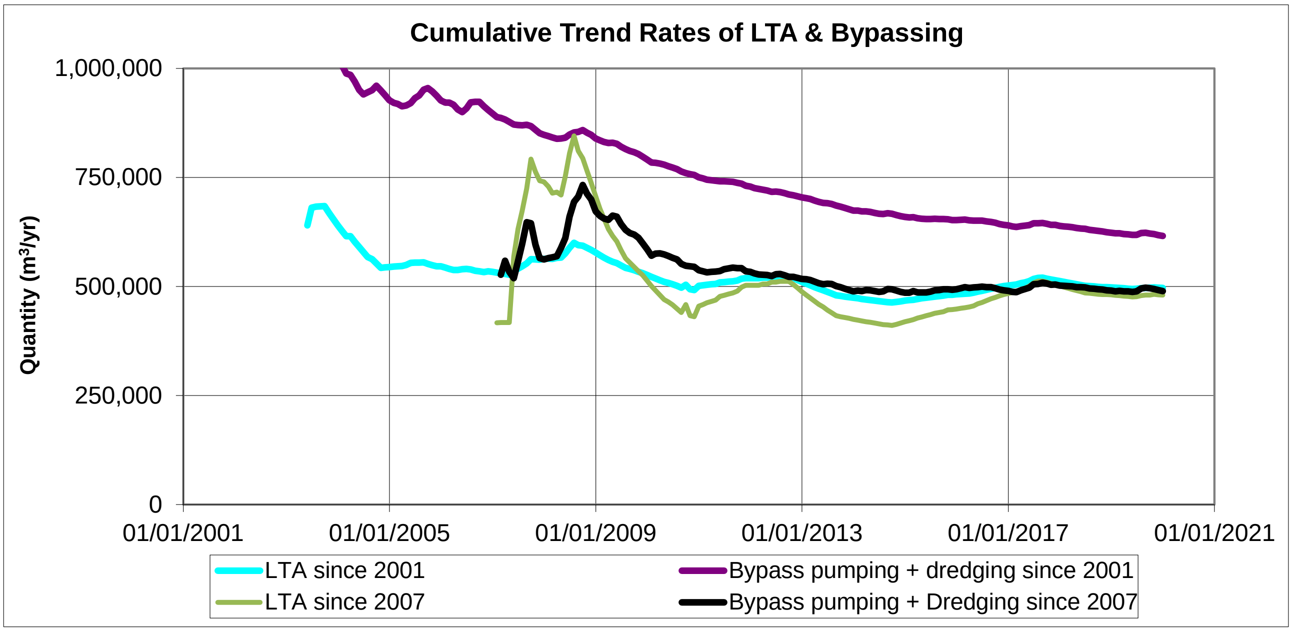


Figure 5-3 Cumulative Trend Rates of LTA & Bypass pumping plus dredging

5.5 Entrance Dredging Requirement

Tweed River entrance navigability will depend on sand bar configurations and wave conditions; however it is reasonable to expect that higher entrance sand volumes will correlate with a higher risk of navigability constraints. Sand volumes within the entrance compartment are shown in Figure 5-4 along with the cumulative (since 1993) entrance dredge volume. This figure shows that more than 2M m^3 was dredged from the entrance in Stage 1A/1B in order to achieve a net reduction in the entrance compartment volume of around 1M m^3. Between Stage 1B and Stage 2 the entrance compartment volume increased by around 0.5M m^3. A further slow increase in Entrance compartment volumes was evident from 2000 to 2009, a period which included another 2M m^3 of dredging. The rate of increase in entrance compartment volume clearly accelerated in the period from 2009 to 2016 during which no further entrance dredging occurred. Recent dredging campaigns in 2016, 2017 and 2019 have collectively removed 410,000 m^3, which has clearly reduced the entrance compartment volumes. However as of June 2020 these are back to just 85,000 m^3 below 1993 levels, having peaked at 20,000 m^3 above 1993 levels in late 2016. This highlights the ongoing need for periodic entrance dredging as part of the overall sand bypassing mix.

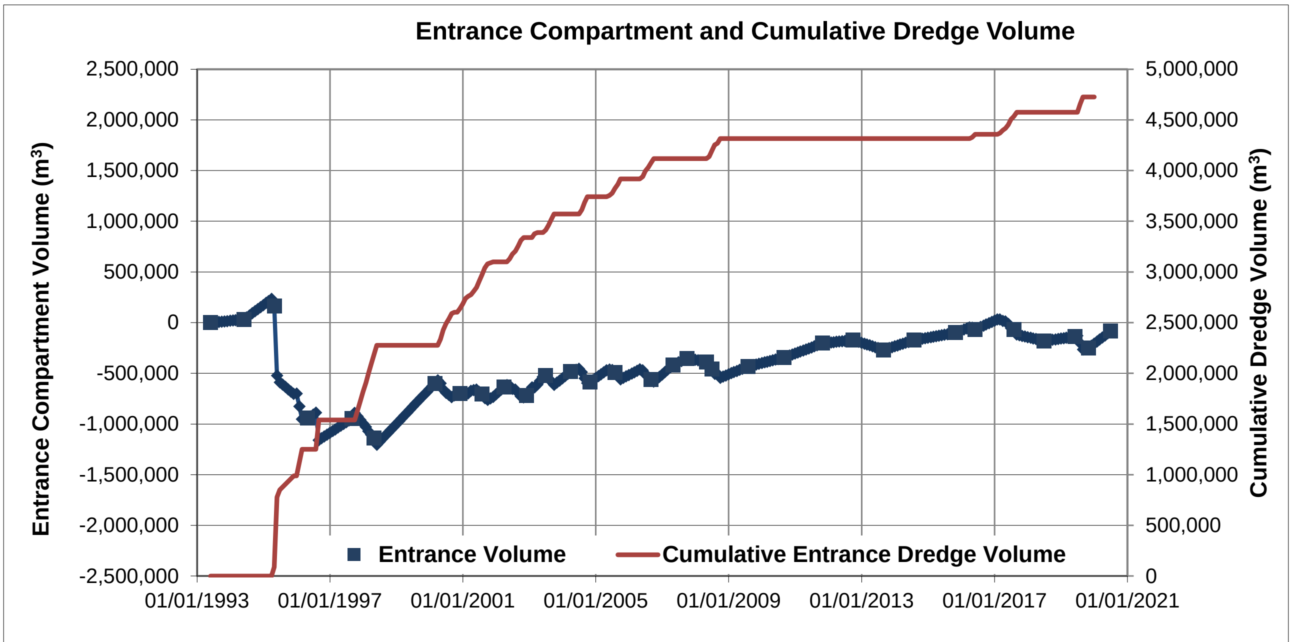


Figure 5-4 Sand volumes within the 'entrance' compartment

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 5-5. This indicates that overall, to December 2019, about 25% of the transport into Letitia North will leak through the trestle system. The estimated cumulative leakage has trended downward from around 30% since 2015 (BMT WBM, 2016).

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 5-6. The current value of this metric reflects the operational history of the project and has trended upwards from around 50% in 2015 to about 67% in 2019 as a consequence of the recent dredging campaigns.

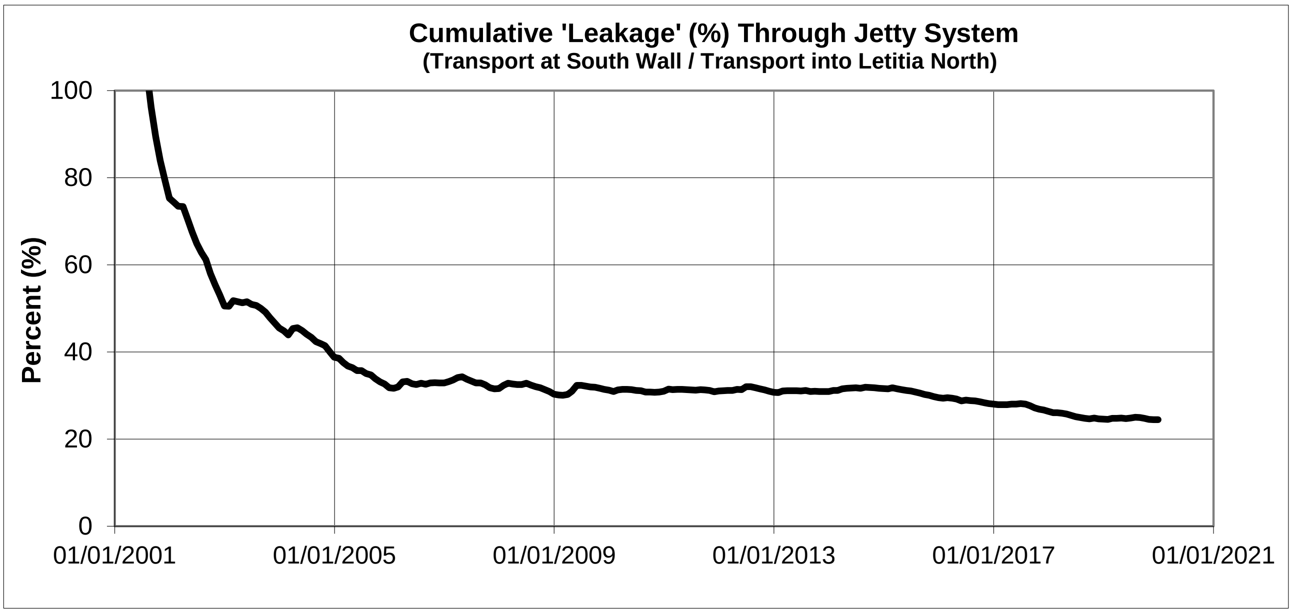


Figure 5-5 Cumulative trend of % leakage through jetty system

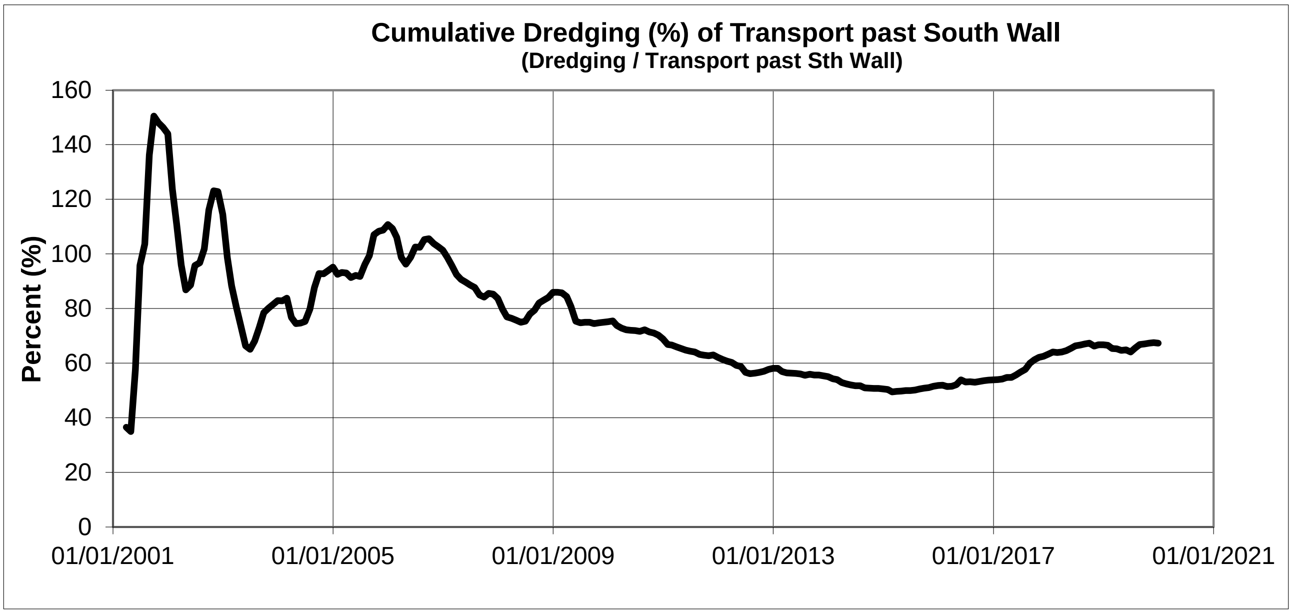


Figure 5-6 Cumulative trend of % dredging of sand leakage

5.6 2020 LTA Re-assessment Summary

In this study the long-term trend values of the Letitia Spit LST and LTA rates have been updated using available data to December 2019. Given that the LTA as defined in the DoA is a quantity that depends not only on the environmental LST quantity but also on the modes and rates of bypassing operations, the estimated split between dredging and pumping quantities consistent with the LTA estimate have been included as supplementary information:

- Letitia Spit LST: 550,000 m^3/yr
- LTA: 490,000 m^3/yr (±20,000 m^3/yr), split between
  - Dredging: 67% of 25% of 550,000 = 90,000 m^3/yr
  - Pumping: 400,000 m^3/yr
- Natural Bypassing: 60,000 m^3/yr.

5.7 Climate change

The present rate of Sea Level Rise (SLR) is around 3.6 mm/year and is exhibiting an accelerating trend (IPCC, 2019). Planning studies in Australia are commonly adopting future SLR projections of up to 0.8 by 2100.

These projected trends are expected to impact on coastal systems such as Letitia to Currumbin by driving profile evolution to maintain "equilibrium" with the rising sea level. The "Bruun" rule is a simple model used in coastal engineering to predict how unconstrained coastal profiles may maintain equilibrium with SLR by translating both upward and shoreward. In reality, beach systems are often constrained by features such as natural headlands and by shore protection structures such as seawalls. This means that profile adjustment to SLR is unlikely to occur in accordance with the Bruun rule but may in reality exhibit substantial alongshore variability.

Modelling studies such as Patterson (2013) have predicted that SLR can significantly alter the longshore sand transport regime along a section of coastline constrained by headlands. Headlands will tend to stabilise the cross-shore position of updrift profiles while transferring a corresponding volume deficit onto downdrift profiles. It is possible that such a response to SLR could result in reduced longshore transport supply into Letitia Spit due to accumulation of sediment at updrift headlands (Fingal, Cudgen, etc.). The Tweed River entrance and lower estuary may also tend to accumulate more sand as a morphological response to SLR.

Future climate change trends may also impact on the wave climate (Morim *et al*, 2018), though the projected trends in terms of wave energy and directionality are less certain than the SLR trends. Any such significant trends would have implications for longshore transport rates and associated shoreline response.

Additional sand nourishment may be required in future to mitigate SLR induced recession where there is a seawall limiting landward translation, such as is largely the case for Gold Coast beaches. In the absence of additional nourishment it would be expected that upper beach sand volumes would be gradually reduced as a result of SLR, with inevitable loss of beach amenity.

It appears likely from the above considerations that future climate change creates additional risks, uncertainties and potentially opportunities that may influence future Tweed Sand Bypassing project objectives.

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Melbourne
Level 5, 99 King Street
Melbourne Victoria 3000
Australia
Tel +61 3 8620 6100
Fax +61 3 8620 6105
Email melbourne@bmtglobal.com

Newcastle
126 Belford Street
Broadmeadow New South Wales 2292
PO Box 266 Broadmeadow
New South Wales 2292
Australia
Tel +61 2 4940 8882
Fax +61 2 4940 8887
Email newcastle@bmtglobal.com

Adelaide
5 Hackney Road
Hackney Adelaide South Australia 5069
Australia
Tel +61 8 8614 3400
Email info@bmtdt.com.au

Northern Rivers
Suite 5
20 Byron Street
Bangalow New South Wales 2479
Australia
Tel +61 2 6687 0466
Fax +61 2 6687 0422
Email northernrivers@bmtglobal.com

Sydney
Suite G2, 13-15 Smail Street
Ultimo Sydney New South Wales 2007
Australia
Tel +61 2 8960 7755
Fax +61 2 8960 7745
Email sydney@bmtglobal.com

Perth
Level 4
20 Parkland Road
Osborne Park Western Australia 6017
PO Box 2305 Churchlands Western Australia 6018
Australia
Tel +61 8 6163 4900
Email wa@bmtglobal.com

London
Zig Zag Building, 70 Victoria Street
Westminster
London, SW1E 6SQ
UK
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Email london@bmtglobal.com

Leeds
Platform
New Station Street
Leeds, LS1 4JB
UK
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UK
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Asia Pacific
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Email asiapacific@bmtglobal.com

Alexandria
4401 Ford Avenue, Suite 1000
Alexandria, VA 22302
USA
Tel: +1 703 920 7070
Email inquiries@dandp.com