Tweed Sand Bypassing Sand Transfer & Energy Efficiency Investigation

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Project Manager:	Mick Varidel
Author:	Mick Varidel, Joris Jorissen & Mal Cotter
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Jacobs Group (Australia) Pty Limited
ABN 37 001 024 095
32 Cordelia Street
PO Box 3848
South Brisbane QLD 4101 Australia
T +61 7 3026 7100
F +61 7 3026 7300
www.jacobs.com

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Executive Summary

Introduction

The NSW Department of Industry (“DoI”) commissioned Jacobs on behalf of TSB to undertake this study on 23 April 2018. TSB is a partnership between NSW DoI and the Queensland Department of Environment and Science (“DES”).

Jacobs was engaged to undertake this study with the goal of exploring the opportunities for improving the sand transfer efficiency, sand trapping efficiency, energy use efficiency and opportunities to utilise alternative energy sources. Operation and maintenance of the sand bypassing system is detailed in a Concession Agreement (CA) made in 1999 between the Tweed River Entrance Sand Bypassing Company (TRESBCo) and the Governments. As the expiry of the CA in 2024 approaches preparations are being made for the transition to a new system of operation. This investigation will enable TSB to plan for beneficial changes to the system so that these can be implemented as part of the new system of operation.

This study focusses on the configuration and operation of the Jetty Mounted Pumping System (JMPS).

The main objectives of this study were as follows:

- Identify sand trapping and transfer capacity constraints and determine opportunities for improvement within the existing JMPS.
- Determine ways to reduce energy cost, consumption and emissions associated with the JMPS.

Existing Sand Transfer System

The system is designed maintain navigability of the Tweed River entrance and maintain a continuing sediment supply to the southern Gold Coast beaches at a rate consistent with the net longshore transport.

It was installed because the prior construction of training walls in the Tweed River inlet had resulted in an accumulation of northward-moving sediment south of the river and across the river entrance, a situation which impeded the natural flow of sand onto the Queensland beaches, and resulted in much greater beach profile depletion than had previously been the case. The training walls also resulted in the formation of a much more substantial bar across the Tweed River mouth, and this both impeded the navigability of the river entrance and made entry to the estuary more hazardous.

The TSB therefore has the dual responsibility of maintaining free navigability of the Tweed River entrance and providing a more natural balance of sand accumulation on the southern Queensland beaches.

TSB extracts littoral sand using a JMPS from the seabed off Letitia Spit and is able to pump the sediment to Kirra Point, Greenmount Beach, West Snapper Rocks, East Snapper Rocks and Duranbah Beach on the Queensland side of the border.

The principle components of the TSB system are the JMPS located on Letitia Spit 250m south of the Tweed River entrance and a network of pipelines discharging sand slurry onto the southern Gold Coast beaches.

The major sub-components of the TSB system are:

- Tweed River seaway training wall
- Raw water intake pump station (located on the Tweed River inlet)
- High pressure booster pump

- Flume dilution pump
- Jetty-mounted jet pumps (10 pumps installed, but usually only 9 are used).
- Transfer sump/tank
- Sand transfer pumps
- Discharge pipeline to various locations on Coolangatta beaches.

Sand Capture Efficiency

The sand trapping efficiency of the sand transfer system (STS) is dependent on a number of factors, but fundamentally is a function of the system ability to trap sand that is transported along the shore by natural coastal processes. The trapping efficiency varies depending on the prevailing wave conditions, the bathymetry around the jetty and the effective length, width and height of the sand trapping cones, including the ability to maintain the cone dimensions over time. Ideally, the STS would have the capacity to capture all the net longshore transport, however in recent years approximately 70% of the estimated net annual longshore sand transport has been transferred by the STS.

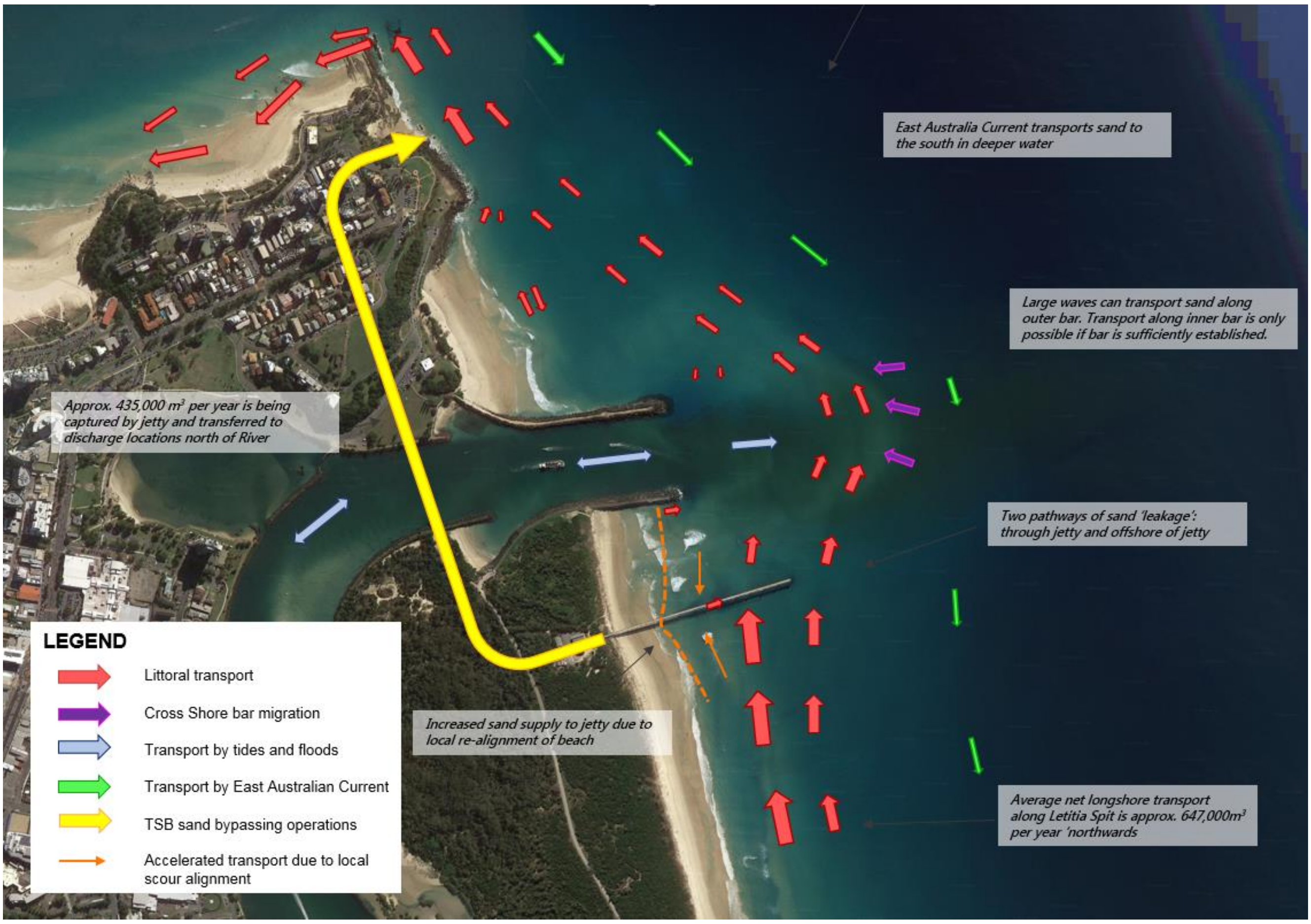

Figure: Conceptual sediment transport model of area around sand trapping jetty (modified from Jacobs, 2018)

Longshore sediment transport occurs predominantly in the mid to outer surfzone (or inner nearshore zone), diminishing in strength with distance offshore into deeper water. The majority of the longshore transport along Letitia Beach occurs in the water depths of less than 4m, in particular around the nearshore bars (Also see figure above). As a result, most of the longshore transport at the jetty occurs within the zone between the four to five most inshore trapping cones. Under most conditions, the daily longshore transport rate is well below the storage volume available of these inshore cones (~2,000 to 3,000 m^3), and most of the longshore transport is trapped by the STS. During large wave events, the littoral zone can extend well beyond of the jetty and large longshore currents may exist. During these events, the sand trapping system does not capture all the longshore transport and 'leakages' occur.

TRESBCo pumping log data indicates that just over 7 million m^3 of sand was transferred between April 2001 and April 2014. Generally, the data shows a slight trend of decreased transport over time with notably higher transfer rates during the first 5 years of operation.

The data of the five years to 2014 indicates that:

- the vast majority of the time (~83%), sand pumping occurs with a slurry density of less than 1.3 t/m^3 in the main slurry transfer system. This is significantly below the density required to achieve the design capacity of the transfer system.
- A strong correlation between higher slurry density and higher sand transfer rates.
- The vast majority of pumping occurs at night; more than 75% of the pumping occurred between 8pm and 7am.
- For approximately 38% of days, the STS has not transferred any sand.
- Sand pumping rarely occurs at a rate that approaches to the design capacity of 625 m^3 per hour of the transfer system.
- During days with low to moderate northerly longshore transport (up to about 1,000m^3/day), the average volume of sand transferred by the STS is generally of the same order as the modelled longshore sand transport. However, during days with large northerly longshore transport (>1,000m^3/day), the volume of sand transferred is generally significantly lower than the modelled longshore sand transport.

System Capacity

The sand transfer capacity of the system is determined by several factors, including:

- The hydraulic capacity of the raw water (low pressure) and booster (high pressure) pumps.
- Hydraulic capacity of the sand transfer pumps.
- The size of the system pipework/pipelines.
- Wear on system components over time, particularly the jet pumps and the sand transfer pump impellers and volutes.
- The number of jet pumps which can be operated simultaneously.
- Susceptibility of the system to blockages (which cause shutdowns and reduce operating time).
- Depth of the jet pumps below the seabed. This changes the size of the drawdown cones, and impacts on the ability of the cones to trap sand.
- The positioning of jet pumps relative to the primary zone of littoral sand movement.
- Spacing of the jet pumps.

- The density of the pumped slurry.

All of the above parameters (with the exception of slurry density) are "locked into" the configuration of the existing system. To change these elements would require substantial reconfiguration of the existing infrastructure. Because the hydraulics of all of the system components are interrelated, modification of one element will result in the modification of a number of other system elements. For example, operating five pumps instead of four will require a 25% increase in flow, which will require upgrading of the raw water pump, the booster pump, flume dilution pump and the overflow, the settling sump and the pipelines between all of these components.

The slurry density on the other hand is primarily dependent on the rate at which sediment enters the active jet pumps, which varies depending on the conditions at each pump at any point in time. Typically the density of the slurry in the transfer pipeline is below 1.3 t/m^3 and the system rarely achieves a design density of 1.46 t/m^3.

This reduction in typical slurry density has a significant impact on the quantity of sand transferred per hour and energy efficiency of the system. For example, a 18% reduction in average slurry density from 1.46 to 1.20 t/m^3 results in a 60% reduction in the amount of sand that is transferred per hour (from 1006 tph to 402 tph) and a 105% increase in power consumption per cubic metre of sand transferred (from 1.02 to 2.10 kWh/m^3).

Based on this information, the most effective means of increasing the performance and energy use efficiency of the system will be to increase the slurry density. Other solutions will all involve increasing the capacity of the existing system (eg: higher flow, more jet pumps etc) which will involve significant cost and disruption to modify the existing TSB system.

Sand Capture Modelling

To provide an improved understanding of how sand 'leaks' past the jetty under a range of environmental conditions and operational settings, a sand trapping analysis tool (SANDTRAP) was developed. SANDTRAP was developed on the basis of analysis of long-term pump log data from the facility's operator (TRESBCo), calculated longshore sediment transport rates and an empirical channel sedimentation prediction method by Van Rijn (1987). The performance of the tool was verified by comparing predictions of sand leakages past the offshore pathway by SANDTRAP against estimates from previous two-dimensional sediment transport modelling by Cardno (2009).

The results of the SANDTRAP modelling undertaken indicate that with increasing longshore transport rates the trapping efficiency of the STS reduces, as both a smaller proportion of the sand transport through the jetty is captured by the cones and an increasingly smaller proportion of the sand transport may flow through the jetty. No significant longshore transport is predicted to occur via the offshore sand transport pathway for total longshore transport rates up to approximately 3,000m^3 of sand per day. For longshore transport rates above 3,000m^3 of sand per day, an increasing proportion of the longshore transport occurs seaward of the jetty. During days with a longshore sediment transport rate of approximately 10,000m^3 per day, about 60% of the longshore transport 'leaks' past the jetty; about half of the leakage is predicted to occur via the offshore pathway and the other half through the jetty.

The SANDTRAP modelling undertaken indicates that, on an annual basis, sand leakages through the jetty (ie. sand flowing through the jetty but not being trapped by the sand trapping cones) form the dominant sand leakage pathway with about two thirds of the annual sand leakage predicted to occur via this pathway.The SANDTRAP model was used to assess the efficacy of several potential strategies for improving the sand capture performance of the JMPS

Energy Use Efficiency

Based on monthly electricity consumption data for the period January 2014 – April 2018, there is considerable variability in the electricity consumption from month to month, with lows of approximately 49,682 kWh (Feb 2014) and highs of approximately 292,237 kWh (Aug 2014). The average electricity consumption of the facility during this period was approximately 163,036 kWh per month. Most of the electricity consumption occurs at night.

Power consumption typically is about 60kW when no sand pumping occurs (base load), and about 1,000kW when sustained pumping occurs. Base load consumes approximately 25% of the total electricity used by the facility.

Sand is transferred by the STS with an average energy consumption of approximately 3.2kWh per m^3 of sand. Generally, a higher energy efficiency is achieved when sand transfers occur at a higher slurry density and thus typically a higher energy efficiency is achieved during periods when large sand volumes have accumulated in the trapping cones.

Several alternatives were considered to improve the efficiency of energy consumption by the TSB facility including:

- Off-peak operation
- Power Factor correction
- Variable speed drives
- Increase in slurry density
- Electricity Tariff

Of these options, only strategies to increase the slurry density are expected to have an appreciable impact on energy use per cubic metre of sand pumped.

Two of the options have already been implemented (variable speed drives, power factor correction).

Off-peak operation restrict the total volume of sand which can be transferred by the system, and will only reduce power cost, and not power efficiency. Changing the electricity tariff will also only reduce power cost and not alter power use efficiency.

Strategies to improve slurry density were incorporated in the options considered in the transfer system improvements evaluation.

Sand Transfer System Improvements

Six potential options to improve the efficiency of the STS were considered:

- **Option 1: Pump Capacity Increase** - eg Operate five pumps simultaneously instead of four.
- **Option 2: Pump Operation Improvement** – Modify pumping operation.
- **Option 3: Lower Jet Pumps** - Lower elevation of jet pumps to create wider cone with larger storage capacity, so will increase the trapping capacity, but may impact on structural capacity of piles)
- **Option 4: Pump spacing Reduction** - Minimise sand leakage through the jetty between the jet pump drawdown cones.
- **Option 5: Extend Jetty Seaward** - Extend the jetty further seaward and install additional jet pumps.
- **Option 6: Modify Seabed Fluidising System** – modify the seabed fluidising system to optimise suspension/turbulence to increase slurry density.

The effectiveness of each of these strategies in improving the efficiency of sand trapping was evaluated using the SANDTRAP model. Estimates of their capital cost were also prepared, and a multi-criteria assessment of their non-cost attributes was undertaken. These results of these assessments are presented in the table below:

Table: Summary of Sand Trapping and Transfer Efficiency Improvement Options Assessment

Option	Description	Predicted Sand Trapping Efficiency Change (Compared to existing operations)	Potential sand transfer efficiency gain	Indicative Capital Cost	Multi-Criteria Assessment Ranking	
				$m	Excl Cost	Incl Cost
Option 1	Increased Pump Capacity	negligible	Negligible	3.1	6	6
Option 2	Modified Pump Triggers	+3%	Negligible	0	2	2
Option 3	Lowering of Jet Pumps	+15%	Low	10.3	4	4
Option 4	Reduced Jet Pump Spacing	+4%	Negligible	10.0	5	5
Option 5	Extend Pumping Jetty	+8%	Low	8.9	3	3
Option 6	**Modify Seabed Fluidising System**	N/A	Significant	0.9	1	1

It is important to consider the cost and MCA ranking data scores in the context of the overall sand transfer efficiency gains these options might achieve. None of the options are expected to provide a substantial increase in sand transfer. The transfer efficiency improvements predicted for Options 1, 2 and 4 are well with within the margin of error for the method use to derive them. Effectively this means that little or no sand transfer efficiency improvements can be expected to be achieve if options 1, 2 or 4 are implemented. Option 5 (jetty extension) may achieve a minor improvement (or 8%) in sand transfer efficiency. Option 3 and Option 6 are the most likely to provide an appreciable improvement.

In this context, it is difficult to justify pursuing Options 1 or 4 given their cost. Modification of the trigger points in the control system (Option 2) is worth implementing because it involves negligible cost or modification of the existing system.

Extension of the jetty (Option 5) could be considered but would involve significant capital works and expense for relatively marginal potential benefit.

Lowering the jet pumps (Option 3) is more likely to be of benefit and its attractiveness is greatly improved if the existing jetty piling does not need to be lowered if it is implemented.

Modifying the seabed fluidising system (Option 6) has the potential to achieve large improvements in sand transfer efficiency and energy use savings at relatively low cost, and with minimal disruption to the TSB system operation.

Alternative Energy Sources

The TSB site is currently powered by mains AC power supplied to the site via an 11kV feeder main to a transformer at the raw water intake (low pressure) pump station and another at the TSB JMPS control building.

Several alternative sources of energy have been considered for implementation for the TSB operation, including:

- Solar energy (photovoltaic cells)
- Wave energy
- Tidal energy

- Wind energy
- Battery storage

All these options (except solar photovoltaic in conjunction with battery storage) will require significant feasibility study to determine for their suitability for use at the TSB facility. They will also probably face environmental and permitting issues. In most cases, they are either not yet proven technologies or have no fuel resource.

Therefore, only the solar photovoltaic option is considered to warrant further consideration for use for the Tweed Sand Bypass system.

Conclusions

The following conclusions have been determined in this study:

Sand Trapping/Transfer Efficiency

- Based on SANDTRAP modelling of the JMPS, the impact on sand trapping efficiency will be as follows:
  - Operating five jet pumps at once (instead of four) will have negligible impact.
  - Modifying the jet pump stop-start trigger points will provide a very minor improvement.
  - Reducing the spacing between jet pumps will provide a very minor improvement.
  - Extending the jetty seaward by 60m and adding two extra jet pumps will provide a minor improvement.
  - Lowering the jet pumps by one metre jet pumps will provide moderate improvement.
  - Altering the seabed fluidisation system may increase slurry density (and thereby improve energy use efficiency), but is expected to have only a marginal impact on sand trapping efficiency.
- The most significant observation to be made from this data is that the actual median density of the slurry being transferred by the TSB system is only about 1.25 t/m^3 (average 1.20 t/m^3) compared with a design density of 1.46 t/m^3.
- A 14% reduction in median slurry density from 1.46 to 1.20 t/m^3 results in a 60% reduction in sand transferred (from 1006 tph to 402 tph) and a 105% increase in power consumption per cubic metre of sand transferred (from 1.02 to 2.10 kWh/m^3).
- The most effective means of increasing the performance and energy use efficiency of the system will be to increase the slurry density. Other solutions will all involve increasing the capacity of the existing system (eg: higher flow, more jet pumps etc) which will involve significant cost and disruption to modify the existing TSB system.
- Based on the outcomes of a multi criteria assessment and cost estimates prepared for a number of options, the following options were concluded to be worth pursuing based on their likely effectiveness (in improving sand transfer efficiency), implementation cost, and potential lower power use:
  - Modifying the pump start-stop trigger points (negligible cost, and possible minor improvement)
  - Modification of the seabed fluidising system (low cost, and potential large improvement).

- Lowering of the jet pumps by one meter *(only if this does not result in the need to re-pile the jetty)* (low cost, and potential minor/moderate improvement).

Energy Efficiency Improvement Options

- Constraining operation of the TSB system to off-peak times could reduce the scheme's cost by 38%. Note however this would not achieve any reduction in energy consumption and would constrain (ie: probably reduce) the volume of sand transferred.
- Increasing the slurry density by 17% from 1.2 to 1.25 t/m^3 could improve power usage by 24% (in terms of volume of sand transferred per kWh of energy used).

Energy Source Options

- Solar energy (photovoltaic cells) in conjunction with battery storage is considered to be a viable alternative source of energy for the non-pumping TSB system power demand.
- Use of photovoltaics is not considered to be feasible for TSB system pumps power supply because the demand is very high and very large photovoltaic arrays would be required (which significantly exceed the area available on the existing TSB site).
- Mains power would need to be retained as a back-up power source if photovoltaic power supply is installed for the TSB system.
- Other alternative energy sources were evaluated (wave energy, wind energy, tidal energy and hydrogen fuel cells), however none of these are considered to be feasible for implementation for the TSB system due to a combination of scaling/size constraints, unproven commercial viability and inability to operate as a dispatchable/baseload power supply.

Recommendations

The following actions are recommended on the basis of the findings of this study:

1. Undertake testing of modifications to the seabed fluidising system at each jet pump (to increase slurry density) and implement on all jet pumps if demonstrated to be feasible.
2. Experiment with modifying the pump operations (start/stop trigger points, frequency of pump cycling etc) to determine an optimum operating regime for the system,
3. Undertake a detailed feasibility assessment of the potential for lowering the level of the jet pumps to determine the scope of works required (particularly whether the existing jetty piles would need to be deeper when the jet pumps are lowered).
4. Undertake detailed modelling of the offshore sand movement processes to more reliably determine the the potential sand transfer efficiency improvements this strategy might achieve.
5. Undertake a detailed feasibility assessment of the potential for providing photovoltaic power supply and battery units to reduce grid power us by the non-pumping components of the TSB facility.
6. Reprogram SCADA to extract individual jet pump data. This will enable assessment of the performance for each individual pump (compared with the current data which applies to the system as a whole).
7. Validate Sandtrap tool outputs against ADCP and SCADA data and the 3D sand transport model results (Recommendations 4 and 6 must be implemented first).
8. Monitor the shape of sand drawdown cones in conjunction with jet pump performance data (implement in conjunction with Recommendation 6).

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to evaluate the efficiency of and transfer and energy usage, and the potential to utilizing alternative energy sources for the Tweed Sand Bypassing system in accordance with the scope of services set out in the contract between Jacobs and the NSW Department of Industry (acting on behalf of TSB).

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Glossary

Term	Meaning
BTO	Build-Transfer-Operate
CA	Concession Agreement
DI	NSW Department of Industry
DES	Queensland Department of Environment and Science
EGL	Energy Grade Line
HGL	Hydraulic Grade Line
JMPS	Jetty Mounted Pumping System
O&M	Operations and Maintenance
STS	Sand Transfer System
TRESBP	Tweed River Entrance Sand Bypass Project (now TSB)
TRESBCo	Tweed River Entrance Sand Bypass Company
TSB	Tweed Sand Bypassing (formerly TRESBP)

1. Introduction

1.1 Background

The NSW Department of Industry (“DoI”) commissioned Jacobs on behalf of TSB to undertake this study on 23 April 2018. TSB is a partnership between NSW DoI and the Queensland Department of Environment and Science (“DES”).

Jacobs was engaged to undertake this study with the goal of exploring the opportunities for improving the sand transfer efficiency, sand trapping efficiency, energy use efficiency and opportunities to utilise alternative energy sources. Operation and maintenance of the sand bypassing system is detailed in a Concession Agreement (CA) made in 1999 between the Tweed River Entrance Sand Bypassing Company (TRESBCo) and the Governments. As the expiry of the CA in 2024 approaches preparations are being made for the transition to a new system of operation. This investigation will enable TSB to plan for beneficial changes to the system so that these can be implemented after it takes over direct operational control as part of the new system of operation.

This study focusses on the configuration and operation of the Jetty Mounted Pumping System (JMPS).

1.2 Objectives

The main objectives of this study were as follows:

- Identify sand trapping and transfer capacity constraints and determine opportunities for improvement within the existing JMPS.
- Determine ways to reduce energy cost, consumption and emissions associated with the JMPS.

1.3 Scope of Investigation

This report evaluates key technical issues relevant to the configuration and energy use efficiency of the Tweed Sand Bypassing system. The scope of assessment undertaken was as follows:

- Review of existing sand transfer and energy use data for the JMPS.
- Undertake an end-to-end assessment of the existing JMPS process.
- Identify and quantify restrictions and constraints within the transfer process.
- Investigate, define and assess options for modification and improvement of the existing sand transfer process.
- Assess the trend of recent energy use of the sand bypass system.
- Investigate the energy efficiency of the existing sand bypass system.
- Investigate and assess energy alternatives for the system.
- Prepare a report summarising the outcomes of the sand transfer investigation.

2. Existing Sand Bypassing System

2.1 Development History

The Tweed Sand Bypassing ("TSB") project (which was formerly known as the Tweed River Entrance Sand Bypassing Project – "TRESBP"). It was constructed under a BTO ("Build-Transfer-Operate") contract which expires in 2024.

The system is currently operated through a Public Private Partnership under a 25-year Concession Agreement (CA) between the New South Wales and Queensland governments and the Tweed River Sand Bypassing Company ("TRESBCo"), a subsidiary of McConnell Dowell Corporation Limited.

The overall configuration of the TSB system is virtually unchanged from that originally installed, however there have been several operational changes over time, including:

- Changes in the times at which the system is operated (in particular, it is now operated primarily during the night).
- Some outlets are infrequently used.
- Usually the most landward pump is not used.

2.2 Purpose

The system is designed to prevent accumulation of sand in the navigation channel in the Tweed River entrance.

It was installed because the prior construction of training walls in the Tweed River inlet had resulted in an accumulation of northward-moving sediment south of the river and across the river entrance, a situation which impeded the natural flow of sand onto the Queensland beaches, and resulted in much greater beach profile depletion than had previously been the case. The training walls also resulted in the formation of a much more substantial bar across the Tweed River mouth, and this both impeded the navigability of the river entrance and made entry to the estuary much more difficult.

The TSB therefore has the dual objective of maintaining navigability of the Tweed River entrance and, achieving and maintaining a continuing supply of sand to the southern Gold Coast beaches at a rate that is consistent with the natural littoral drift. The project aims to meet these objectives in perpetuity by pumping of sand slurry via a jetty mounted pumping system (JMPS) at Letitia Beach and dredging of the Tweed River entrance using floating dredging equipment.

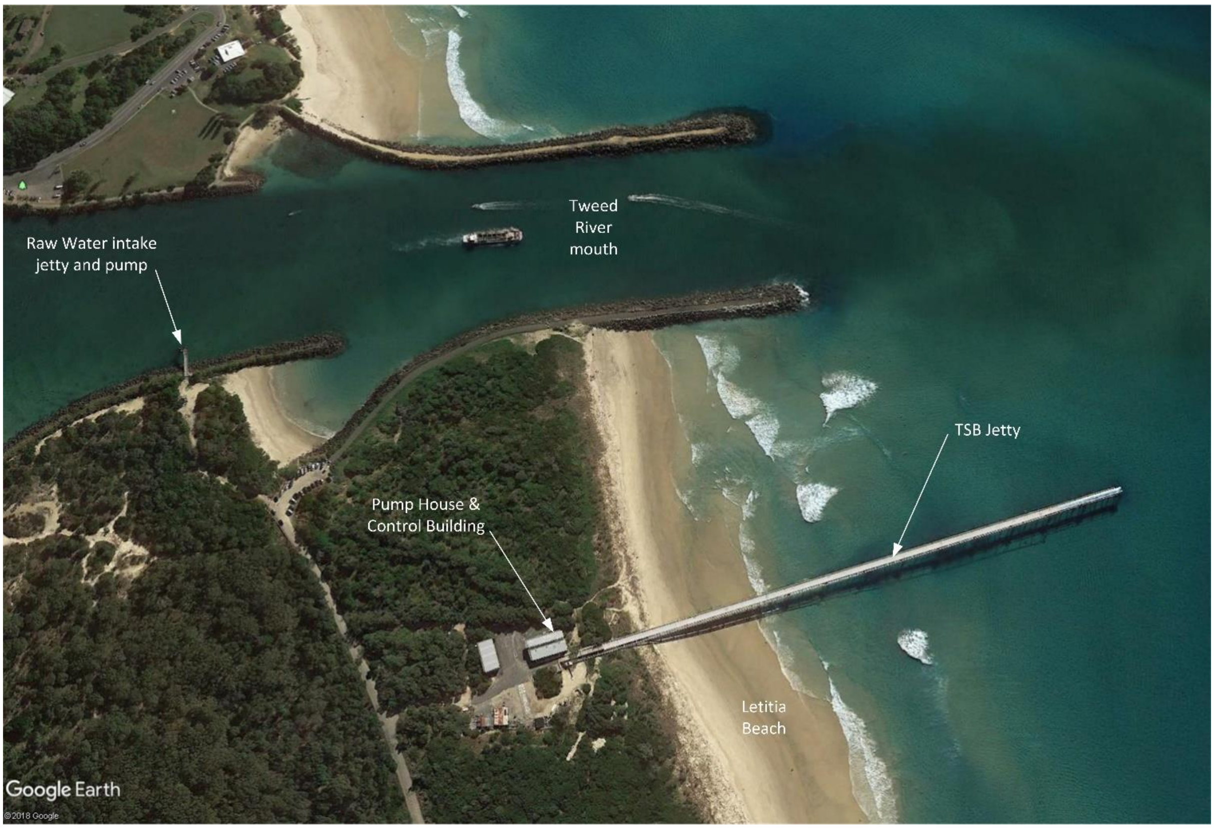
2.3 Functional Overview

TSB extracts littoral sand using a jetty mounted pumping system (JMPS) from the seabed off Letitia Spit and pumps it to one of the discharge locations at Kirra Point, Greenmount Beach, West Snapper Rocks, East Snapper Rocks or Duranbah Beach to the north of the Tweed River.

The principle components of the TSB system are a jetty mounted pumping system (JMPS) located on Letitia Spit 250m south of the Tweed River training wall (Refer to **Figure 1** and **Figure 2**), and a network of pipelines transferring sand as a slurry to the beaches immediately north of the Tweed River (Refer to Figure 4).

Figure 1 TSB Locality Plan

Figure 2 TSB Site Plan



2.4 System Configuration

The system operates by mobilising the seabed under the JMPS and drawing it as a slurry into a flume which discharges into a slurry tank from where it is pumped to the discharge point on the Queensland beaches.

The configuration of the Tweed Sand Bypassing system is presented in **Figure 3** and the overall layout of the major system pipelines is depicted in **Figure 4**. Most of the core components of the TSB system are located at the jetty and control building site on Letitia Spit; a general layout for this site is provided in **Figure 5**.

The major operational components of the TSB system are:

- Tweed River seaway training wall
- Raw water intake pump station (located on the Tweed River inlet)
- High pressure booster pump
- Flume dilution pump
- Jetty-mounted jet pumps
- Transfer sump/tank
- Sand transfer pumps
- Discharge pipeline to various discharge locations to the north of the Tweed River entrance..

Figure 3 Existing TSB System Configuration (TSB design drawings)

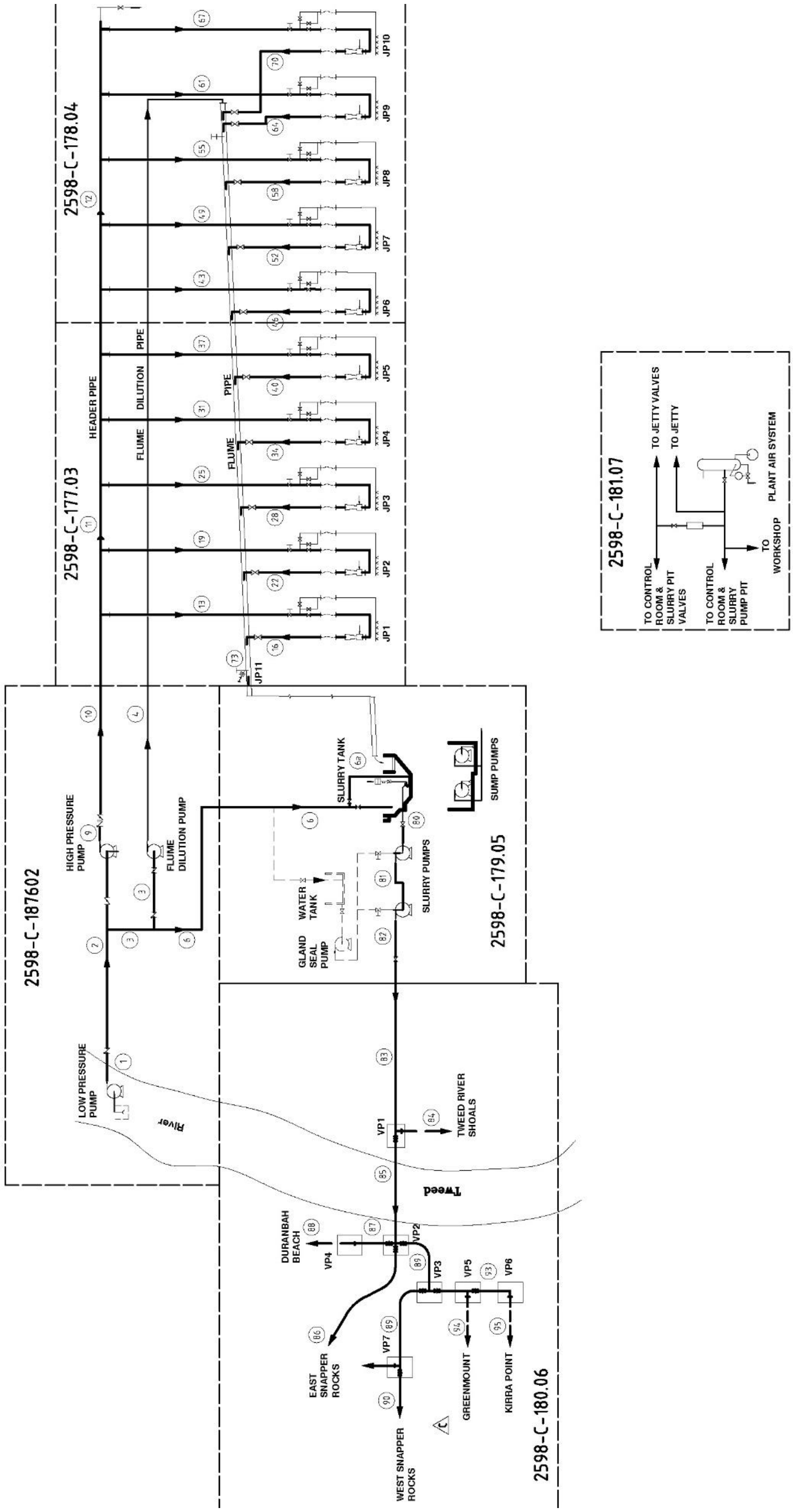
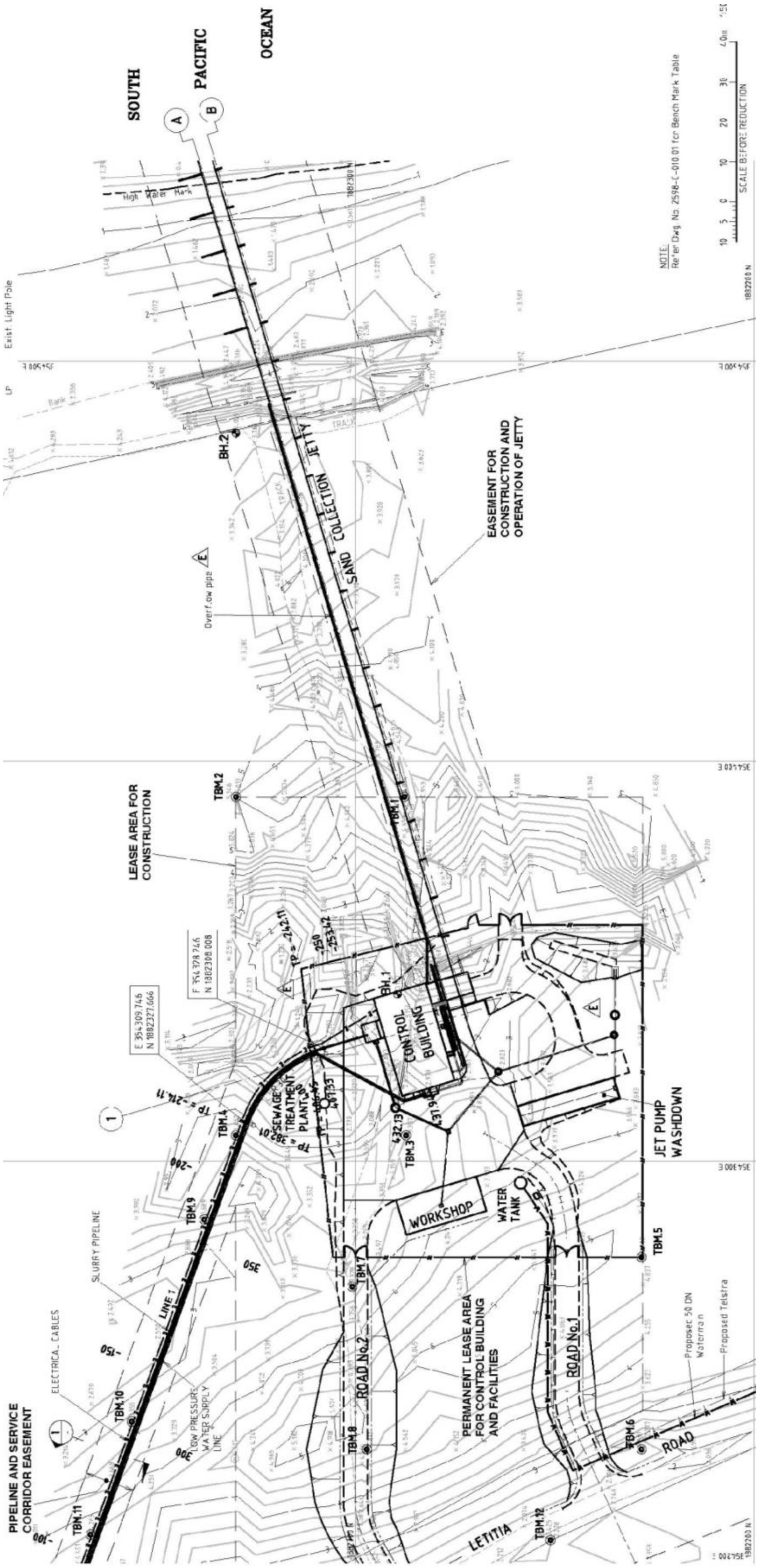


Figure 4 TSB System Layout

Figure 5 TSB Jetty and Control Building Site (TSB design drawings)



2.5 System Components

2.5.1 Pipelines

There are a number of pipeline components in the system; these are summarised in **Table 1**. In general, the raw water pipelines are mild steel cement lined (MSCL) or medium density polyethylene (MDPE) pipe, and the slurry pipelines are either polyurethane lined mild steel (PULS) pipe (at the upstream ends) or medium density polyethylene (MDPE) pipe (at the lower pressure downstream ends).

Table 1 Transfer System Pipelines

Item	Start	End	Material	Nominal Diameter	Length
				(mm)	(m)
Raw Water Pipelines					
Raw Water Supply Pipeline	Tweed River raw water pumping jetty	High pressure pump	MSCL MDPE	450 560	36 409
	High Pressure Pump offtake	Flume dilution pump	MSCL	350	19
	Flume Pump offtake	Slurry Tank	MDPE	300	21
Header Pipe	High Pressure Pump	JMPS Flume (d/s of JP2) JMPS Flume (d/s of JP6) JMPS Flume (d/s of JP10)	MSCL MSCL MSCL	600 500 400	205 120 120
Flume Dilution Pipe	Flume Dilution Pump	Header Pipe	MSCL	250	453
Jet Pump Suction	Header pipe offtake	Jet pump suction	DICL	200	14 (JP11) 24 (JP1 – JP 6) 27 (JP7 – JP 10)
Slurry Pipelines					
Jet Pump Discharge	Jet Pump	Flume connection	PULS	250	13 (JP11) 23 (JP1 – JP 6) 26 (JP7 – JP 10)
Flume	Jet Pump 10 discharge connection	Slurry Tank	PULS	600	440
Sand Transfer Pump Suction	Slurry Tank	Sand Transfer Pumps	PULS	450	~10
Sand Transfer Pipelines[1]	Slurry Transfer Pumps	Duranbah Beach	PULS MDPE	400 450	655 540
		East Snapper Rocks	PULS	400	1160
		West Snapper Rocks	PULS MDPE	400 450	1945 75
		Greenmount	PULS MDPE	400 450	1240 500
		Kirra Point	PULS MDPE	400 450	1240 1425

Notes:

1) The lengths of the sand transfer pipelines are the total length of pipeline from the sand transfer pumps to the discharge point.

2.5.2 Pumps

There are four pumps in the TSB system. Details of these pumps are presented in **Table 2**.

Table 2 Existing Pumps

Item	Configuration	Nominal Duty Point	Power Rating	Make & Model	Notes
		Flow x Head	(kW)		
Raw Water Intake Pumps	1 duty pump	655 L/s @ 14.4mH	130	Forrers FK350-500	Jetty mounted case submersible centrifugal pump.
Raw Water Booster	1 duty pump	540 L/s @ 124mH	789	Weir Uniglide SDK 400/600B	Dry-mounted inline split case centrifugal pump.
Flume Dilution Pump	1 duty pump	111 L/s @ 13mH	19.5	KSB Ajax IS 200-200	Dry-mounted end suction centrifugal pump.
Sand Transfer Pumps	2 pumps in duty/standby	395 L/s @6 2.5mH	477	KSB AJAX LCC-VHP 250-660A	Dry-mounted inline split case centrifugal pump.

The function of these pumps are as follows:

- **Raw Water Intake Pump:** Draws water from the Tweed River and delivers it to the high pressure Raw Water Booster Pump at the TSB Letitia Beach pump station.
- **Raw Water Booster Pump:** Increases the pressure in the header pipe supplying the jet pumps on the JMPS to operating levels.
- **Flume Dilution Pump:** Supplies water to the slurry flume to ensure the sand slurry stays in suspension, and (if necessary) aiding in re-starting flume flow after a shutdown.
- **Sand Transfer Pumps:** Transfers sand slurry from the TSB pump station to the discharge locations on the Queensland beaches north of the Tweed River entrance.

The raw water intake pump (refer **Figure 6**), Booster Pump (refer **Figure 7**) and Flume Dilution Pump (refer **Figure 7**) are all installed as single duty pumps. A spare booster pump is kept on site and can be manually swapped for the installed pump when required.

Figure 6 Raw Water Intake Pump Configuration (TSB design drawings)

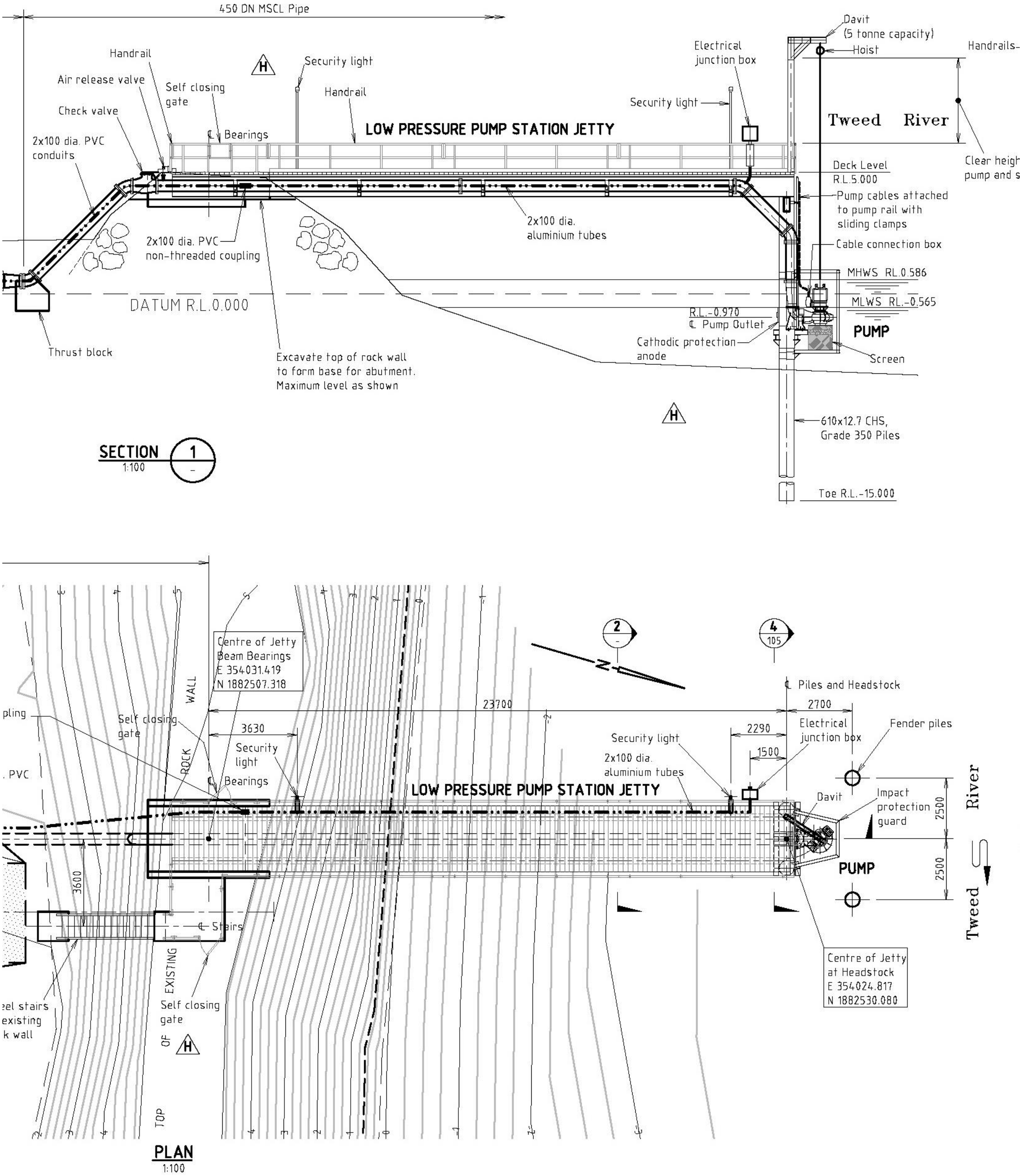
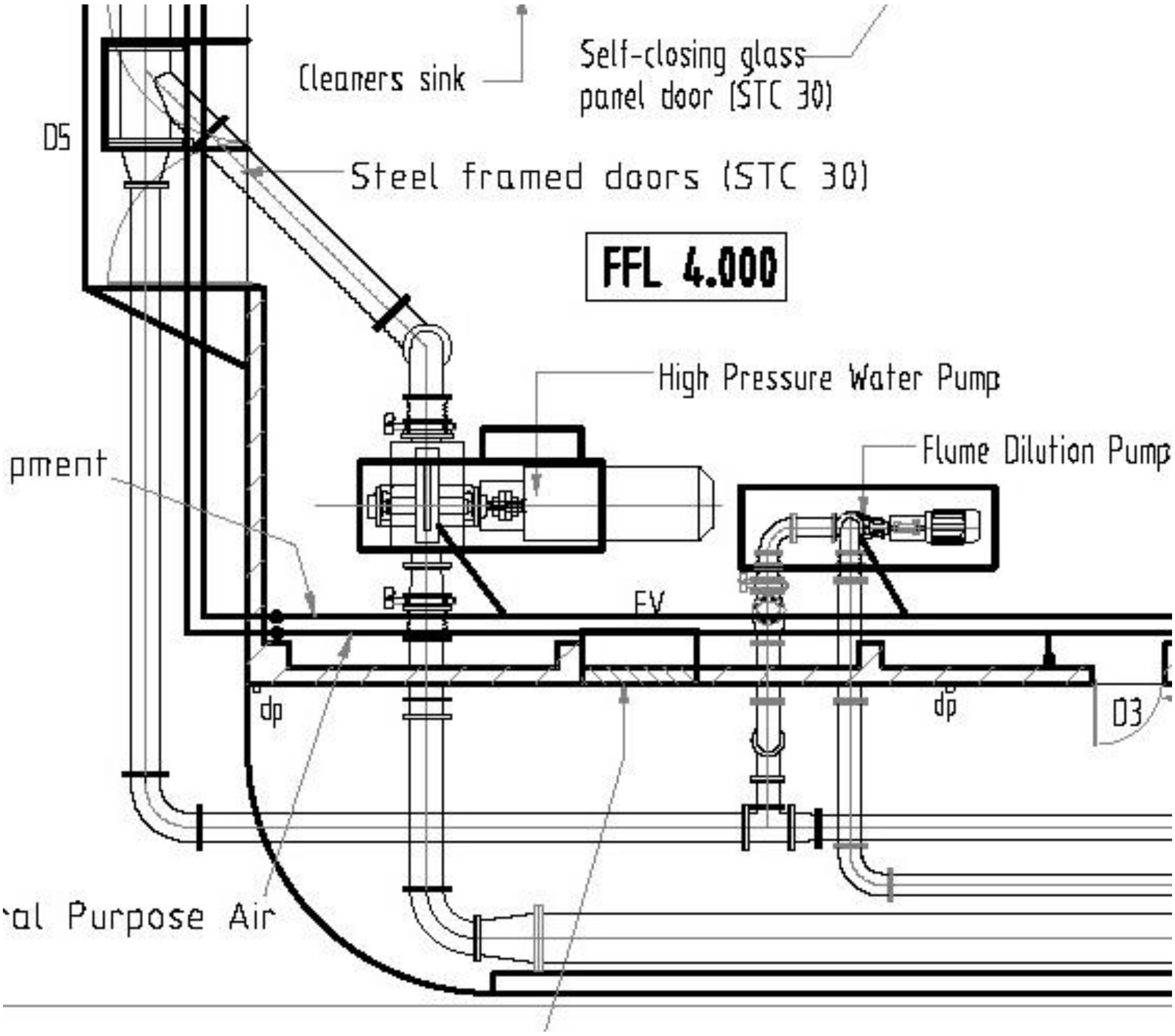
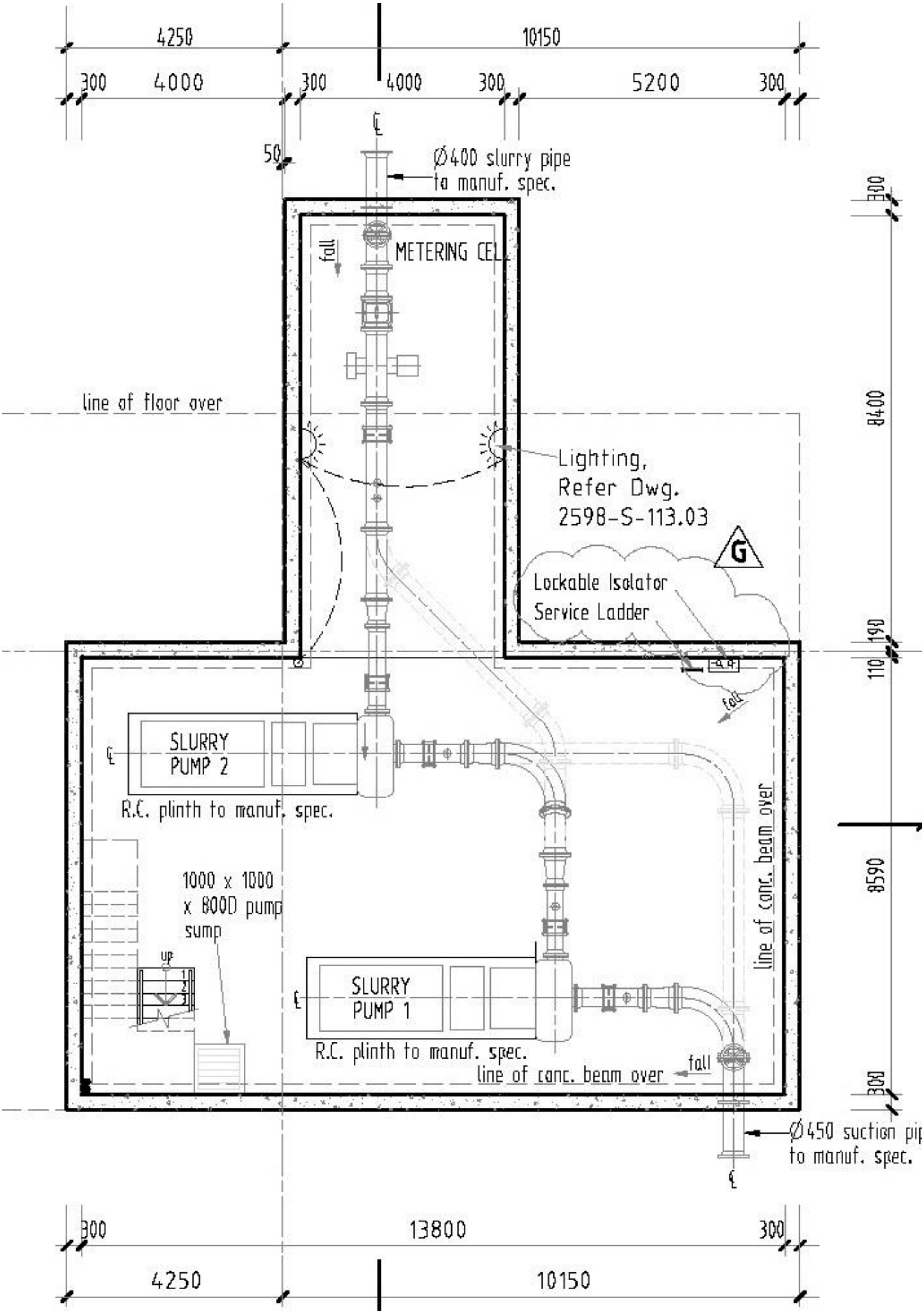


Figure 7 Booster (High Pressure) Pump and Flume Pump Configuration (TSB design drawings)



The two sand transfer pumps can be operated in either a duty/standby or series modes by manually re-configuring the pump suction pipework. These pumps are shown configured in series mode in **Figure 8**, but the usual operational arrangement is for only one pump to be connected at any time. The alternate pipework configurations are also visible in grey lines in **Figure 8.**

Figure 8 Sand Transfer (Slurry) Pumps Configuration (TSB design drawings)



2.5.3 Jet Pumps

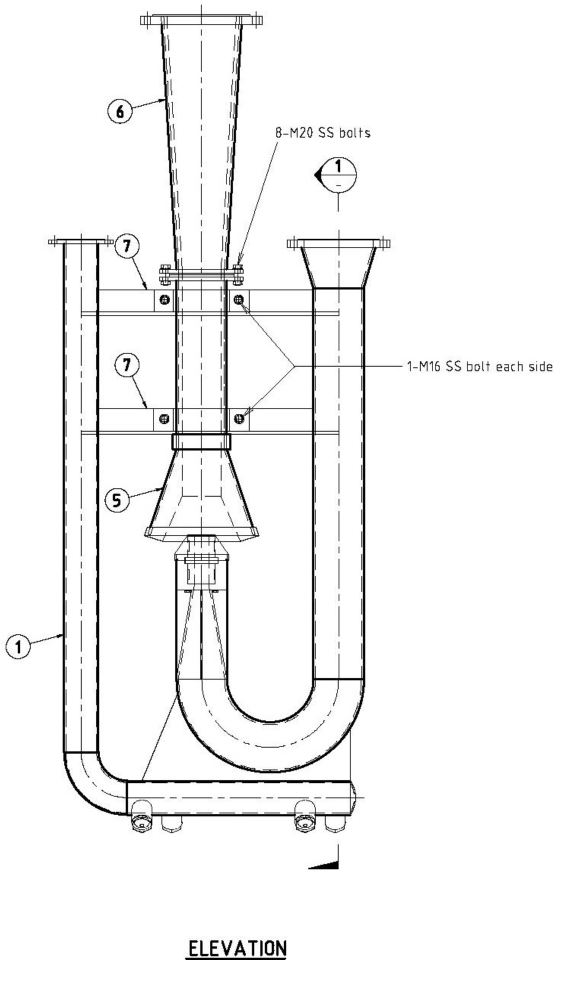
Ten jet pumps are installed on the TSB jetty. The configuration of these pumps is presented in **Figure 9**.

The pumps operate on the principle of a venturi jet. The jet pump pipework is installed below the normal seabed level. It is “turned on” by delivering water from the high pressure pumps to the nozzle which delivers a high-velocity water jet into the bell aperture of a venture, which creates a suction that draws surrounding fluid into the jet pump. Side-stream pipework simultaneously injects several high velocity jets into the surrounding seabed, mobilising the seabed sediment into a slurry which is drawn into the jet pump.

The TSB jet pumps are nominated JP1 (at the landward/western end of the jetty approximately 165m from the pump station) through to JP10. There is provision for an eleventh jet pump (JP11) on the landward side of JP1, but it has not been installed.

Operation of JP1 has been found to cause severe depletion of Letitia Beach around the jetty, so it has not been in operation except for a brief period when the TSB system was first commissioned in 2001. Because of this experience, and because the position of JP11 will cause even greater beach depletion than JP1 (because it located closer to the shore), JP11 is highly unlikely to ever be used.

Figure 9 TSB Jet Pump Configuration (TSB design drawings)



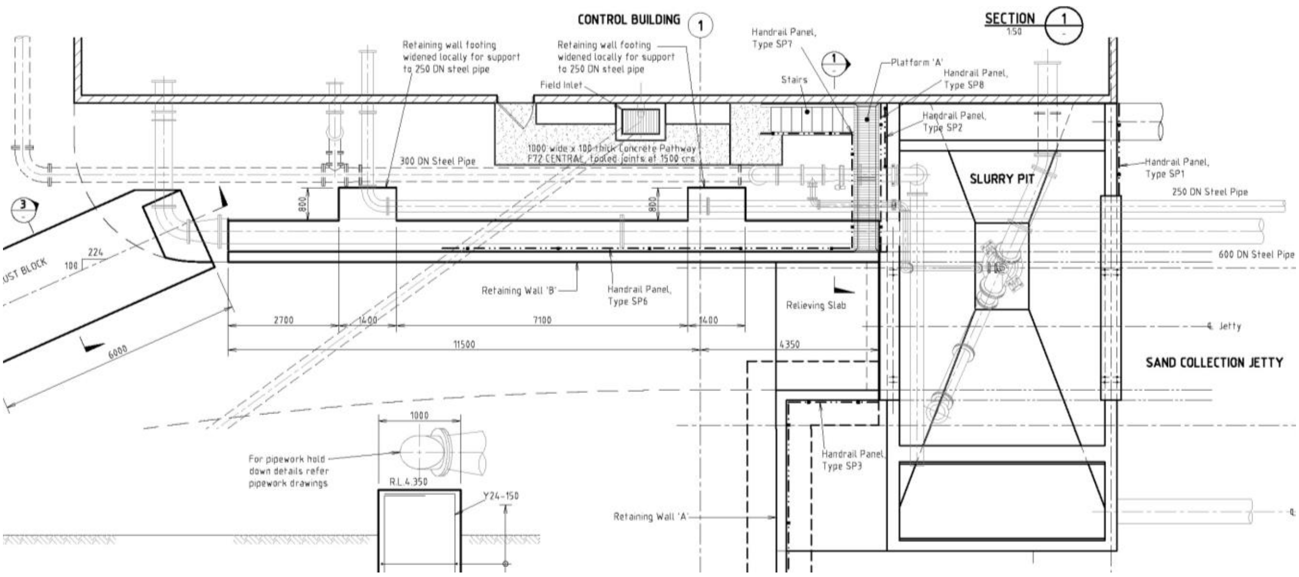
2.5.4 Slurry Pit

The slurry tank (presented in **Figure 10**) provides operating buffer storage between the slurry flume and the sand transfer (slurry) pumps. The tank has a capacity of approximately 110 m^3 (ie: about 3 minutes of capacity at the design flowrate of 600 L/s).

Slurry is maintained in suspension in the pit by a combination of a raw water flow injection from the raw water intake pipeline and the turbulence generated by the slurry pump suction from the pit and the slurry flume discharge into the pit.

Overfilling is prevented by the provision of a high level overflow weir discharging via a DN600 pipe to Letitia Beach.

Figure 10 Slurry Pit Configuration (TSB design drawings)



2.5.5 Electrical and Control System

Mains power is supplied to the raw water pump station site and the TSB transfer JMPS site via 11kV power lines. Power is converted to operating voltage at transformer substations at both of the sites.

The pumps are powered via variable speed drives; these are used to regulate start-up power draw and not to control the pump speed.

The operator can select which jet pumps are operated at any given time; the operating sequence (which pumps operate and for how long) can be programmed into the control system for automatic operation, or manually turned on and off.

Blockages in the system (which at times can occur frequently) cause a loss of discharge pressure which can be detected, enabling the operator to take action to either clear the pump or take it offline and switch operation to another pump.

2.5.6 Structures

The jetty is the most visible component of the TSB system. It extends approximately 440m from the TSB control building into the Pacific Ocean. The header pipeline, slurry flume, dilution assist pipeline and the flume pumps (all of which constitute the jetty mounted pumping system) are all attached to the jetty.

There are two primary buildings on the JMPS site: the JMPS control building and a workshop. The control building houses all of the pumps, power and controls systems for the JMPS system and the operator control room and amenities. The workshop and an adjacent laydown yard provides on-site maintenance facilities and spare parts storage for the system.

A small building at the raw water intake pump station site houses the power supply system and an (unmanned) controlroom/switchroom. The raw water intake pump is mounted on a jetty which extends 20m into the Tweed River estuary.

There are seven buried valve pits in the pipeline network.

2.6 System Operation

The sand bypassing system comprises of a sand collection jetty with an overall length of 450m constructed perpendicular to Letitia Spit beach. A sand trap has been developed under the jetty by the operation of a series of submerged jet pumps, which aim to maintain a permanent depression of the seabed that can trap sand that moves along the shoreline by natural coastal processes. **Figure 11** presents a diagram of how sand is collected at the jetty.

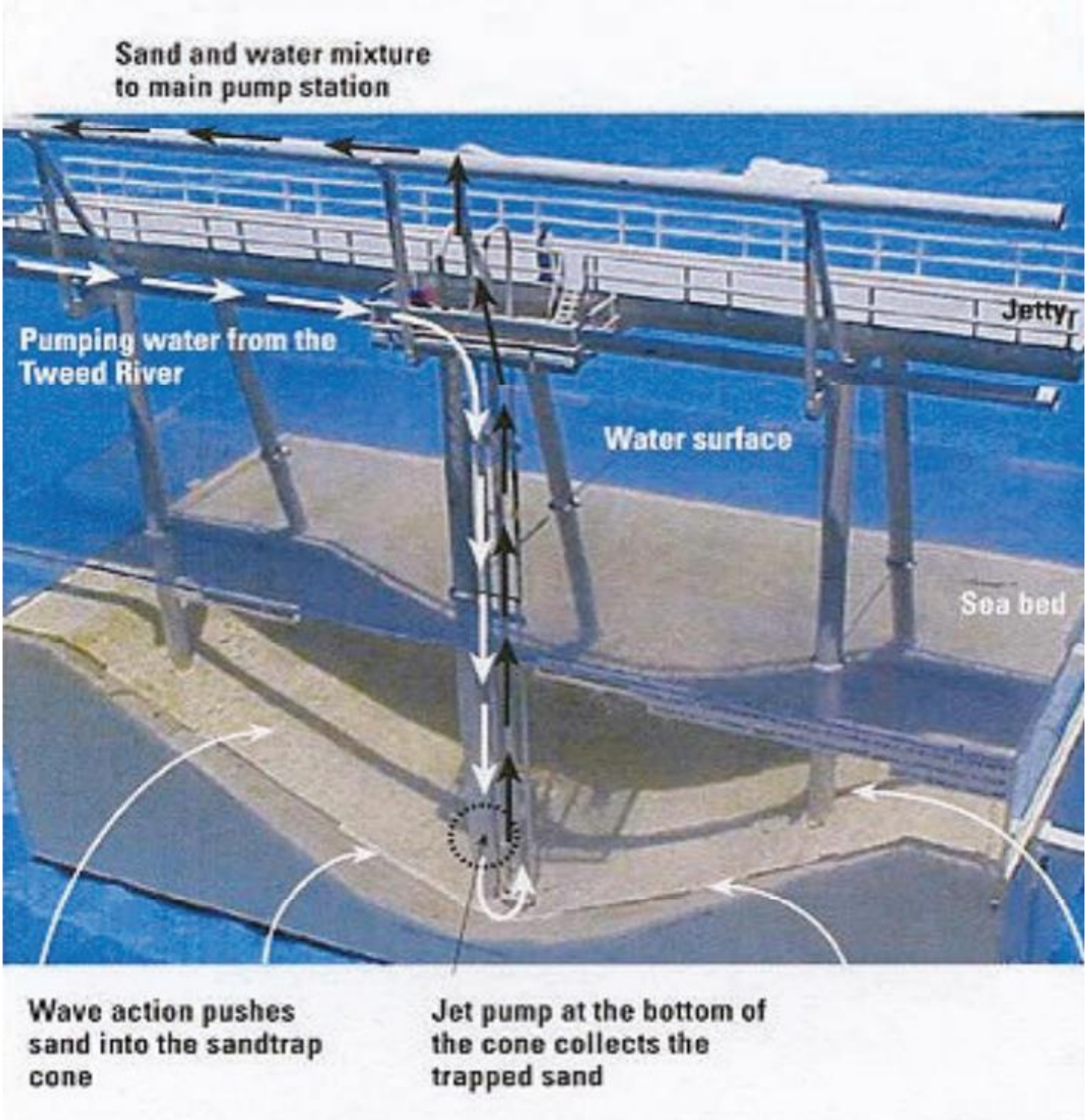


Figure 11 Sand collection by the jetty's jet pumps (Courtesy of McConnell Dowell Constructors).

There is a total of 10 jet pumps installed at 30m spacing along the most seaward 270m of the jetty. The elevation of the pump inlets ranges from -12mAHD for the four landward most pumps ('JP1' to 'JP4') to -15mADH for the four seaward most pumps ('JP7' to 'JP10'). The most landward jet pump ('JP1') is generally not used.

The jet pumps are powered by water that is sourced at the raw water intake in the Tweed River (refer **Figure 1** for location). When the sand transfer system is operational, approximately 600 litres per seconds is supplied to the four active jet pumps. The system cycles through the 9 used jet pumps "looking" for sand. This cycling is controlled by a monitoring and control system which monitors the density of the sand slurry extracted at each jet pump location and determines which jet pumps should be activated. Generally, four jet pumps operate at one time.

If the density drops below a pre-defined threshold for a sustained period of time, the system back-flushes the pipelines to dislodge potential debris. If back-flushing has been performed twice and the threshold density from the jet pump is still not achieved, it is assumed that the cone is empty and the next programmed jet pump will be initiated.

Each jet pump features a series of fluidising jets which fluidise the sand under the jet pump nozzle. The fluidised sand is drawn into the jet pumps by under pressure generated by the high flow velocities in the pump nozzle (Venturi effect).

As more sand enters the Sand Transfer System (STS), sand from further away is driven to the jet pump by local geotechnical instabilities, creating a cone-shaped hollow in the seabed. Typically, these cones have a height of about 4-5m height and a diameter of 20 to 25m at the seabed surface when fully established (Cardno, 2009).

The design sand transfer capacity of the STS is about 14,800m^3 per day of insitu sand (Cardno, 2009), but in practice this capacity cannot be achieved because it is difficult to maintain the density of the slurry in the main pipeline due in part to temporal fluctuations in the sand supply at the active jet pumps, as well as the time taken to switch between the jet pumps. In practice, the capacity of the system is about 10,000 m^3 per day (See also **Section 3.3**).

2.7 Previous Studies

Several previous studies have investigated aspects of the TSB. Key outcomes of these studies are summarised below.

Tweed River Entrance Sand Bypassing Project. Jetty Efficiency Study – Supplement No. 3 – February 2004 to July 2005 (KBR, 2006)

This report documents a study prepared by KBR on behalf of McConnell Dowell to investigate the trapping efficiency of the STS up to July 2005 and estimate future shoreline changes around the jetty. It estimates that the trapping efficiency of the jetty during the period February 2004 – July 2005 was approximately 51% of the net longshore transport.

The report provides a number of options to improve the efficiency of the STS. Improvement options include lengthening of the southern training wall, installation of an offshore breakwater near the end of the jetty, constructing a groyne immediately north of the jetty and creating a larger sand trap.

Tweed River Entrance Sand Bypassing Project. Five-Year Review Report (KBR, 2007).

This report outlines a study that was undertaken by KBR on behalf of McConnell Dowell to examine possible improvements to the JMPS.

Recommendations for the improvement the trapping efficiency of the jetty contained in the report include lowering of the jet pumps, reducing the spacing between the jet pumps and increasing the pumping capacity to allow extra pumps to be run during storm events.

Review of Sand Bypassing Efficiency Tweed River Entrance (Water Technology, 2007)

This report outlines a study that was undertaken by Water Technology on behalf of McConnell Dowell to examine possible improvements to the JMPS.

Recommendations for the improvement the trapping efficiency of the jetty contained in the report include modification of the pumping strategy to allow several starts during a working cycle, constructing a groyne immediately north of the jetty or extension of the southern Tweed River training wall to reduce transport capacity at the jetty and trap more sand, harvest sand from sand shoal between the jetty and river entrance using mechanical equipment or small scale sand bypass equipment and increasing the volume of sand transported by the STS via backpassing to locally re-align the beach to the north and south and allow more sand to be driven towards the jetty.

Tweed River Entrance Sand Bypassing System Review of Operations Coastal Processes Modelling. (Cardno Lawson Treloar, 2009)

This report describes a number of investigations that were undertaken by Cardno to the coastal processes that affect the operation of the sand trapping jetty, including 1D and 2D sediment transport modelling and shoreline evolution modelling.

The report estimates that the net longshore sand transport rate at a location approximately 1,500m south of the southern training wall was about 530,000m3/yr during the three financial years up to July 2008. It estimates, based on 2D sediment transport modelling that during days with a longshore sand transport rate of 3,900 m3/day, approximately 612m^3 would be transported offshore of the jetty and approximately 3,300m^3 during a day with a longshore transport rate of 10,410m^3/day.

Reassessment of Long Term Average Annual Net Sand Transport Rate (BMT WBM, 2011).

This report describes a study undertaken by BMT WBM to re-assess the long term average sand transport rate at Letitia Spit. It includes estimates of transport rates based on sediment transport modelling and analysis of bathymetric survey data. The report estimates that the long term average sand transport rate into Letitia Spit at Fingal isabout 550,000m3/yr. The calculated rate of transport at a location 1,000m south of the southern training wall for the period 2001-2009 was approximately 752, 000m3/yr.

Tweed River Entrance Sand Bypassing System – Review of Operations (Little, K, 2013).

This report by K. Little Engineering provides a review of the TSB sand transfer system, including the pumps. It suggests that reducing the flow rate through the main pipeline could be an effective means of saving power use. The report contains an assessment of alternative energy sources. It concludes that there are no viable alternatives to powering the system than receiving main power.

Reassessment of Long Term Average Annual Net Sand Transport Rate 2015 (BMT WBM, 2016).

This report describes an update of the 2011 report by BMT WBM to incorporate data up to 2015. The updated assessment revised the long term average sand transport rate into Letitia Spit at Fingal to about 574,000m3/yr. The calculated rate of transport at a location 1,000m south of the southern training wall for the period 2009-2015 was approximately 646, 000m3/yr.

Tweed Quantified Conceptual Sediment Transport Model (Jacobs, 2017)

This report by Jacobs provides a synthesis of the understanding of coastal processes that affect the coastal zone between Fingal Heads and Currumbin as of 2017 and presents a series of conceptual models of the sediment transport mechanisms and pathways through this area.

2.8 Transfer System Capacity

2.8.1 Existing System Hydraulic Capacity

The hydraulic capacity of the main TSB system components is summarised in **Table 3**.

The sand transfer capacity is a function of the slurry density, which varies depending on the pumping conditions at each pump at any point in time. For the purpose of this analysis, it has been assumed that the slurry density is 1.2 t/m^3. This is approximately the median density of the historical transfer records for the system.

Table 3 Existing System Capacity

Item	Destination	Hydraulic capacity	Material Pumped	Average Fluid Density	Sand Transfer Capacity
		(L/s @ mH)		(t/m3)	(t/hr)
Raw Water Intake	JMPS Flume	655 @ 15mH	Seawater	1.03	-
Raw Water Booster	JMPS Flume	540L/s @ 124mH (135 L/s per jet pump for both jet pumping and seabed fluidisation)	Seawater	1.03	-
Flume Dilution Pump	JMPS Flume	115 @ 13mH	Seawater	1.03	-
Sand Transfer Pumps	Duranbah Beach East Snapper Rocks West Snapper Rocks Greenmount Kirra Point	395 @ 63mH	Sand slurry	1.20[2]	395

Notes:

1) The raw water booster pump supplies up to 135 L/s per jet pump assuming that four jet pumps are operating simultaneously.
2) Typical actual slurry density achieved by the system is in the range of 1.17-1.3 t/m3, compared with the design density of 1.46 t/m3. This results in much lower sand transfer capacity.

Pipeline hydraulic calculations have been prepared to confirm the theoretical hydraulic performance of the system. These calculations assessed as-built pipeline design details for all of the major pipelines in the system, including the raw water pipeline from the Tweed river pump station to the booster pump, the raw water feed to the jet pump offtakes, the jet pump feed and discharge pipework the slurry flume and flume dilution pipes, and the slurry transfer pipeline from the JMPS to the northern beaches. The Hazen-Williams formula was used to determine the pipeline flow characteristics with the pipe friction factor being calculated using the Churchill method. Slurry flow characteristics we calculated using the Durand method.

Important observations from this analysis were:

- The theoretical performance of the JMPS system is consistent with the actual recorded performance – ie: at a slurry density of 1.20 t/m3 and flowrate of 395 L/s, the system will theoretically transfer 395 t/hr (approx. 3600 m^3/d) of sand.
- Because there is no slurry density data for the jet pumps, it is not possible to determine whether there is a difference in slurry density between the flume feed from the jet pumps and the transfer flow from the slurry pumps. Such a differential would imply that sand is being “lost” from the system, presumably through the overflow pipe from the still sump. However given that large volumes of sand are not accumulating at the sump overflow outlet, it is most likely the densities of the dredged flow and the slurry delivery pumps is small.
- The theoretical pipe hydraulic analysis indicates that about 60% of the flow (82L/s) into each jet pump assembly is direct through the jet pump, and about 40% (50L/s) is directed through the seabed fluidiser nozzles. Given the relative feed pipe diameters to the jet pump (DN200) and fluidiser nozzles (DN100) and all other factors being equal, an 80%/20% flow split would be expected. It is possible, that the higher flow through the fluidiser nozzles may be mobilising the seabed too aggressively, and this could be reducing the slurry density. Providing additional ability to control flow rate though the fluidisation nozzles may enable better control of seabed mobilisation and result in increased slurry density.

- Flow velocity in the water pipelines are much higher than usual for water pipeline (ie: they are in the range of 2-3m/s compared with a typical maximum of about 1.5 m/s. These higher velocities are within the usual maximum allowable pipe velocity, but it does increased headloss. However, because the pipeline lengths are relatively short, the culmulative total headloss is relatively low and within the capacity of standard pumps. The most significant implication lf the high velocity is that there is very limited ability to increase flow rate through the system by simply replacing the pumps with large units.
- The velocity of flow in the flume and the transfer pipelines (between the JMPS and the Queensland beaches) is lower than the minimum velocity required to prevent solids settling (calculated using the Durand method). This could be causing “pulsing” of the solids transport rate which may impact sand transfer performance.

It is important to note that these calculations are theoretical. To confirm these observations it will be necessary to undertake testing of the system and/or testing a physical model.

2.8.2 Factors Affecting Transfer Capacity

The sand transfer capacity of the system is determined by several factors, including:

- The hydraulic capacity of the raw water (low pressure) and booster (high pressure) pumps.
- Hydraulic capacity of the sand transfer pumps.
- The size of the system pipework/pipelines.
- Wear on system components over time, particularly the jet pumps and the sand transfer pump impellers and volutes.
- The number of jet pumps which can be operated simultaneously.
- Susceptibility of the system to blockages (which cause shutdowns and reduce operating time).
- Depth of the jet pumps below the seabed. This changes the size of the drawdown cones, and impacts on the ability of the cones to trap sand.
- The positioning of jet pumps relative to the primary zone of littoral sand movement.
- Spacing of the jet pumps.
- The density of the pumped slurry.

All of the above parameters (with the exception of slurry density) are “locked into” the configuration of the system. To change these elements would require substantial reconfiguration of the existing infrastructure. Because the hydraulics of all of the system components are interrelated, modification of one element will result in the modification of a number of other system elements. For example, operating five pumps instead of four will require a 25% increase in flow, which will require upgrading of the raw water pump, the booster pump, flume dilution pump, the settling sump and the overflow discharge pipe.

2.8.3 Impact of Slurry Density on Transfer Capacity

The most significant observation to be made from this data is that the actual typical density of the slurry being transferred by the TSB system is only about 1.20 t/m^3 compared with a design density of 1.46 t/m^3 (See **Section 3.3** for further details on achieved slurry densities)

The impact of this reduction in density on the quantity of sand transferred per hour and power consumption for the scenario of pumping from the JMPS to Duranbah is set out in **Table 4**. An 18% reduction in average slurry density from 1.46 to 1.20 t/m^3 results in a 60% reduction in sand transferred (from 1001 tph to 400 tph) and a 106% increase in power consumption per cubic metre of sand transferred (from 1.02 to 2.10 kWh/m^3).

Based on this information, the most effective means of increasing the performance and energy use efficiency of the system will be to increase the slurry density. Other solutions will all involve increasing the capacity of the existing system (eg: higher flow, more jet pumps etc) which will involve significant cost and disruption to modify the existing TSB system.

Options for increasing the sand transfer capacity of the existing system are explored in more detail in **Section 5**.

Table 4 Design vs Actual Density (for the scenario of pumping from the JMPS to Duranbah)

Scenario	Fluid						Sand transfer		Pump Power[2]	Pump Power per tonne transfer
	SG	L/s	kL/hr	t/hr	% water by vol	% sand by vol	m^3/hr	tph	kW	kWh/m3
Design	1.46	395	1422	2076	0.74	0.26	375	1001	382	1.02
Actual[1]	1.2	395	1422	1706	0.89	0.11	150	400	314	2.10

Notes:

1) "Actual" data derived from a nominal "actual" slurry density of 1.20 t/m^3. Recorded slurry density downstream of the slurry pumps is in the range 1.17-1.3 t/m^3.
2) Pump power determined using a pumping head of 63m and a pump efficiency of 84% (as per the McConnell Dowell pump data sheet for the installed slurry pumps). Assumes pumping with a single slurry pump.

3. Sand Capture Efficiency Evaluation

3.1 Overview

The sand bypassing system comprises of a sand collection jetty with an overall length of 450m constructed perpendicular to Letitia Spit beach. A sand trap by means of a series of cylindrical cones has been developed under the jetty by the operation of a series of submerged jet pumps.

The sand trapping efficiency of the STS is dependent on a number of factors, but fundamentally is a function of the system ability to trap sand that is transported along the shore by natural coastal processes. The trapping efficiency varies depending on the prevailing wave conditions, the bathymetry around the jetty and the effective length, width and height of the sand trapping cones, including the ability to maintain the cone dimensions over time. Ideally, the STS would have the capacity to capture all the net longshore transport, however in recent years approximately 70% of the estimated net annual longshore sand transport has been transferred by the STS (BMT WBM, 2017).

To provide an improved understanding of the circumstances that lead to ‘leakage’ of sand through the jetty, a sand trapping efficiency analysis was undertaken whereby sand pumping logs from the operator’s SCADA, were compared against modelled longshore sand transport rates.

3.2 Sand transport processes

3.2.1 Natural Sand Transport Process

The natural coastal processes influencing the supply and movement of sand through the STIS Project Area are complex. The coastline is exposed to a moderate to high wave climate with significant seasonal variability. Consequently, the coastal zone across the STIS Project Area is highly dynamic. The mechanisms of sand bypassing around the jetty and Tweed River entrance are extremely complex due to the intricate interaction of numerous oceanic and estuarine processes that are of significance, and the influences of sand pumping and dredging.

Figure 12 presents a conceptual model of the key sediment transport processes around the jetty(based on the work undertaken in project STIS001 (Jacobs, 2017)).

The dominant natural sand transport process around the jetty is wave-driven longshore transport, however around the Tweed River entrance tidal currents and rips are also of significance.

Wave-driven longshore transport is related to shore parallel current that are caused by breaking of waves that approach the shoreline from an oblique angle. Depending on the prevailing wave direction, the sediment transport may be directed either north or south along the coast. During prevailing conditions of south easterly waves, sand is transported to the north, whilst during north-easterly wave conditions, sand can be transported to the south.

Longshore sediment transport occurs predominantly in the mid to outer surfzone (or inner nearshore zone), diminishing in strength with distance offshore into deeper water. The majority of the longshore transport along Letitia Beach occurs in the water depths of less than 4m, in particular around the nearshore bars. As a result, most of the longshore transport at the jetty occurs within the zone between the four to five most inshore trapping cones. Under most conditions, the daily longshore transport rate is well below the storage volume available of these inshore cones (~2,000 to 3,000 m^3), and most of the longshore transport is trapped by the STS. However, during large wave events, the littoral zone can extend well beyond of the jetty and large longshore currents may exist. During these events, the sand trapping system does not capture all the longshore transport and ‘leakages’ occur.

The effect of sand extraction is a local setback of the shoreline at the jetty with commensurate re-alignment of the adjacent beach to the north and south (as indicated by the orange dashed lines on **Figure 12**). There will be accelerated longshore transport from the south during south-easterly conditions and accelerated transport from the north during north-easterly conditions. Accordingly, the local supply rate to the sand trap is expected to be higher than net longshore transport at other locations along Letitia Beach.

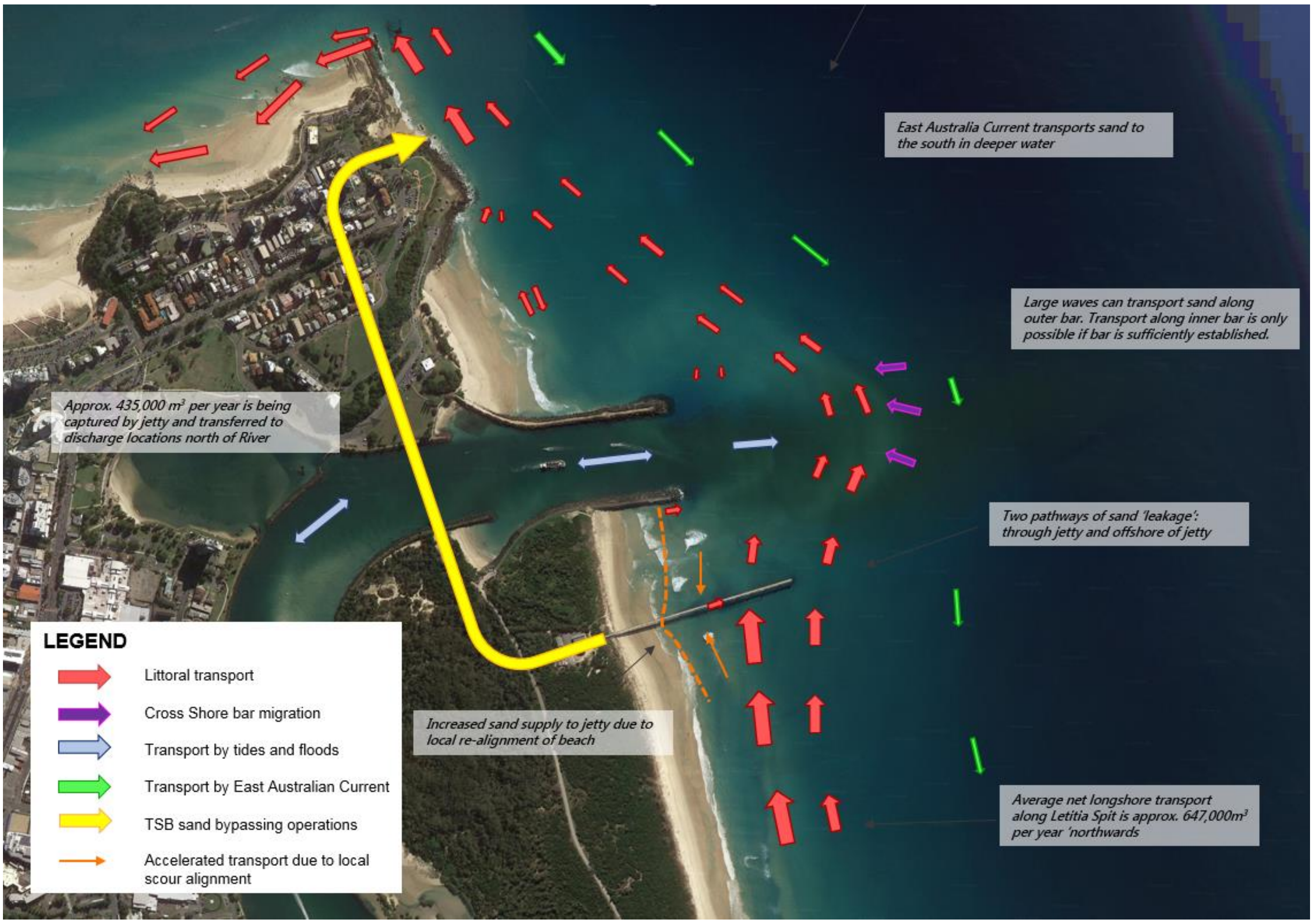


Figure 12 Conceptual sediment transport model of area around sand trapping jetty (modified from Jacobs, 2018)

North of the jetty, a portion of the sand drift is transported to the entrance bar, where is can be temporarily stored in the bar system or transported across the entrance by larger waves. Sand will also be driven into the river entrance where it can become subject to tidal processes.

The interaction of the tidal currents through the entrance and the littoral processes has led to a horse shoe shaped bar system around the river entrance. The dimensions of the entrance bar are predominantly determined by the quantum of sand that is being supplied to the entrance and the prevailing wave conditions. By increasing amounts of littoral drift, the depth of the bar will decrease and its width increase. Under the current sand bypassing regime of the STS, the bar tends to develop to a height of about -3 to -4mAHD and is located 300 to 400m offshore of the river mouth.

Rip currents also play a role in the sand transport regime within the area around the jetty. Rip currents are strong, localised seaward directed currents that are generated by longshore variations in wave setup. On long straight beaches, these currents are usually spaced at 2 to 5 times the width of the surfzone and their location varies depending on the bar configuration and wave conditions. However, at the northern end of Letitia Beach, the location of the rip currents is more fixed, and a frequent rip exists immediately south of the southern training wall and at the jetty, through the depression of sand trap. The rip current along the southern training wall can be quite strong, well over 2m/s, and can from time to time deliver a significant amount of sand to the Tweed River entrance area (Water Technology, 2007).

3.2.2 Wave Climate

The regional wave climate is a dominant factor in the coastal processes affecting the Project Area. The deep-water wave climate of the northern NSW / southern Queensland coast comprises a highly variable wind wave climate superimposed on a persistent long period, moderate to high energy south to south-easterly swell.

Typically, the swell offshore may range up to 3-4m significant wave height with periods in the range 7 to 15 seconds. Prevailing wind waves are incident from a wider range of directions, consistent with the wind climate for the region, and range from small short period local 'sea' conditions to large storm and cyclone waves in excess of 6-7m significant wave height.

As part of the TRESBP, a directional wave recording buoy was established offshore from Letitia Spit in 20-30m of water depth, which has recorded local wave conditions since January 1995.**Table 5** a**Error! Reference source not found.**nd **Table 6** present wave parameter statistics, based on wave recordings during the period between March 1995 and March 2017. **Error! Reference source not found.** shows the frequency of occurrence FOR NOT in terms of significant wave height and peak wave direction, and Table 6 in terms of significant wave height and spectral peak wave period.

In addition, wave measurement data from an offshore location near Point Lookout (Brisbane Offshore) was sourced from the Queensland Department of Science, Information Technology and Innovation. Basic wave parameter statistics for this location, derived from wave recordings during the period between March 1997 and March 2017, are presented in **Table 7** and **Table 8**.

The ambient wave climate tables illustrate the predominance of the southeasterly offshore wave direction, meaning that most of the time (>80% of time) waves approach the Tweed Heads wave buoy from a downcoast direction. Modal wave heights at the Tweed Heads wave buoy are 0.5-2.0m with spectral peak periods predominantly (~65%) in the range 7-12 seconds. **Table 5** a**Error! Reference source not found.**nd **Table 6** show that waves with a significant wave height in excess of 7.5m have been observed at the Tweed Heads wave recorder. The highest recorded (hourly) significant wave height at Tweed Heads during the 22 year monitoring period was 7.52m and was recorded on 3rd May 1996. During the May 1996 event, large north-easterly waves were experienced for a 4-day period with the recorded significant wave height exceeding 5m for a period of approximately 28 hours (See also **Figure 13**). The maximum wave height recorded during this event was 13.1m.

There is seasonal variability in the wave climate with the summer and autumn months being the most energetic. Large wave events (events with a maximum significant wave height of greater than 5m) predominantly occur during the summer and autumn months, and rarely occur during spring or winter. During the winter months, the wave climate is mostly influenced by swell. Consequently, the average peak wave period is larger during these months and the energy-weighted wave direction is more southerly (ie. moved in a clockwise direction), compared to the other seasons.

Table 5 Wave Height and Direction Occurrence Frequency – Tweed Heads Wave Buoy (%)

Hs (m)		Peak Wave Direction (degrees TN) 0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100–110	110–120	120–130	130–140	140–150	150–160	160–170	170–180	TOTAL
0	0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.3%	0.2%	0.0%	0.0%	0.0%		0.0%	1.2%
0.5	1	0.0%	0.1%	0.6%	1.1%	1.0%	0.7%	1.1%	2.0%	3.8%	5.7%	6.2%	6.5%	4.8%	1.3%	0.1%	0.0%	0.0%	0.0%	35.0%
1	1.5	0.0%	0.1%	0.7%	1.2%	0.8%	0.5%	1.4%	3.8%	6.4%	7.3%	6.5%	6.4%	4.7%	1.4%	0.1%	0.0%	0.0%	0.0%	41.3%
1.5	2	0.0%	0.0%	0.1%	0.2%	0.1%	0.1%	0.6%	2.1%	2.8%	2.8%	2.5%	2.2%	1.4%	0.3%	0.0%				15.2%
2	2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.8%	1.0%	1.1%	0.8%	0.6%	0.2%	0.0%	0.0%			0.0%	5.0%
2.5	3			0.0%	0.0%	0.0%	0.0%	0.1%	0.4%	0.4%	0.3%	0.2%	0.1%	0.0%	0.0%					1.4%
3	3.5					0.0%	0.0%	0.1%	0.2%	0.2%	0.1%	0.0%	0.0%							0.6%
3.5	4					0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%								0.2%
4	4.5					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%								0.1%
4.5	5						0.0%	0.0%	0.0%	0.0%	0.0%									0.1%
5	5.5					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.0%
5.5	6						0.0%	0.0%	0.0%	0.0%										0.0%
6	6.5						0.0%	0.0%	0.0%											0.0%
6.5	7						0.0%	0.0%	0.0%											0.0%
7	7.5							0.0%	0.0%											0.0%
	>7.5							0.0%												0.0%
	Grand To	0.0%	0.3%	1.4%	2.4%	1.9%	1.5%	3.8%	9.5%	14.8%	17.5%	16.4%	16.0%	11.3%	3.0%	0.2%	0.0%	0.0%	0.0%	100%

Table 6 Wave Height and Peak Period Occurrence Frequency – Tweed Heads Wave Buoy (%)

Hs (m)		Peak Wave Period (s) 2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	>21	TOTAL
0	0.5	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%
0.5	1	0.0%	0.4%	1.6%	2.4%	3.1%	4.3%	4.6%	5.3%	5.5%	3.2%	2.6%	1.1%	0.5%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	35.0%
1	1.5		0.0%	0.8%	2.4%	3.5%	5.8%	6.7%	6.5%	6.8%	3.9%	2.9%	1.2%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	41.3%
1.5	2			0.0%	0.2%	0.9%	2.0%	3.0%	2.9%	2.6%	1.6%	1.2%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%		0.0%		15.2%
2	2.5				0.0%	0.1%	0.4%	0.9%	1.0%	1.0%	0.6%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%				5.0%
2.5	3					0.0%	0.1%	0.2%	0.3%	0.4%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%					1.4%
3	3.5						0.0%	0.0%	0.1%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%						0.6%
3.5	4							0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%						0.2%
4	4.5							0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%								0.1%
4.5	5								0.0%	0.0%	0.0%	0.0%	0.0%	0.0%								0.1%
5	5.5								0.0%	0.0%	0.0%	0.0%	0.0%	0.0%								0.0%
5.5	6								0.0%	0.0%	0.0%	0.0%	0.0%									0.0%
6	6.5									0.0%	0.0%	0.0%	0.0%									0.0%
6.5	7										0.0%	0.0%	0.0%									0.0%
7	7.5										0.0%	0.0%	0.0%									0.0%
	>7.5											0.0%										0.0%
	TOTAL	0.0%	0.4%	2.4%	5.0%	7.6%	12.7%	15.7%	16.3%	16.8%	9.9%	7.8%	3.1%	1.4%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	100%

Table 7 Wave Height and Direction Occurrence Frequency – Brisbane Offshore Wave Buoy (%)

Hs (m)		Peak Wave Direction (degrees TN) N	NNE	NE	WNE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0	0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.1%
0.5	1	0.5%	0.7%	0.6%	1.5%	3.0%	3.8%	4.6%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.7%
1	1.5	1.3%	1.2%	0.8%	4.4%	7.4%	6.6%	10.2%	2.7%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	35.0%
1.5	2	0.5%	0.3%	0.2%	2.9%	5.2%	4.6%	7.8%	2.9%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	24.6%
2	2.5	0.1%	0.0%	0.1%	1.3%	2.5%	2.6%	4.8%	2.3%	0.1%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	13.7%
2.5	3	0.0%	0.0%	0.0%	0.5%	1.1%	1.1%	2.2%	1.2%	0.0%							0.0%	6.2%
3	3.5	0.0%		0.0%	0.2%	0.4%	0.4%	1.0%	0.6%	0.0%		0.0%						2.7%
3.5	4			0.0%	0.1%	0.2%	0.2%	0.4%	0.2%	0.0%								1.1%
4	4.5			0.0%	0.1%	0.2%	0.1%	0.1%	0.1%	0.0%				0.0%				0.5%
4.5	5			0.0%	0.0%	0.1%	0.0%	0.0%	0.0%									0.2%
5	5.5			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.1%
5.5	6			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.0%
6	6.5			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%									0.0%
6.5	7			0.0%	0.0%	0.0%	0.0%	0.0%										0.0%
	> 7.0			0.0%		0.0%	0.0%							0.0%				0.0%
	TOTAL	2.5%	2.2%	1.8%	11.1%	20.1%	19.6%	31.1%	11.0%	0.3%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.1%	100%

Table 8 Wave Height and Peak Period Occurrence Frequency – Brisbane Offshore Wave Buoy (%)

Hs (m)		Peak Wave Period (s) 2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	>21	TOTAL
0	0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%						0.1%
0.5	1	0.0%	0.3%	0.7%	0.9%	1.1%	2.0%	2.4%	2.5%	2.2%	1.2%	1.3%	0.7%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.7%
1	1.5		0.1%	1.1%	2.5%	2.3%	4.5%	6.4%	6.1%	5.2%	2.8%	2.3%	1.1%	0.5%	0.1%	0.0%	0.0%	0.0%	0.0%			35.0%
1.5	2		0.0%	0.1%	1.1%	2.0%	3.2%	4.6%	4.3%	4.0%	2.3%	1.8%	0.9%	0.4%	0.1%	0.0%	0.0%	0.0%				24.6%
2	2.5				0.1%	0.9%	2.2%	2.8%	2.5%	2.1%	1.3%	1.1%	0.5%	0.2%	0.0%	0.0%	0.0%					13.7%
2.5	3				0.0%	0.1%	0.8%	1.4%	1.3%	1.0%	0.7%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%					6.2%
3	3.5				0.0%	0.0%	0.1%	0.6%	0.6%	0.5%	0.4%	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%					2.7%
3.5	4					0.0%	0.0%	0.1%	0.2%	0.3%	0.2%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%					1.1%
4	4.5						0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%						0.5%
4.5	5						0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%						0.2%
5	5.5							0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%							0.1%
5.5	6							0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%							0.0%
6	6.5								0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%							0.0%
6.5	7								0.0%	0.0%	0.0%	0.0%										0.0%
	>7.0									0.0%	0.0%	0.0%										0.0%
	TOTAL	0.0%	0.4%	1.8%	4.6%	6.5%	12.9%	18.3%	17.6%	15.5%	9.0%	7.6%	3.7%	1.6%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	100%

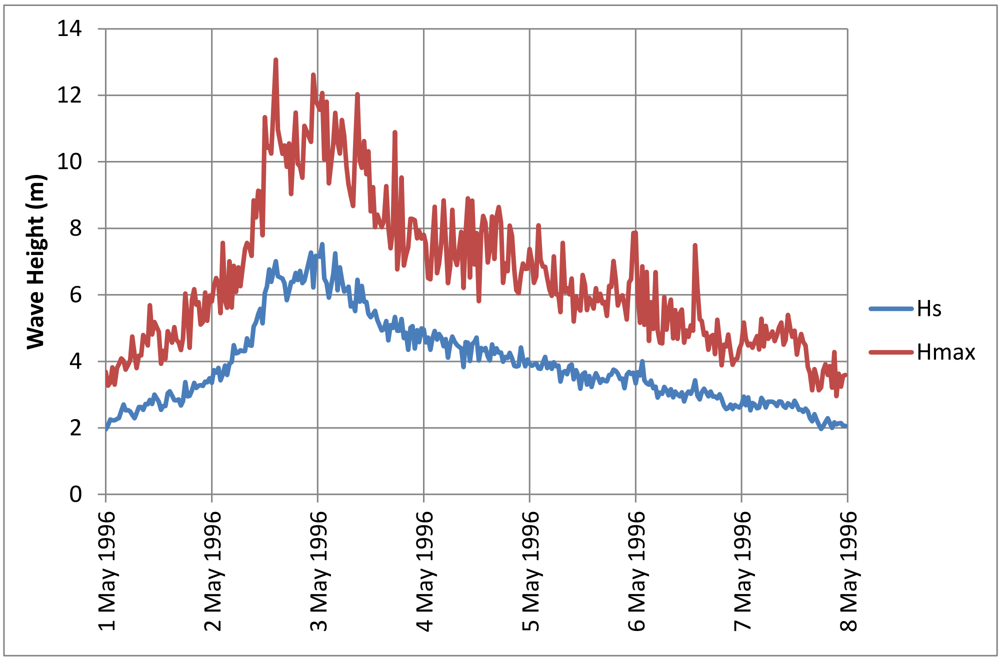


Figure 13 Recorded Wave Height during the May 1996 event

3.2.3 Longshore transport modelling

Longshore sand transport modelling was undertaken to provide an insight in the temporal pattern of the movement of sand around the jetty. Longshore sand transport rates were calculated directly from recorded directional wave data from the Tweed Heads wave buoy and the observed shoreline orientation at a location approximately 1,000m south of the southern training wall. Transport rates were calculated using the modified Kamphuis method (1991), as proposed in Van Rijn (2014).

The modelling indicates that a large portion of the longshore sand transport occurs during large wave events, even though these events are reasonably uncommon. The modelled average net longshore transport rate for the period 2009 to 2015 is approximately 647,000 m^3 per year (refer **Table 9**), which is consistent with estimates by BMT WBM (2016, 2017) for the corresponding period.

A break-down of the annual longshore transport over selected wave conditions is provided in **Appendix C**.

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Table 9 Modelled net annual longshore sand transport along Letitia Spit

Year	Net Longshore Sand Transport Rate (m^3 per year)
2009	752,902
2010	469,623
2011	753,199
2012	722,192
2013	537,929
Average	**647,169**

3.3 Historical sand transfer

TRESBCo's pumping logs document a number of parameters at 100 seconds intervals, including discharge pressure, total flow discharge rate, slurry density and sand transfer rates through the centrifugal transfer pump. No data is available for the individual jet pumps. Data for the period between April 2001 and April 2014 was made available for this study.

The pumping log data indicates that just over 7 million m^3 of sand has been transferred between April 2001 and April 2014. Generally, the data shows a slight trend of decreased transport over time with notably higher transfer rates during the first 5 years of operation.

The data for the five-year period between 1 January 2009 and 1 January 2014 (refer to **Table 10**) was analysed in greater detail as this data is considered representative for the present operational regime of the facility (i.e. not affected by Supplementary Increment activities, which were aimed at supplying the southern Queensland beaches with a quantum of sand above the natural sand transport rate).

Table 10 Historical Sand Pumping Data

Year	Sand Transferred (m^3)	Total Pumping Hours (hr/year)
2009	412,746	1,602
2010	386,224	1,553
2011	520,029	1,952
2012	440,004	1,778
2013	322,898	1,457
Total	2,081,901	
Average	**416,400 m3/year**	**1,682**

Data for the average sand transfer rate as a function of total slurry density for the 2009-14 period is presented in **Figure 14**. This data demonstrates a strong correlation between higher slurry density and higher sand transfer rates.

The variability of the density of pumped slurry over the 2009-2014 period is presented in **Figure 15.** This data indicates that the vast majority of the time (~83%), sand pumping occurs with a slurry density of less than 1.3 t/m^3 in the main slurry transfer system. The average density of the pumped sand slurry over this period was about 1.2 t/m^3, which is significantly below the design density of 1.46 t/m^3.

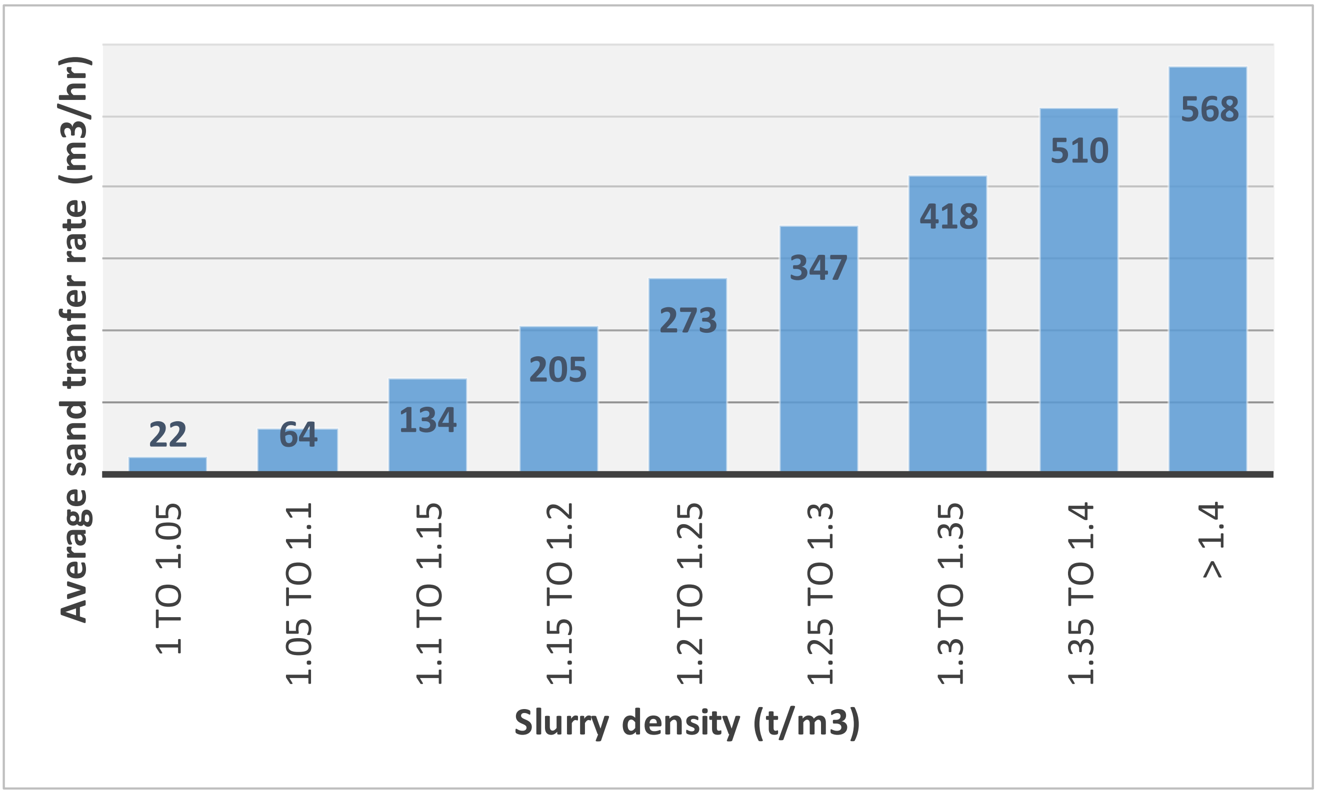


Figure 14 Average sand transfer rate as a function of total slurry density

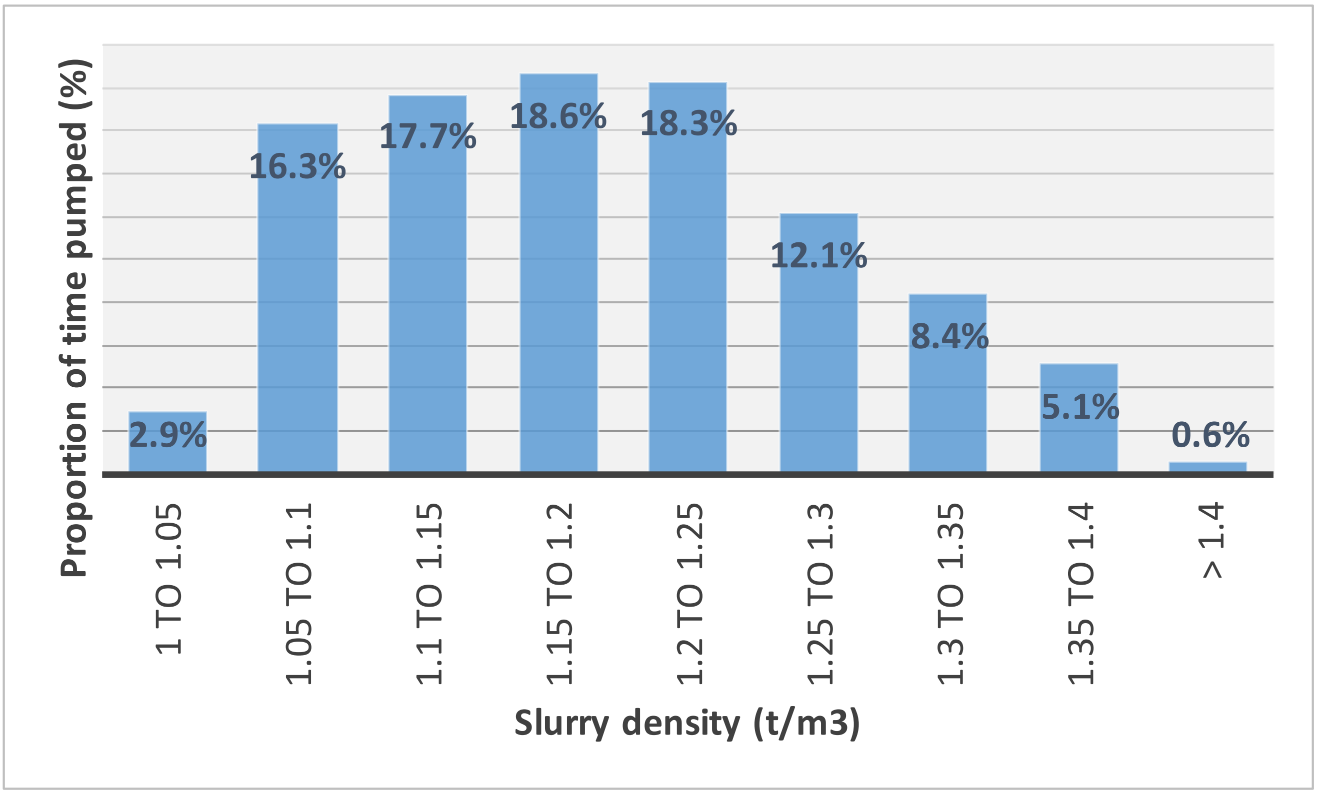


Figure 15 Frequency of Occurrence of sand slurry density (% of time pumped)

The 2009-2014 data indicates the following:

- The STS has on average been operating approximately 1,682 hours per year (or about 20% of the time) and transferred an average volume of approximately 417,000 m^3 per year.
- The vast majority of pumping occurs at night; more than 75% of the pumping occurred between 8pm and 7am (refer **Figure 16**). Sand transfer during peak energy tariff periods (Mon-Fri 7am-9am, 5pm-8pm) is generally avoided and only has occurred on 21 occasions during the 5-year period.
- For approximately 38% of the days in a year, the STS has not transferred any sand. The probability that the STS does not transfer any sand is substantially higher during days of low longshore transport, compared to days with high longshore transport (see **Figure 17**).
- Sand pumping rarely occurs at a rate that approaches to the design capacity of 625 m^3 per hour of the transfer system (see **Figure 14**). On average, sand is transferred at a rate of 230m^3 per hour. A higher average transfer rate is achieved during days of high longshore transport and a lower rate during days of low transport. The vast majority of the time (~83%), sand pumping occurs with a slurry density of less than 1.3 tonnes per m^3 in the main slurry transfer system (refer **Figure 15**), which is significantly below the density required to achieve the design capacity of the transfer system.
- During days with low to moderate northerly longshore transport (up to about 1,000m^3/day), the average volume of sand transferred by the STS is generally of the same order as the modelled longshore sand transport (refer **Figure 18**), suggesting that all longshore transport is captured by the STS during these days. However, during days with large northerly longshore transport (>1,000m^3/day), the volume of sand transferred is generally significantly lower than the modelled longshore sand transport, indicating that sand may 'leak past the jetty during these days (see **Figure 18**).
- The amount of sand that is transferred by the STS in a day rarely approaches the practical pumping capacity of about 10,000 m^3/day, even during days when the supply by littoral processes is substantially larger than this capacity. During the 5-year period, there have been only six days where the sand transfer rate was larger than 8,000m^3 per day.

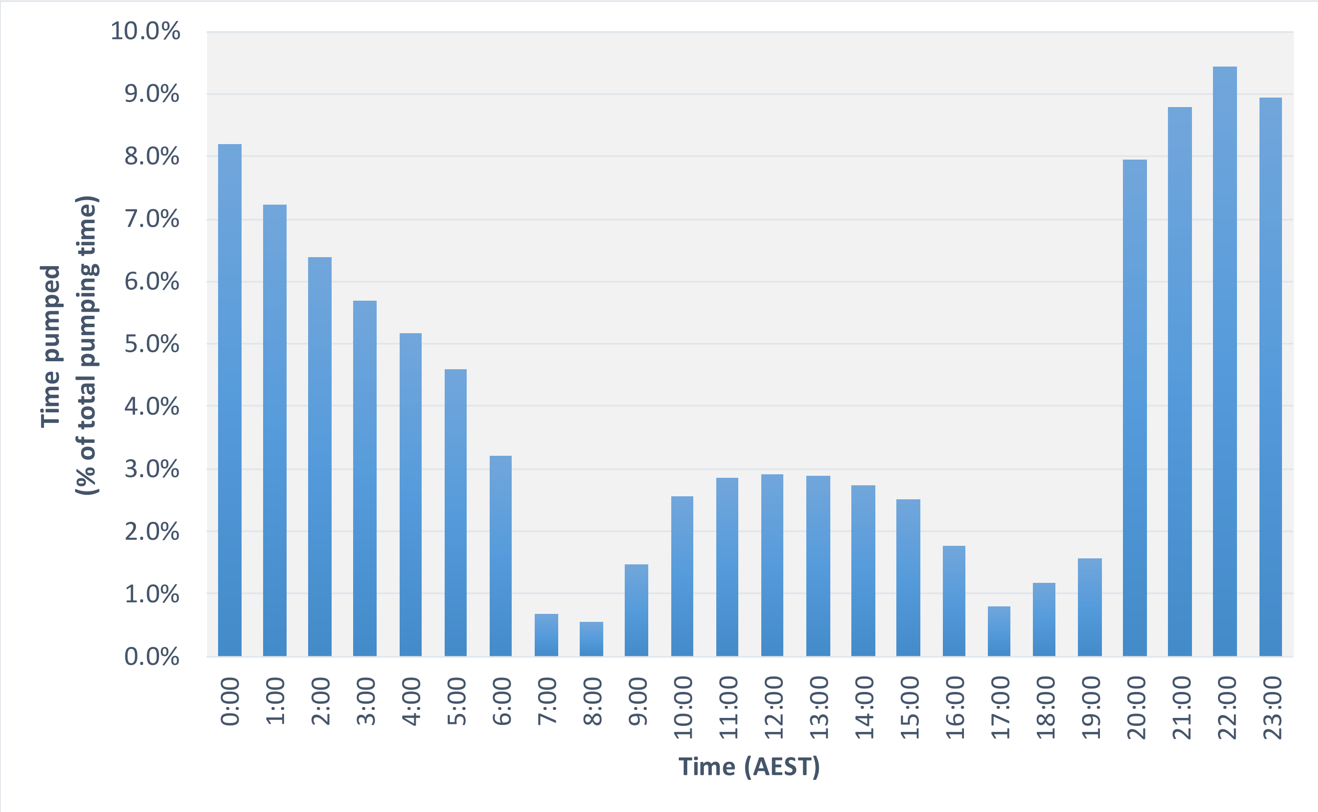


Figure 16 Histogram of Timing of Sand Pumping

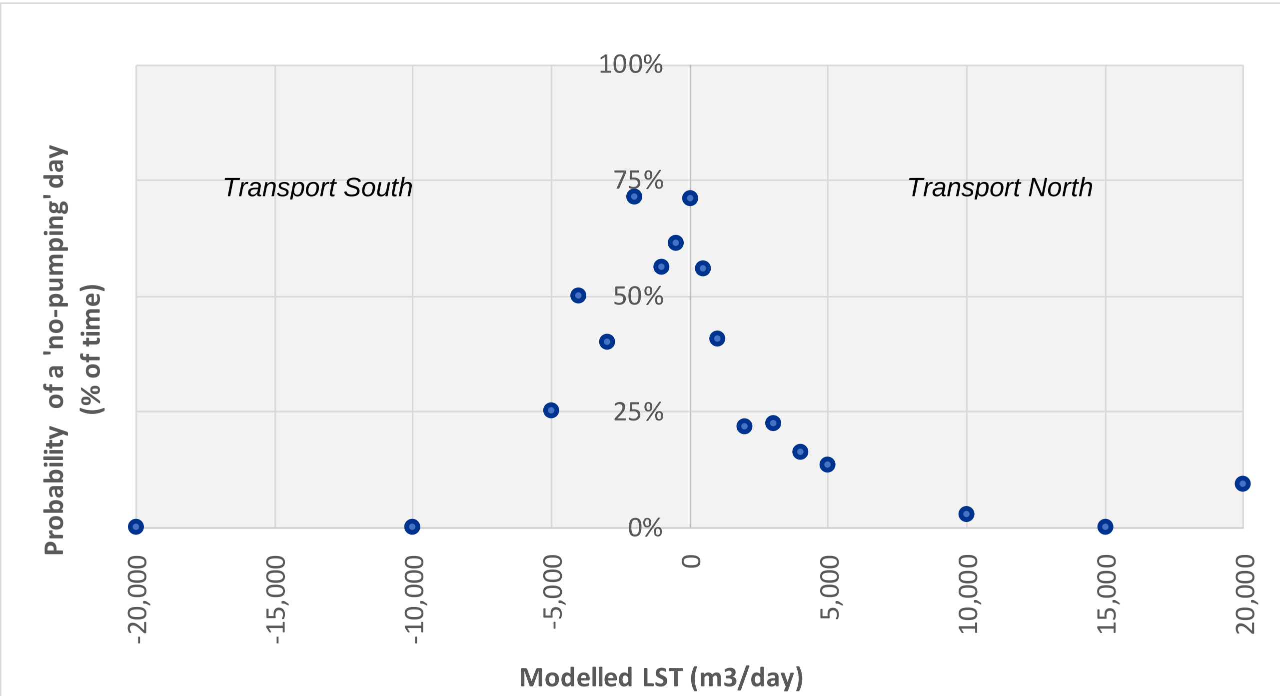


Figure 17 Probability of a "No-pumping' day as a function of modelled daily longshore sand transport

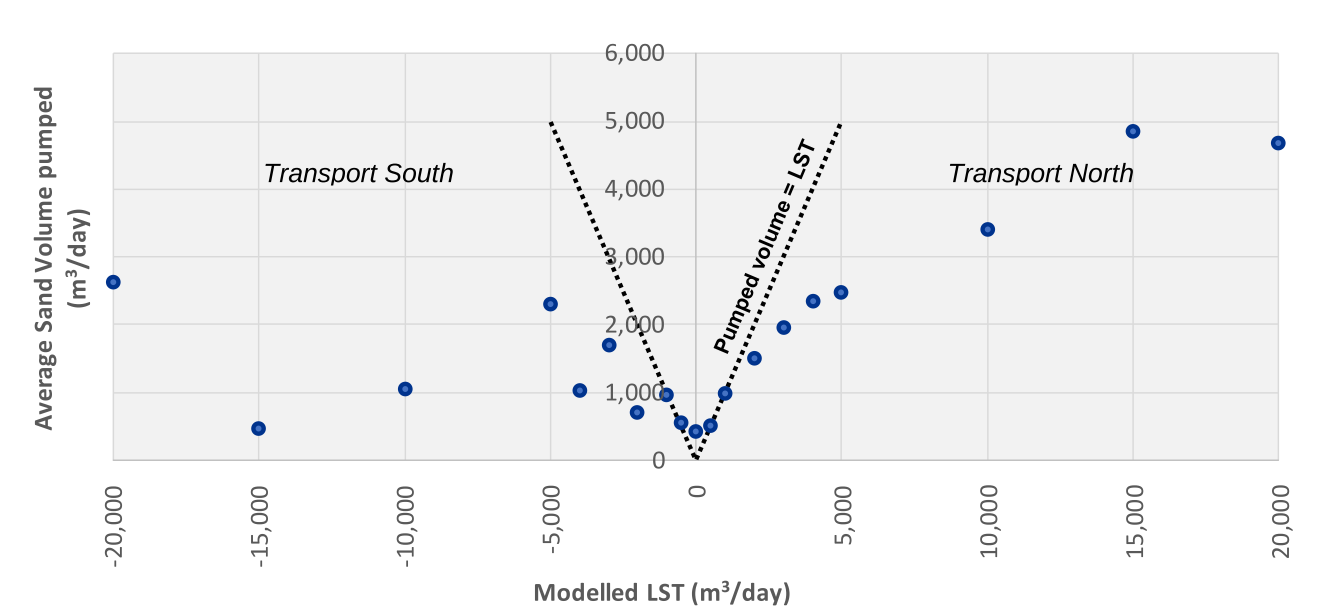


Figure 18 Average sand transfer rate as a function of modelled daily longshore sand transport (2009 – 2014 period)

3.4 Sand trapping efficiency analysis

Table 11 presents a calculation of the sand capturing regime of the STS. The table shows that even though the majority of the time (>75% of the time), the modelled longshore sand transport at the jetty is between 0 and 2,000 m³/day northwards, their contribution to the annual leakage is relatively small. The vast majority of the leakage is predicted to occur during days where the northerly transport is larger than 2,000 m³/day.

Table 11 Sand leakage through TSB jetty (based on pumping logs)

Littoral Sand Movement Regime	Modelled LST rate (m3/day)	Frequency of occurrence (% of time)	Average Sand Transfer Rate (m³/day)	Average duration of pumping (hr/day)	Sand supply rate to river entrance area (m³/day)	Leakage (% LST)	Modelled annual LST (m³/yr)	Calculated supply to river entrance area (m³/yr)
Southerly LST	**< -20,000**	0.2%	2,621	10.5	-20,000	N/A	-20,508	-20,508
	-15,000	0.1%	457	1.3	-15,000	N/A	-2,653	-2,653
	-10,000	0.1%	1,048	6.7	-10,000	N/A	-3,713	-3,713
	-5,000	0.2%	2,289	6.9	-5,000	N/A	-3,722	-3,722
	-4,000	0.3%	1,017	3.6	-4,000	N/A	-4,955	-4,955
	-3,000	0.2%	1,677	3.8	-3,000	N/A	-3,543	-3,543
	-2,000	0.3%	697	2.3	-2,000	N/A	-1,846	-1,846
	-1,000	1.0%	941	3.0	-1,000	N/A	-4,324	-4,324
	-500	3.8%	532	2.5	-500	N/A	-6,437	-6,437
Northerly LST	**0**	12.7%	415	1.8	0	0%	2,432	0
	500	21.7%	500	2.5	0	0%	38,196	0

Littoral Sand Movement Regime	Modelled LST rate (m3/day)	Frequency of occurrence (% of time)	Average Sand Transfer Rate (m^3/day)	Average duration of pumping (hr/day)	Sand supply rate to river entrance area (m^3/day)	Leakage (% LST)	Modelled annual LST (m^3/yr)	Calculated supply to river entrance area (m^3/yr)
	1,000	23.0%	974	4.2	26	3%	90,351	2,367
	2,000	16.6%	1,496	6.2	504	25%	117,852	29,687
	3,000	6.8%	1,940	7.3	1,060	35%	76,069	26,876
	4,000	4.4%	2,336	8.0	1,664	42%	62,114	25,847
	5,000	4.8%	2,460	8.5	2,540	51%	108,729	55,231
	10,000	2.6%	3,385	11.6	6,615	66%	95,588	63,233
	15,000	0.5%	4,847	14.7	10,153	68%	24,428	16,535
	> 20,000	0.7%	4,670	14.1	15,330	77%	83,112	63,704
TOTAL							**647,169**	**231,776**

Notes:

1) Northerly littoral sand movement is presented as positive numbers and southerly movement is presented as negative numbers.
2) "Leakage" is the volume of sand supplied to area immediately to the north of the JMPS.

3.4.1 Modelling of Sand Trapping

When the longshore current crosses the sand trap, the sediment transport capacity is reduced due to smaller flow velocities and reduced agitation by waves. As a result, bed-load particles and a certain amount of suspended sediment particles will be deposited in the trapping cones. Conceptually, the deposition processes at the sand trap are similar to those at a navigation channel exposed to a channel perpendicular flow, albeit the flow field within the sand trap is likely to be more complex, and less uniform than that of a typical navigation channel.

Van Rijn (1987) proposes a formula (Equation 1) to determine the trapping efficiency of suspended sediments from oblique flows over an infinitely long channel, based on a given channel geometry, flow velocity and particle fall velocity. **Figure 19** shows an example of the predicted trapping efficiency for a channel with an ambient water depth of 5m and a representative particle fall velocity of 2.4cm/s (Parameters considered representative for the STIS site). The figure illustrates how the trapping capacity of the channel reduces with increasing approach flow velocity and reducing trench dimensions.

$$\boldsymbol{e_s = 1 - \exp(-\frac{A_{vr} \cdot L \cdot d}{{h_1}^2})}$$ **Equation 1**

With

$A_{vr} = 0.25[\frac{w_s}{{u_1}^*}] \cdot [\frac{2w_s}{{u_1}^*}]$

L = effective settling length (m)

d = channel depth (m)

h_1 = flow depth in channel (m)

u_1^* = bed-shear velocity in channel (m/s)

w_s = sediment particle fall velocity (m/s)

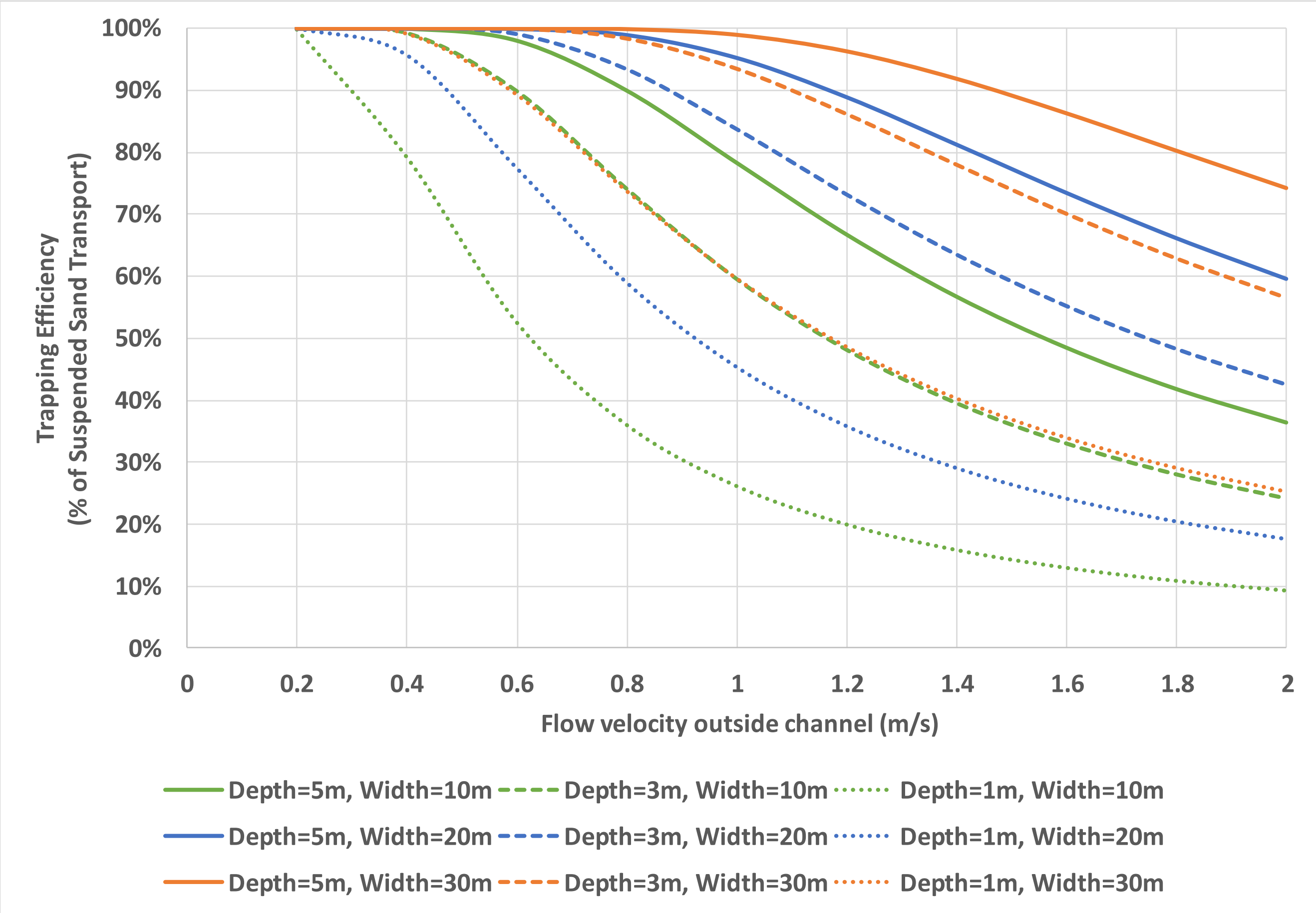


Figure 19 Trapping efficiency of a trench, according to Van Rijn (1987)

Van Rijn's trapping efficiency formula was used in conjunction with sand transfer data from the facility's operator (refer **Section 3.4**) to develop a modelling tool (SANDTRAP) that predicts the proportion of sand that leaks past the jetty via the principal two leakage pathways under varying environmental conditions and operational settings.

SANDTRAP calculates the portion of the longshore transport that is captured by the sand trapping cones using the Van Rijn's trapping efficiency formula and assuming that the longshore transport takes place as suspended load only and that the transport is evenly distributed over the nominated number of active cones. The representative flow current speed of the approach channel was taken as the average peak flow velocity during comparable longshore transport scenarios, calculated using Longuet-Higgins (1972), and the effective settling length as the diameter of the trapping cones at the seabed surface. A sand pumping rate of 300m^3 per hour was adopted in the modelling, derived from the pumping monitoring data. A summary of the key input parameters is given in **Table 13**.

Figure 19 present the leakages predicted by SANDTRAP for a day with a longshore sand transport rate of 3,000m^3 per day and a total sand pump rate of 2,000 m^3/day (A pump volume of approximately 2,000 m^3 is a typical pumping volume for days with a longshore transport rate of about 3,000m^3/day, refer to **Table 11**). In the model simulation, it is assumed that the trapping cones are fully established at the start of the simulation and the longshore transport is spread evenly over 9 active cones.

Figure 19 shows that at the start of the simulation, when the cones are fully established, the trapping efficiency is estimated to be approximately 75% of the longshore transport. Over time, the trapping capacity is predicted to reduce steadily (due to infilling of the trapping cones) until pumping commences at t=17.5hours. From t=17.5 hours to the end of the simulation, the cones capacity increases from approximately 72% to approximately

100%. The modelled total leakage during the 24-hour simulation is 965m^3, or 32% of the longshore sand transport. This is compares well with the implied leakage of the pumping monitoring data (which yields 1,000m^3/day).

For large longshore sand transport rates, sand may also 'leak' past jetty via the offshore sand transport pathway. For these conditions, the total leakage can be found iteratively by adjusting the percentage of the total longshore transport that travels past the jetty via the offshore sand transport pathway and matching the modelled leakage to the total leakage implied by the pumping monitoring data.

Table 13 presents the leakages for a range of longshore transport scenarios as predicted by SANDTRAP. It shows that SANDTRAP predicts that at a longshore transport of 4,000m^3/day, 15% of the total sand transport occurs offshore of the jetty, and approximately 30% at a rate of 10,000m^3/day. This compares to approximately 16% at a transport rate of approx. 3,900m/day and approximately 32% at a rate of 10,410m^3/day predicted by Cardno (2009) using detailed 2D sediment transport modelling. A comparison of the modelled total sand leakages against the leakages implied by the pumping monitoring records is shown in **Figure 20** showing good correlation.

SANDTRAP seems to replicate the sand leakages past the facility under a broad range of operational conditions reasonably well, and as such is considered to be a useful tool to provide an insight in the key factors leading to sand leakages at the existing facility and test the relative performance of potential improvement options. However, the tool in its present form is not considered suitable to provide quantitative estimates of the sand leakages of these options nor to estimate sedimentation rates in the cones under specific environmental conditions. To allow SANDTRAP to be used for these purposes in the future, the tool and its input should be refined and it performance validated against field observations and/or model results of more advanced coastal processes models. The density measurements undertaken at each individual jet pump and the proposed ADCP measurements at the jetty should may provide valuable data in this regard.

The SANDTRAP results indicate that with increasing longshore transport rates the trapping efficiency of the STS reduces, as both a smaller proportion of the sand transport through the jetty is captured by the cones and an increasingly smaller proportion of the sand transport may flow through the jetty.

No significant longshore transport is predicted to occur via the offshore sand transport pathway for total longshore transport rates up to approximately 3,000m^3 of sand per day. For longshore transport rates above 3,000m^3 of sand per day, an increasing proportion of the longshore transport occurs seaward of the jetty. During days with a longshore transport rate in the order of 15,000m^3, approximately 35% of the longshore transport (5,250 m^3/day) is predicted to 'leak' past the jetty via the offshore sand transport pathway. A similar amount is predicted to 'leak' through the jetty.

On average, leakage of sand across the sand trap is found to be the dominant mechanism of sand leakages with about two thirds of the annual sand leakage predicted to occur via this pathway

In all model runs undertaken, the rate of infilling of the sand trap was smaller than the practical pumping capacity of the system. The largest infill rate occurred at the start of the model run with a total longshore transport of 20,000m^3/day when the sand trap was fully established (i.e. the sand trap had nine empty cones). The modelled maximum infill was approximately 7,100m^3/day (compared to the practical pumping capacity of approximately 10,000m^3/day). In other words, the modelling suggests that the trapping efficiency of the existing facility is predominantly constrained by rate at which the cones can trap sand, rather than the pumping capacity of the sand transfer system.

The assessment of the trapping efficiency of a number of potential improvement options using SANDTRAP is discussed in **Section 5.2.**

Table 12 Summary of key inputs for SANDTRAP simulations – Existing operations scenario

Longshore sand transport rate	Sand volume pumped (m3/day)	Approach flow current speed (m/s)	Number of cones being infilled
1,000m^3/day	1,000	0.8	4
2,000m^3/day	1,500	1.0	7
3,000m^3/day	2,000	1.1	9
4,000m^3/day	2,350	1.1	9
5,000m^3/day	2,500	1.2	9
10,000m^3/day	3,400	1.2	9
15,000m^3/day	4,700	1.4	9
20,000m^3/day	4,700	1.5	9

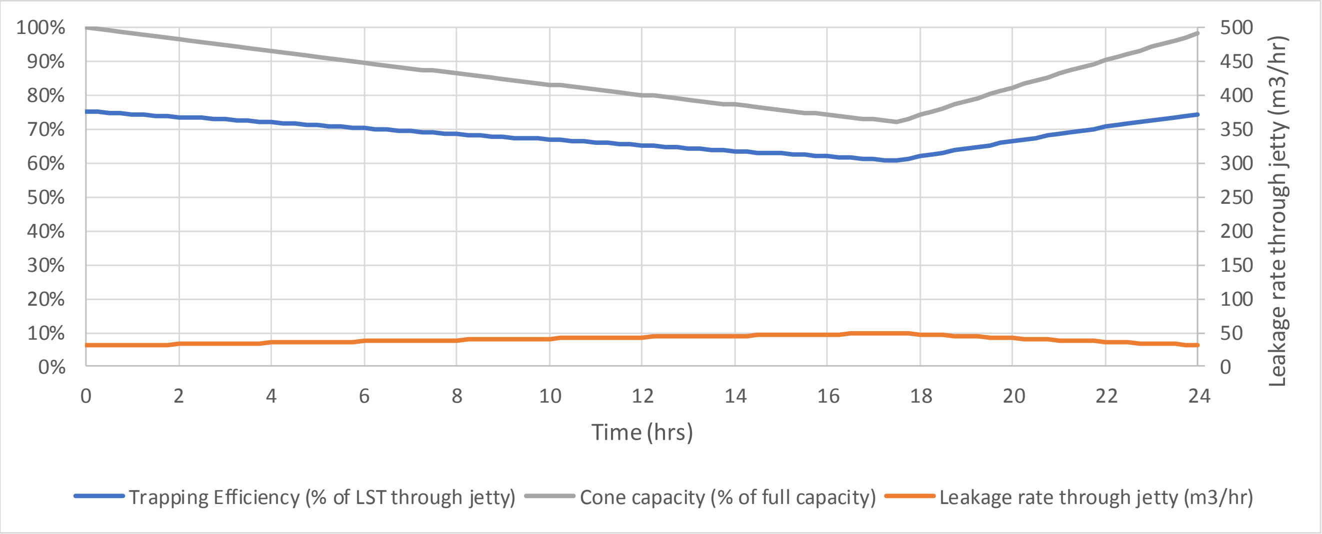


Figure 20 Timeseries output – SANDTRAP simulation of 'Base case - 3,000m^3/day' scenario

Table 13 Summary of results of SANDTRAP simulations – Existing operations scenario

Scenario	Modelled volume trapped (m^3)	Sand leakage through jetty (% of total LST)	Sand leakage offshore of jetty (% of total LST)	Total Sand leakage (% of total LST)	Modelled northward LST (m3/year)	Calculated annual leakage (m^3/year)
Base case - 1,000m3/day	909	11.4%	0.0%	11.4%	90,351	10,308
Base case - 2,000m3/day	1,483	26.3%	0.0%	26.3%	117,852	30,986
Base case - 3,000m3/day	2,004	30.1%	5.0%	35.1%	76,069	26,715
Base case - 4,000m3/day	2,333	27.5%	15.0%	42.5%	62,114	26,407
Base case - 5,000m3/day	2,519	30.4%	20.0%	50.4%	108,729	54,778
Base case - 10,000m3/day	4,082	29.7%	30.0%	59.7%	95,588	57,057
Base case - 15,000m3/day	5,033	32.3%	35.0%	67.3%	24,428	16,431
Base case - 20,000m3/day	5,299	34.2%	40.0%	74.2%	83,112	61,671
Other					-11,075	-71,368
Total					**647,169**	**212,984**

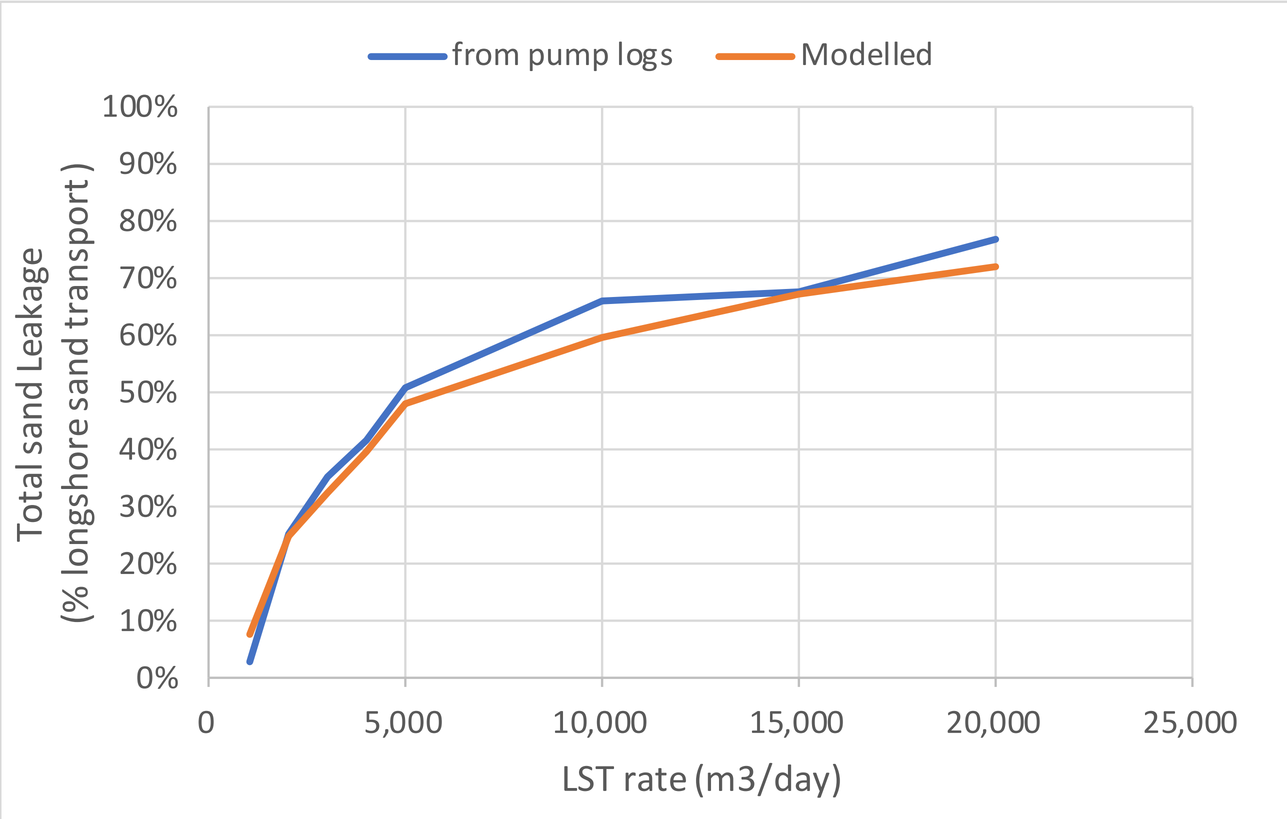


Figure 21 Comparison of modelled sand leakage against leakages implied by pumping logs

4. Energy Use Efficiency Evaluation

4.1 Energy Use Efficiency

Figure 22 presents the monthly electricity consumption of the facility for the period between January 2014 and January 2018. The figure shows that there is considerable variability in the electricity consumption from month to month, with lows of approximately 49,682 kWh (Feb 2014) and highs of approximately 292,237 kWh (Aug 2014). The average electricity consumption of the facility during the period was approximately 163,036 kWh per month. Most of the electricity consumption occurs at night, as demonstrated by **Figure 23**.

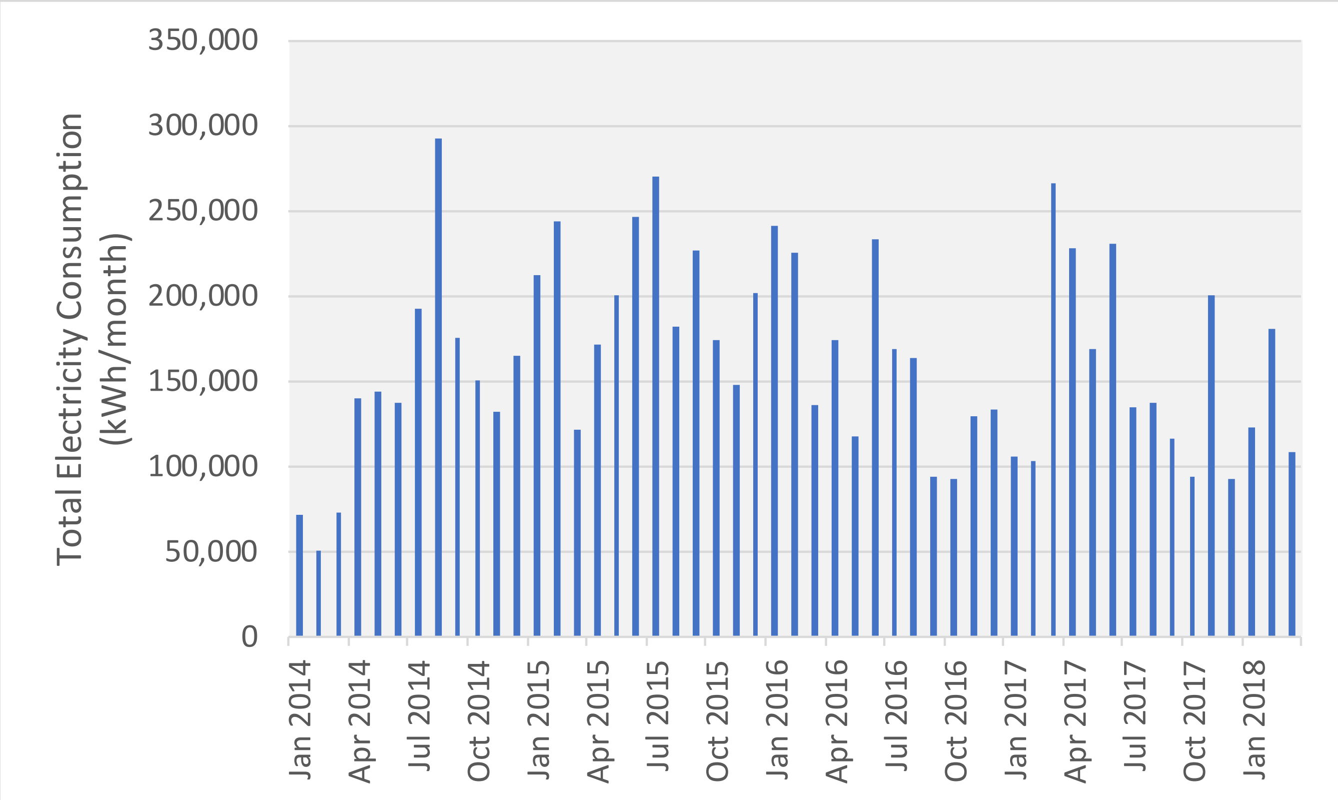


Figure 22 Historical TSB Energy Use of TSB

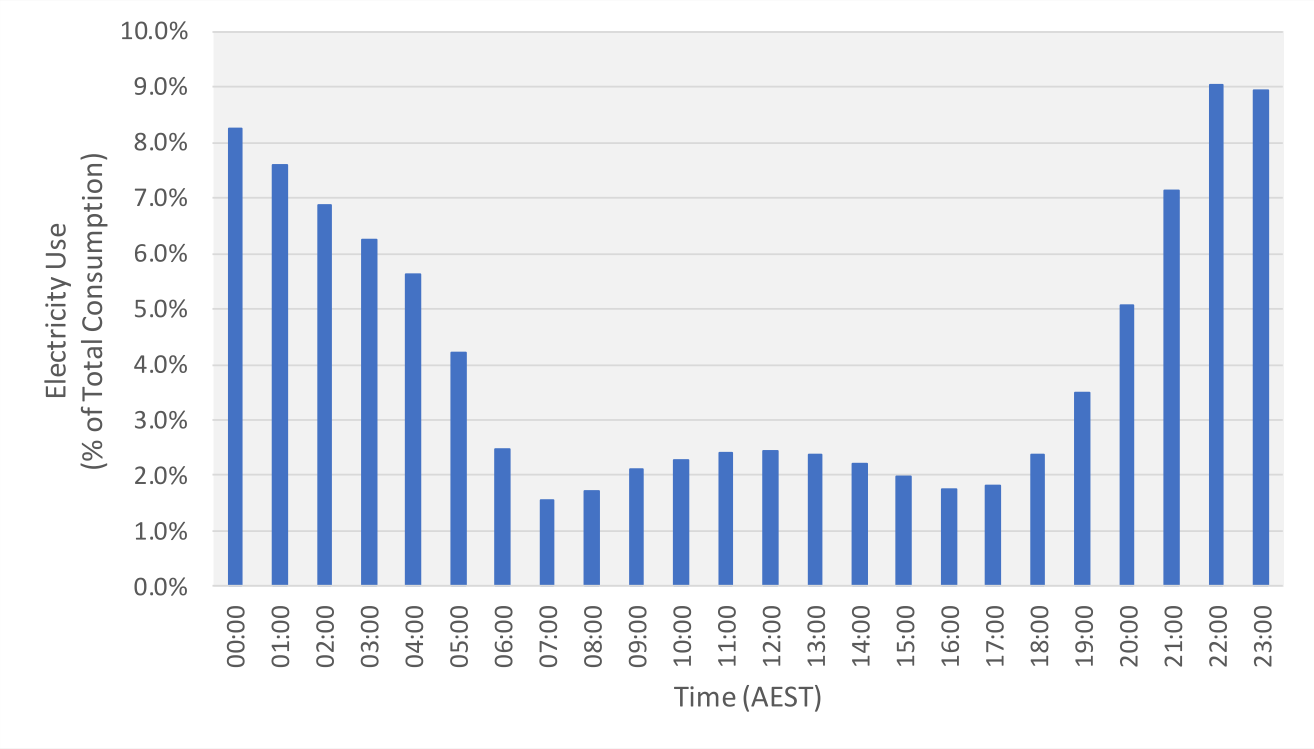


Figure 23 Histogram of Electricity Use at TSB

Figure 24 presents the typical pattern of power consumption at the facility, showing that the power consumption typically is about 60kW when no sand pumping occurs (base load), and about 1,000kW when sustained pumping occurs. Base load consumes approximately 25% of the total electricity used by the facility.

Sand is transferred by the STS with an average energy consumption of approximately 3.2kWh per m^3 of sand. Generally, a higher energy efficiency is achieved when sand transfers occur at a higher slurry density (refer **Figure 25**), and thus typically a higher energy efficiency is achieved during periods when large volumes of sand have accumulated in the trapping cones.

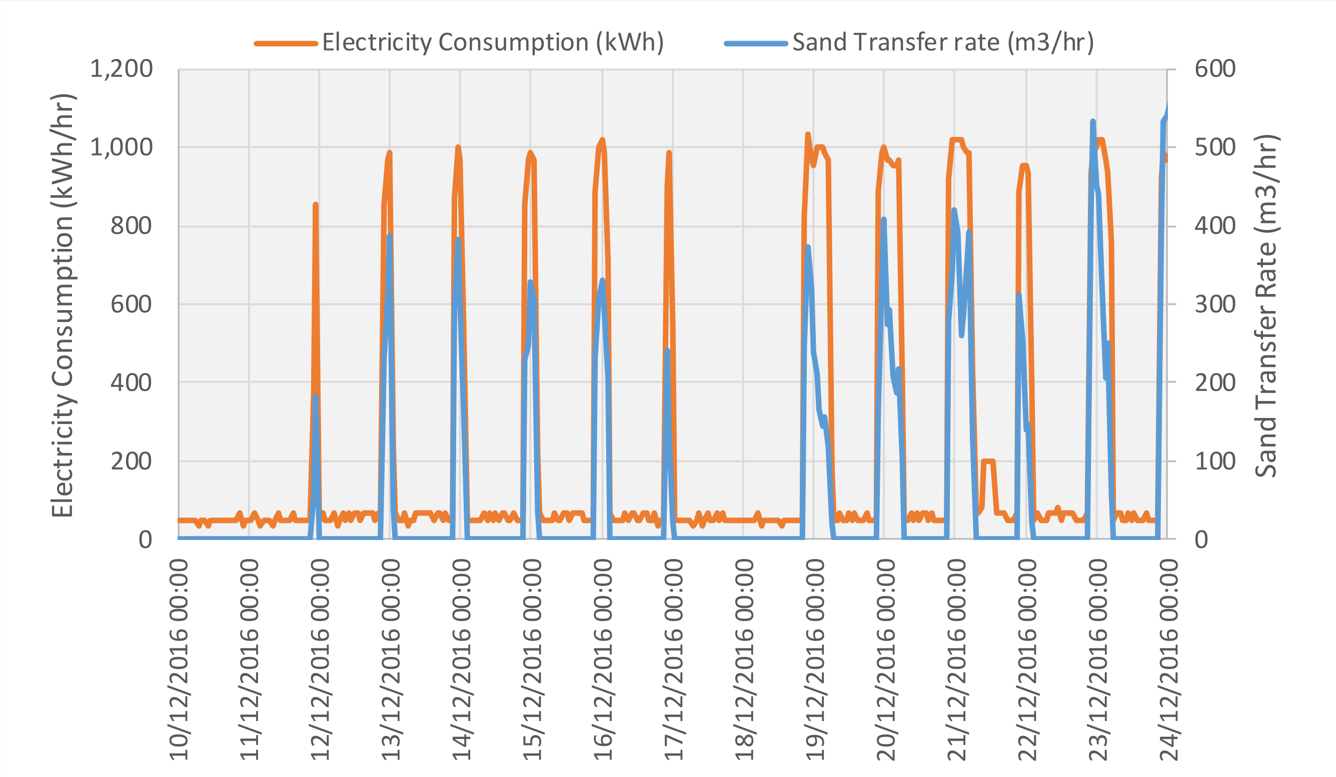


Figure 24 Electricity use and sand transfer volumes between 10 and 24 December 2016

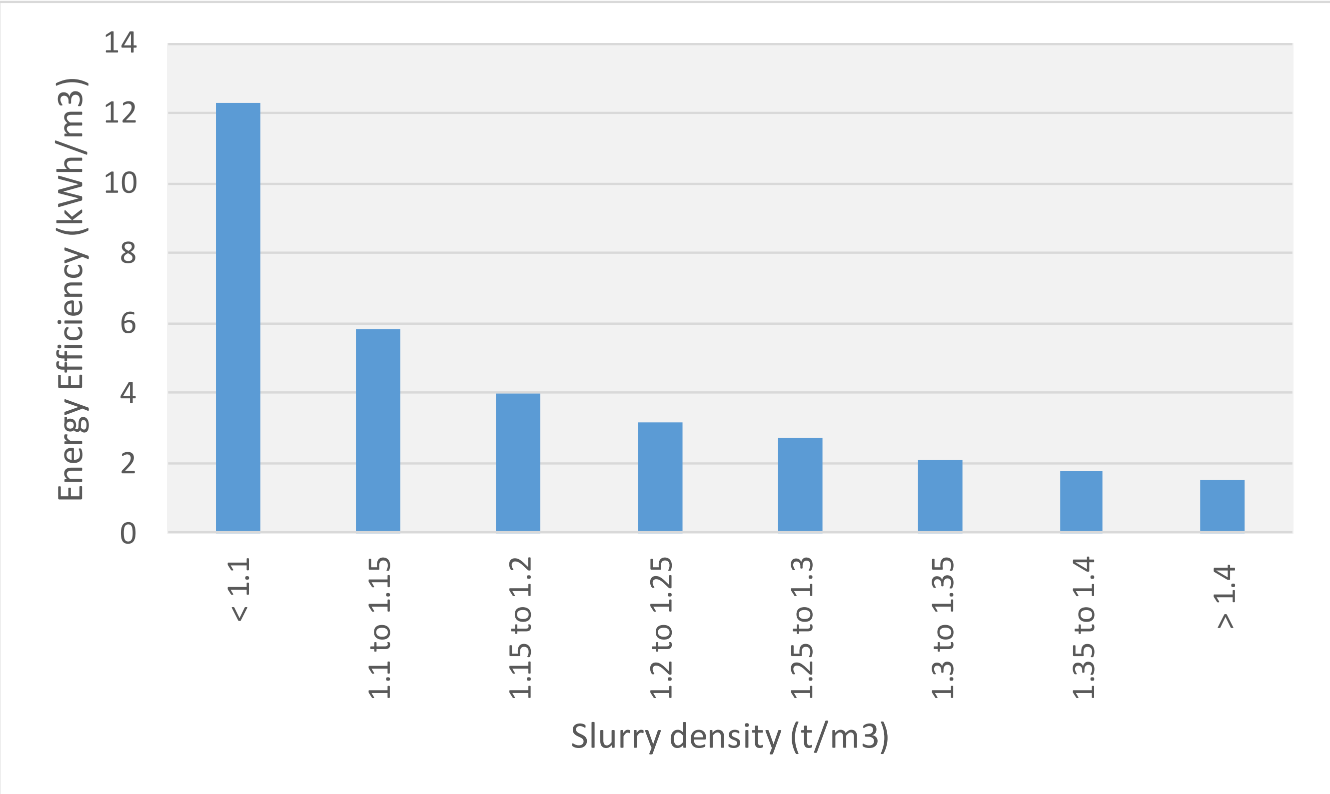


Figure 25 Average energy efficiency as a function of total slurry density

4.2 System Energy Use by Component

The available energy consumptions data is for the overall energy usage of the TSB facility, and it does not record energy usage by individual system components. It is therefore not possible to assess the efficiency of each element of the system using historical data.

However, estimates of the energy consumption of system components based on their rated capacity and assumed usage are presented in **Table 14**.

Table 14 TSB System Component Power Consumption

Component	Rated capacity	Estimated typical hours usage per year[1]	Estimated annual power consumption
	kW	hr/yr	MWh/yr
Raw water pump station	122	1,682	205
Booster pumps	789	1,682	1,328
Flume dilution pumps	20	1,682	34
Transfer pumps	477	1,682	803
Control Building and general lighting	60	8,760	526
Total	**1448**	**-**	**2,896**

Notes:

1) Average hours of operation per year derived from historical SCADA records.

4.3 Energy Efficiency Strategies

4.3.1 Off-peak operation

An examination of the November 2017 electricity bill from the electricity retailer (Energy Australia) reveals that the Tweed Sands operations are controlled to run mainly at off-peak (10pm – 7am) or shoulder (8pm – 10pm) time periods. This takes advantage of the reduced tariff for the Off-Peak time zone (Peak-and Shoulder $0.080548/kWh, Off-Peak- $.049958/kWh).

However, if operations were to be restricted solely to Off-Peak time zones, a significant electricity cost saving could be made. Using the November 2017 invoice as an example, the potential cost saving by restricting operations to the Off-Peak time zone would be approximately $14,800.

4.3.2 Power Factor correction

Efficiency gains in industrial applications can often be made by correcting the power factor, usually by the installation of capacitors. However, the power factor at Tweed Sands as indicated on the November electricity invoice is 0.96. This is already very close to unity, so it is doubtful that any capital investment to gain further improvement would provide an economic rate of return.

4.3.3 Variable speed drives

The pumping system already uses variable speed drives. These provide an efficient method of regulating the flow while avoiding repeated starts/stops, and minimising/optimising the headloss in the delivery pipes.

4.3.4 Increase in slurry density

The primary method by which energy use improvement could be achieved by the TSB is to increase the average density of the sand slurry being transferred. For instance, a 17% increase of average density from a specific gravity of 1.20 to 1.25 would increase energy use efficiency by 29% in terms of tonnes of sand transferred hour, but only increase energy use by about 4%, resulting in a 24% net energy use efficiency improvement in terms of tonnes of sand transferred per kilowatt hour of energy used (refer **Table 15**).

Table 15 Slurry Density vs Sand Transfer Rate and Energy Use Efficiency

Average Slurry Density	Increase compared with existing average density in…			
	Specific Gravity	Sand Transfer Rate	Energy Use (while pumping)	Tonnes of sand transferred per kWh
t/m3	%	%	%	%
1.20 (Existing measured density)	-	-	0	0
1.25	4	29	4	24
1.30	8	58	8	46
1.40	17	116	17	85
1.46 (Design)	22	150	22	106

Increasing average slurry density is largely a function of controlling pump operation so that pumping only occurs when the density of the slurry flow from individual pumps falls below a control system set point. Increasing the density set point will result in an increase in average density.

The existing system already regulates jet pump operation based on slurry density, so it is expected that this opportunity for energy use efficiency is already being realised. It is recommended that some experimentation/trails be undertaken varying the control system settings (set points and pump selection logic) to determine whether additional energy use efficiency gains might be possible.

5. TSB System Evaluation

5.1 Sand Trapping Improvement Options

The following options to increase the trapping efficiency of the STS have been considered:

- **Option 1: Pump Capacity Increase** - eg Operate five pumps simultaneously instead of four.
- **Option 2: Pump Operation Improvement** – Modify pumping operation.
- **Option 3: Lower Jet Pumps** - Lower elevation of jet pumps to create wider cone with larger storage capacity, so will increase the trapping capacity, but may impact on structural capacity of piles)
- **Option 4: Pump spacing Reduction** - Minimise sand leakage through the jetty between the jet pump drawdown cones.
- **Option 5: Extend Jetty Seaward** - Extend the jetty further seaward and install additional jet pumps.
- **Option 6: Modify Seabed Fluidising System** – modify the seabed fluidising system to optimise suspension/turbulence to increase slurry density.

Each of these options are assessed below in terms of their effectiveness in improving sand trapping efficiency, cost, capital works requirements, operational changes, and overall feasibility.

5.2 Improvement Options Sand Trapping Benefits Analysis

Preliminary indicative modelling using the SANDTRAP tool has been undertaken to assess the likely performance of potential improvement options in terms of sand trapping efficiency. The improvement options modelled are summarised in **Table 16**.

Table 16 Sand trapping improvement options modelled

Option	Scenario Name	Description
Option 1	**Increased Pump Capacity**	In this scenario, the pumping capacity of the system is increased by 25% compared to the existing situation.
Option 2	**Modified pump triggers**	In this scenario, the trigger to commence pumping is modified and pumping starts when the storage volume of the sand trapping cones drops below 80% of full capacity. As per the existing operation, four jet pumps operate simultaneously.
Option 3	**Lowering of Jet Pumps**	In this scenario, the nine jet pumps are lowered to achieve a cone that is 1m higher and 5m wider than the existing situation when fully established. As per the existing operation. Four jet pumps operate simultaneously.
Option 4	**Reduced Jet Pump Spacing**	In this scenario, the number of jet pumps is increased from 9 to 13 and the spacing of the jet pumps is reduced from 30m to 20m. As per the existing operation, four jet pumps operate simultaneously.
Option 5	**Extend Pumping Jetty**	In this scenario, the jetty is extended seaward by 60m and two additional jet pumps will be installed at 30m intervals. As per the existing operation, four jet pumps operate simultaneously.
Option 6	**Modify Seabed Fluidising System**	NA - not modelled. (Possible that performance will be similar to Option 1.)

The improvement scenario modelling adopted the same longshore sand transport statistics as the modelling of the existing operations (discussed in **Section 3.4**), which were based on wave conditions and the shoreline configuration for the period between 2009 and 2014.

As a general note, an important consideration for all of the improvement scenarios is that changing the sand transfer regime will alter sediment transport rates around the STS facility and thus will also alter the natural sand supply. This means that in practice the actual performance of the sand trapping improvement options considered in this report will likely be different to the modelled results. More detailed modelling would improve the reliability of the predicted outcomes, but uncertainty regarding the outcomes will still remain.

A summary of the predicted annual leakages is presented in **Table 17**. (More detailed results of the modelling are provided in **Section 3.4)**.

The data shows that increasing the pump capacity has little effect on the sand trapping efficiency of the STS. The scenario whereby the jet pumps are lowered to improve the sand trapping capacity of cones achieves the largest reduction in annual sand leakage. Under this scenario, the trapping efficiency of the STS is predicted to improve from approximately 68% to approximately 83% of the net longshore transport.

Table 17 Results of Sand Trapping Scenario Modelling

Option	Description	Sand Leakage Rate		Trapping efficiency	
		Predicted (m3/year)	Change cf Base Case	Predicted (% of longshore transport)	Change cf Base Case
Base case	Existing system	212,984		67%	
Option 1	Increased Pump Capacity	210,442	-2,542	67%	
Option 2	Modified Pump Triggers	191,024	-21,960	70%	3%
Option 3	Lowering of Jet Pumps	110,248	-102,736	83%	15%
Option 4	Reduced Jet Pump Spacing	181,677	-31,307	72%	4%
Option 5	Extend Pumping Jetty	159,662	-53,322	75%	8%

5.3 Option Feasibility

Each of these options are discussed below.

5.3.1 Option 1: Pump Capacity Increase

Currently, the system is constrained to operate four pumps. Modification of the system to allow simultaneous operation of a fifth jet pump would increase the instantaneous hydraulic capacity of the system by up to 25%. In practice, the constraints of the system pressure rating and pump capacity will restrict the increase to something much less.

Based on available data for the existing pumps, the raw water pump, the high pressure pump and the flume dilution pump would need to be replaced with larger pumps to achieve a 25% capacity increase. The existing raw water pump could achieve an 18% increase by replacing the motor and impeller with larger units. There is less pump performance data available for the flume dilution pumps and the high pressure pump, however based on the information available, both of these units are close to the capacity of the existing pump frame size. Replacement of these three pumps is very likely to also require upgrades or modifications to switchgear, pump mounts and the connecting pipework.

Increasing the flow by 25% will result in a proportionate increase in flow velocity. The flow velocity in the raw water pipeline (3.2 m/s) is already quite high for a water pipeline (which are typically less than 1.5 m/s), and the flow increase would increase this to 3.9 m/s. While this velocity is very high, it is within the allowable velocity limits for PE pipe material. Steady state operating conditions for the pipeline would remain within its rated pressure capacity of PN6.3, but the same would need to be confirmed for dynamic (ie: “water hammer”) pressure scenarios by modelling.

Increasing the flowrate would also increase flow and velocity in the JMPS pipework (including the water feed pipe and the slurry flume) from 2.3 to 2.9 m/s. These velocities are also high for water pipelines, like the raw water pipeline, the increase is feasible in terms of allowable velocity and steady state pressure for MSCL pipe.

Based on this assessment, it has been assumed for this report for this 25% flow increase scenario that the existing raw water pipeline, high pressure delivery pipeline and flume dilution pipelines can be retained.

Based in the SANDTRAP modelling, this change is predicted to increase the volume of sand trapped by an estimated 2,542 m^3/year, which is a negligible increase in the overall sand transfer capacity of the system. Given the uncertainty inherent in the modelling method, in real terms increasing the pump capacity can be expected to produce no benefit.

Feasibility: *Given that the predicted increase in sand transfer capacity achievable from a 25% increase in pump capacity is predicted to be negligible, this option is not considered to be feasible or warrant further investigation.*

5.3.2 Option 2: Pump Operation Improvement

This option involves changing the pump start/stop decisions to they are directly related to the volume of sand in the trapping cone, compared with the current method which uses a combination of pre-programmed time sequences and real-time slurry density to start and stop the jet pumps.

Based in the SANDTRAP modelling, this change is predicted to increase the volume of sand trapped by an estimated 21,960m^3/year, which is a 3% increase in the overall sand transfer capacity of the system. This is a very small predicted increase, and is well within the uncertainty of the modelling method, so in real terms the increase achievable will probably be marginal.

However, the capital cost of implementing this option is low, so TSB may wish to consider implementing it. It is recommended that TSB consider installing the necessary instrumentation (and making the required control system programming adjustments) on a single jet pump and undertaking a trial to determine the effectiveness of various pump operation scenarios.

Feasibility: *The sand trapping benefit of changing the pump operation is predicted to be marginal at best, however because it can be implemented a low cost, it is considered to be feasible. It is recommended that the effectiveness of the change be tested on a single jet pump before implementing it on the entire system.*

5.3.3 Option 3: Lower Jet Pumps

Lowering the jet pumps by one metre will create a deeper and wider drawdown cone during pumping, increasing the volume of sand which can be pumped during a pump cycle operation.

Based on the analysis presented in **Section 5.2**, lowering the jet pumps by one meter will increase the volume of sand trapped by an estimated 102,736 m^3/year, which is a 15% increase in the overall sand transfer capacity of the system. This is most effective of the options considered in terms of sand transfer efficiency improvement by a substantial margin.

This option would be relatively simple to implement in that the works required would be to insert pipework extensions into the water feed and riser pipes on each of the jet pump assemblies. The additional pipe length will marginally increase the operating head of the system. This will marginally decrease the flow produced by the booster pump and the jet pumps and therefore reduce the instantaneous rate of sand extraction.

Alternatively, the pump capacity could be increased to match the marginally higher system resistance (due to the extra pipework length) by increasing the pump speed and/or installing a slightly bigger impeller.

An important consideration is that deepening the drawdown cones will reduce the amount of material around the jetty's pile foundations. This may decrease the stability of the piles. To confirm the feasibility of this option, a detailed structural check of the stability of the jetty structure with the increased cone depth would be required. For this report, it has been assumed that all of the jetty piles will need to be lowered (ie: driven deeper into the seabed) by one metre, and an extension added to the top of each pile. This work will be costly and very disruptive to the operation of the JMPS. Depending on the condition of the existing piles, it may also not be feasible, in which case the entire piles would need to be replaced and the cost would be significantly higher.

Feasibility: Lowering of the jet pumps by one metre is expected to produce a 15% increase in sand trapping efficiency, making it feasible from an effectiveness viewpoint. A detailed structural check of the impact of this option on the jetty pile foundations and the scope of any pile modification/replacement works needed will be required to confirm the feasibility and scope of this option.

5.3.4 Option 4: Pump Spacing Reduction

This option would require the addition of extra jet pumps to the jetty, either by inserting additional pumps between the existing units, or repositioning all of the existing units to a closer spacing.

Implementing this option would be a major change to the configuration of the jetty, and the capital cost would be relatively high.

Based on the SANDTRAP modelling, this change is predicted to increase the volume of sand trapped by an estimated 31,307 m^3/year, which is a 4% increase in the overall sand transfer capacity of the system. This is a very small predicted increase, and is well within the uncertainty of the modelling method, so in real terms the increase achievable will probably be marginal.

Feasibility: *While it is technically feasible to crease the jet pump spacing, the marginal sand trapping benefit it would provide and its high capital cost makes it infeasible overall.*

5.3.5 Option 5: Extend Jetty Seaward

This option would require the construction of a 60m extension to the jetty and two additional jet pumps. Implementing this option will be a major change to the configuration of the jetty, and the capital cost will be high.

Based on the SANDTRAP modelling, this change is predicted to increase the volume of sand trapped by an estimated 53,322 m^3/year, which is an 8% increase in the overall sand transfer capacity of the system. This is the second highest predicted increase of those considered, and it is likely (after taking into account the uncertainty of the modelling method) that it will achieve an appreciable increase in sand trapping and transfer.

However, the high capital cost of extending the jetty means that the cost effectiveness of achieving this increase is low.

Feasibility: *While it is technically feasible to crease the extend the jetty and install two additional jet pumps, and it is likely increase the volume of sand trapped and transferred, the cost of implementation will be high, making it infeasible overall.*

5.3.6 Option 6: Modify Seabed Fluidising System

This option involves modifying the seabed fluidising system to increase the density of the slurry being draw into the jet pumps.

The current fluidising system is a simple configuration which operates on a fixed flow basis. This means that the intensity of the jets mobilising the seabed cannot be adjusted to optimise the degree of turbulence induced or to accommodate different hydraulic conditions at the jet pumps.

The logic underlying this option is that if the velocity of flow from the fluidising jets can be modulated, the intensity of turbulence induced at the jet pumps can be adjusted in real time based on the actual slurry density observed at each pump.

Modifications to the existing system would need to be trialled to determine the effectiveness of this strategy and to determine the modifications which achieve the highest slurry density. A number of combinations of modifications can be trialled. For this study, the following modifications have been assumed:

- Installation of actuated valves on the fluidiser jet feed pipework to enable flow to be regulated.
- Use of data from the nuclear density meters on each jet pump assembly to adjust flow to the fluidiser jets to optimise slurry density.

The cost of implementing this option will be relatively low and cause minimal disruption to the operation of the TSB system. Its effectiveness will be unknown until the proposed system modifications are tested, however based on the data presented in **Section 2.8**, even relatively small increase in average slurry density will have a large impact on both the rate of sand transfer and energy use efficiency.

Feasibility: *Given the relatively low cost of implementing this option (particularly given that its effectiveness can be tested and optimised before fully implementing it), and the large benefits it offers in terms of both sand transfer and energy use efficiency, this option is recommended for future consideration.*

5.4 Options Scope of Works & Cost

5.4.1 Option Capital Works Scope

The works required to implement each shortlisted Option described in **Section 5.3** are listed in **Table 18**.

Table 18 Sand Transfer Improvements Options – Implementation Works

Option		Capital Works	Operational Changes
1	Increased Pump Capacity	• Replace the raw water pumps to increase flow by 25%. • Replace the high pressure pumps to increase flow by 25%. • Replace the flume dilution pumps to increase flow by 25%. • Construct an extension to the existing stilling basin, or provide a second stilling basis to accommodate the additional inflow.	• No change in day-to day operations.
2	Modified Pump Triggers	• No capital works required.	• No change in day-to day operations once modified control regime has been established and tested.
3	Lowering of Jet Pumps	• Extend existing piles (note: this may not be feasible – piles may need to be completely replaced). • Upgrade the booster pump impeller (to provide marginal additional pumping head).	• No change in day-to day operations.

Option		Capital Works	Operational Changes
		• Install 1m extensions on the jet pump pipework (to lower the pumps).	
4	Reduced Jet Pump Spacing	• Install eight additional jet pumps midway between the existing jet pumps. • Install new connections to the flume, header and flow assist pipework. • Install additional control panel panels to provide connections for the additional pumps. • Modify control system programming to accommodate the additional pumps.	• No change in day-to day operations once the control system for the extra pumps has been established and tested. • The additional pumps will increase maintenance marginally.
5	Extend Pumping Jetty	• Install a 60m seaward extension of the existing jetty. • Install two additional jet pumps on the jetty extension. • Install additional control panels to provide additional connections for the additional pumps. • Modify control system programming to accommodate the additional pumps.	• No change in day-to day operations once the control system for the extra pumps has been established and tested. • The additional pumps and jetty length will increase maintenance.
6	Modify Seabed Fluidising System	• Install actuated control valves on the fluidiser feed pipe (to regulate flow). • Modify control system programming to modulate flow to the jet pumps to optimise/maximise slurry density based on reel-time data from the density meters on each jet pump.	• No change in day-to day operations once the control system for the extra pumps has been established and tested. • The addition of actuated valves will increase maintenance marginally.

5.4.2 Cost Estimates

High level estimates of the costs of constructing and operating each of the shortlisted options are presented in **Table 19**. These estimates have been derived based on the scope of work assumed for each option as described in **Table 18**.

Details of the basis of basis of these estimates are provided in **Appendix A**. The bespoke nature of the works make the preparation of realistic estimates challenging; to mitigate this risk, the estimates prepared for this report have been benchmarked against a valuation estimate for the existing TSB system (NSW Department of Commerce, 2007).

It is important to note however that these estimates are only generally indicative of the capital cost of implementing each option. To develop more reliable estimates, more detailed investigation would be required to confirm the scope, design and construction method for each of the options.

Table 19 Cost Estimates

Option		Capital Cost $m
1	Increased Pump Capacity	3.1
2	Modified Pump Triggers	0
3	Lowering of Jet Pumps	10.3
4	Reduced Jet Pump Spacing	10.0
5	Extend Pumping Jetty	8.9
6	Modify Seabed Fluidising System	0.9

5.5 Multi-Criteria Options Assessment

5.5.1 Assessment and Scoring Criteria

Fifteen assessment criteria and corresponding scoring guidelines were formulated in collaboration with TRESBP or TSB representatives for the assessment of options to improve the efficiency of the existing sand transfer system.

The assessment criteria were as follows:

- Operational disruption
- Efficiency improvement magnitude
- Efficiency improvement likelihood
- Operational improvement
- Improved operational reliability
- Reduced maintenance
- Tweed River channel dredging
- Energy use efficiency improvement
- Safety impact
- Potential for environmental impact
- Approval difficulty
- Community and stakeholder perception (incl political)
- Public amenity/access impact
- Future proofing
- NPV Cost

Scoring guidelines and weightings for each of these criteria are presented in **Table 22**.

5.5.2 Correlation with TSB Risk Register

Evaluation criteria were selected based on a combination of key risks taken from the TSB risk register and other criteria specific to this project.

The TSB risk register items are cross referenced to the relevant MCA criteria in **Table 20**.

Table 20 MCA Criteria Cross-Reference to TSB Risk Register Items

TSB Risk Register Item	Corresponding MCA Criteria
Control of sand delivery volumes	Improved operational reliability
Clear navigation channel not maintained	Efficiency Improvement (magnitude) Efficiency Improvement (likelihood) Tweed River channel dredging
Consistency with natural supply	Potential for environmental impact
Asset condition	Reduced maintenance
Community engagement	Community and stakeholder perception
Stakeholder engagement	Community and stakeholder perception
Op Cost	NPV Cost
Project knowledge	NA
Public safety	Public amenity/access impact
Land leases	Add
Catastrophic failure	Improved operational reliability
Letitia Beach recession	Potential for environmental impact
Project transition	Future proofing

5.5.3 MCA Results

The criteria assessed for the multi-criteria analysis (MCA), their weightings, assessment basis and results are presented in **Table 22**.

. A summary of the MCA results is provided in **Table 21**.

Table 21 Options MCA Results Summary

Option		With Costs		Without Costs	
		MCA Score	Rank	MCA Score	Rank
1	Increased Pump Capacity	48	6	58	6
2	Modified pump triggers	58	2	70	2
3	Lowering of Jet Pumps	53	4	66	4
4	Reduced Jet Pump Spacing	50	5	61	5
5	Extend Pumping Jetty	55	3	67	3
6	Modify Seabed Fluidising System	79	1	97	1

The relatively narrow spread of scores across the options indicates that there is limited overall differentiation between the options.

The relative capital cost of the options makes no difference to the MCA rankings.

Option 6 (Modified seabed fluidiser system) ranks highest overall because it offers the highest potential increase in potential sand transfer efficiency increase and energy use efficiency with very little modification of the existing TSB system and therefore relatively low cost.

Option 2 (modified pump triggers) ranks second highest overall, mainly because it requires no physical works means that no approvals will be required and there is very unlikely to be any objections to the work from the public.

Option 3 (lowering the jet pumps) and Option 5 (extending the jetty and installing more pumps) scored virtually the same with Option 5 being marginally higher. However, if Option 3 does not require re-piling (which would be the case if future investigation determines that the jetty piles to not need to be modified/replaced if the jet pumps are lowered), its Cost-Inclusive MCA ranking changes from third to second, and becomes cleared preferable over Option 5.

The MCA scores for Option 1 (increased pump capacity) and Option 4 (reduced pump spacing) are similar, but lower than the other options.

It is important to consider these MCA scores in the context of the overall sand transfer efficiency gains they might achieve. None of the options are expected to provide a substantial increase in sand transfer. The transfer efficiency improvements predicted for Options 1, 2 and 4 are well with within the margin of error for the method used to derive them. Effectively this means that little or no sand transfer efficiency improvements can be expected to be achieve if options 1, 2 or 4 are implemented. Option 5 (jetty extension) may achieve a minor improvement (or 8%) in sand transfer efficiency. Option 3 is the may provide an appreciable improvement in sand transfer efficiency. Option 6 can potentially delivery the largest improvement in sand transfer efficiency.

5.5.4 Outcome

In this context, it is difficult to justify pursuing Options 1 or 4 given their cost. Modification of the trigger points in the control system (Option 2) is worth implementing because it involves negligible cost or modification of the existing system.

Extension of the jetty (Option 5) could be considered, but would involve significant capital works and expense for relatively marginal potential benefit.

Lowering the jet pumps (Option 3) is more likely to be of benefit and its attractiveness is greatly improved if the existing jetty piling does not need to be lowered if it is implemented.

Modifying the seabed fluidising system (Option 6) has the potential to achieve large improvements in sand transfer efficiency and energy use savings at relatively low cost, and with minimal disruption to the TSB system operation.

5.6 Implementation Strategy

The following implementation strategy is recommended based on this assessment:

- Undertake testing of modifications to the seabed fluidising system at each jet pump (to increase slurry density) and implement on all jet pumps if demonstrated to be feasible.
- Experiment with modifying the pump operations (start/stop trigger points, frequency of pump cycling etc) to determine an optimum operating regime for the system,
- Undertake a detailed feasibility assessment of the potential for lowering the level of the jet pumps to determine the scope of works required (particularly whether the existing jetty piles would need to be deeper when the jet pumps are lowered).
- Undertake detailed modelling of the offshore sand movement processes to more reliably determine the potential sand transfer efficiency improvements this strategy might achieve.

Options 1, 4 and 5 are not recommended for implementation.

Table 22 Multi Criteria Assessment – Sand Transfer Efficiency Improvement Options

				Options						Scoring Criteria						
	Criteria			1	2	3	4	5	6							
No.	Description		Weighting *(1-10)*	Increased Pump Capacity	Modified Pump Triggers	Lowering of Jet Pumps	Reduced Jet Pump Spacing	Extend Pumping Jetty	Modify Seabed Fluidising System	1 (Worst)	2	3	4	5 (Best)	Key assessment words	Assumptions
1	Operational disruption		3	1	5	1	1	2	5	29+days	8-28 days	3-7 days	1-2 days	None	Downtime, installation duration	Works occur in spring
2	Efficiency improvement magnitude		8	1	1	3	1	2	5	Very Low	Low	Moderate	High	V. High	Reduced blockages, higher flux density, less bypass	
3	Efficiency improvement likelihood		8	2	2	3	2	4	4	Uncertain	Possible	Probable	Likely	Almost certai	Same as 2	
4	Operational improvement		1	1	1	1	1	1	1	Very Low	Low	Moderate	High	V. High	Reduced operator workload, automation	
5	Improved operational reliability		4	1	1	1	1	1	1	Very Low	Low	Moderate	High	V. High	Unscheduled breakdown, failure incl catastrophic	
6	Reduced maintenance		1	1	1	1	1	1	2	Very Low	Low	Moderate	High	V. High	Reduced wear, increased operating frequency	
7	Tweed River channel dredging		8	1	1	3	1	2	4	No change	Minor red	Reduced	Occasional	Not needed	Frequency, material volume	In terms of channel compliance activities
8	Energy use efficiency improvement		7	1	3	2	3	2	5	Signif incrs	Increase	Nil	0-15% decrs	>15% decrs	Power use efficiency kWh/m3	
9	Safety impact		8	3	3	2	3	3	3	FF	Minor Dec	No change	Increase	Signif incrs	Public safety (beach acccess, discharge at outlet), operational safety	
10	Potential for environmental impact		8	3	3	4	3	4	3	Signif incrs	Increase	No change	Decrease	Signif decrs	Receiving beaches, seabed, beach erosion, flauna	
11	Approval difficulty		4	4	5	2	3	2	5	V. High	High	Moderate	Low	Very Low	Land leases, enviro, heritage etc	
12	Community and stakeholder perception (incl politi		5	3	5	2	3	2	5	Against	Negative	Neutral	Positive	Supportive	Media, complaints, perception	
13	Public amenity/access impact		8	3	3	2	3	2	3	Signif decrs	Decrease	No change	Increase	Signif incrs	Beach access, nearshore safety, visual amenity	
14	Future proofing		7	5	5	5	5	5	5	None	1-5 years	6-10 years	11-15 years	>15 years	Upgrade horizon, current technology	Project transition/commerical issues assumed to be mitigated
15	Capital Cost		5	3	4	2	3	3	4	>+2.0 sd	+1 to +2 sd	-1 to +1 sd	-1 to -2 sd	<-2.0 sd	Standard deviations from the mean of the option	
	Normalised Score	Including Cost Scores		48	58	53	50	55	79							
	(out of 100)	Excluding Cost Scores		58	70	66	61	67	97							
	Ranking	Including Cost Scores		6	2	4	5	3	1							
		Excluding Cost Scores		6	2	4	5	3	1							

6. Energy Source Evaluation

6.1 Existing Energy Source

The TSB site is currently powered by mains AC power supplied to the site via an 11kV feeder main to a transformer at the raw water intake (low pressure) pump station and another at the TSB JMPS control building.

6.2 Energy Source Alternatives

6.2.1 Overview

Several alternative sources of energy have been considered for implementation for the TSB operation, including:

- Solar energy (photovoltaic cells)
- Wave energy
- Tidal energy
- Wind energy
- Battery storage

The feasibility of implementing these options as an alternative source of power for the TSB system is explored below.

6.2.2 Solar Energy

Photovoltaic (PV) electricity is currently the fastest growing renewable energy technology used in Australia, with over 7000 MW currently installed. The size of the plants installed varies from a few kW on domestic rooftops to over 200MW on commercial solar farms.

Concentrated Photovoltaic (CPV) systems replace most of the PV cell area in a standard system with mirrors or lenses. These direct the sunlight onto small solar cells which then convert the light into electrical energy. The more widely known concentrated solar thermal systems allows for the storage of energy in the form of heat in thermal energy storage systems. These thermal energy storage systems usually consist of large tanks of a medium that has a high specific heat capacity such as molten salt or oil. A steam turbine using this stored heat allows electricity generation during night time or during cloud cover, and can provide a predictable power supply on a more continuous basis. It is relatively expensive and lends itself to use with large scale projects. Only one such project is currently under development in Australia, a 150 MW project by Alinta Energy in Port Augusta. These systems offer electricity storage, which is advantageous for renewable energy projects. However, they are not feasible for small power outputs.

Conventional photovoltaic systems consist of an array of solar panels connected to the grid through an inverter. These systems are scalable, limited in size only by the capacity of the grid to connect it.

The use of photovoltaic electricity is a proven technology, and the energy yield potential at any location is readily predictable based on the normal direct irradiance data readily available from published sources. Costs have reduced dramatically in recent years, with the installed costs reducing to as little as $1,000 per kilowatt, depending on the location.). The feasibility of use of solar generation in any location depends on the availability of a suitable area for location of the solar panels. For domestic and commercial applications this usually involves rooftop installations. This technology requires approximately 10m^2 of land/roof area to produce 1kW, so for Tweeds Sands only a 40 kW output is anticipated (based on the roof area of the control building). For a larger scheme to be used at TSB would first require a study on available land area, the protection of any vegetation required for clearance, and any shading problems due to surrounding structures or bush.

The government-funded small scale renewable energy target (SRET) provides additional financial incentive for renewable energy investment. The feed-in tariff which must be negotiated with the energy supplier can affect the economics significantly.

Generation from photovoltaic systems is only possible during daylight hours, unless significant battery storage is installed. Therefore solar photovoltaic is often used as part of a hybrid battery system which can also provide power during night time.

Feasibility: Solar power generation is considered to be a viable power source for TSB for non-pumping power demands (such as the control building). Mains power should also be retained as the limited solar power available capacity will offer mains support only and will be insufficient as a stand-alone supply.

6.2.3 Wave Energy

Wave energy is still very much an experimental technology, and remains unproven commercially. The suitability of wave energy at Tweed Heads would be subject to a satisfactory feasibility study, and no doubt subject to strict environmental compliance.

Feasibility: Wave energy power generation is not considered to be viable as a power source for TSB.

6.2.4 Tidal Energy

Tidal energy is regarded as largely unproven commercially. There has been some experimental tidal research work in Australia (in areas such as North Western Australia which has a large tidal differential). However, there are only a small number of installations of tidal power generation schemes operating worldwide. These range in size from less than 1 MW to 240 MW. The suitability of tidal energy at Tweed Heads would be subject to a satisfactory feasibility study, and no doubt subject to strict environmental compliance.

Feasibility: Tidal power generation is not considered to be viable as a power source for TSB.

6.2.5 Battery Storage

Battery storage potentially offers three main benefits to the project:

- Increased reliability: The reliability of power supply can be increased by installing a battery storage system of sufficient capacity to operate the pumping system during periods when the grid supply is not available. For Tweed Sands this would require a very large battery capable of driving the 750 kW pumps (two slurry pumps operating in series). It is understood that supply interruptions are not a major concern at Tweed Sands, and any benefit from increased reliability will therefore be limited. A large area would be required to provide any significant battery capacity.

- Load levelling: This can be beneficial when the load demand curve imposes high maximum demand charges, which can be levelled out using battery storage. This normally requires a smaller battery than that required for reliability purposes. For Tweed Sands, the benefits would be limited because the pumping load profile is fairly constant.

- Energy Management: If used in conjunction with a renewable energy source (eg solar), battery storage can allow rescheduling of the energy use to suit operations. This could be useful, for example, if sand-pumping operations were required at night, which would allow storage of the solar energy during the day. Some studies would be required to optimise the battery capacity. A large area would be required to provide any significant battery capacity.

To be effective in a project using renewable energy, battery charging should be done primarily using electricity generated from the renewable resource (otherwise the charge/discharge cycle using grid power will result in a nett energy loss due to inefficiencies in the energy conversion process). Therefore battery storage at Tweed Sands should be used in conjunction with a solar scheme of a capacity exceeding the normal daytime operations (approximately 60kW). Solar PV panels of this capacity would exceed the space available on the roof of the control building and would require a footprint on the ground elsewhere at TSB, which is clear of vegetation and shading issues.

Latest technology batteries for this application are of the lithium-ion type. The battery lifetime is expected to be approximately 10 years, although they can sometimes still perform after this time with reduced performance. Current pricing in Australia is in the region of $800/kWh. The battery capacity for TSB would be determined by an optimisation study, but a typical installation might consist of eight Tesla PowerWall modules with a capacity of 105 kWh, costing approximately $84,000 installed. The economics and Rate of Return would need to be determined by a study considering the solar generating capacity, the tariff structure, and the load profile.

If no operational benefits (such as security of supply or load levelling) can be provided by battery storage, as is the case at TSB, then the use of storage batteries would need to be justified on purely economic grounds. As a guide, some estimates indicate the cost of batteries would need to reduce by approximately 60% from current costs for this to occur, but this will depend on the particular installation.

Feasibility: Battery storage should not be considered for the TSB in conjunction with solar power generation.

6.2.6 Wind

There is currently approximately 4,500 MW of wind power installed in Australia, mostly in large wind farms up to 420 MW. The feasibility of wind energy at Tweed Heads will depend on the proving of the resource, (which requires long term analysis of the wind energy), and the obtaining of the necessary consents. As with solar energy, wind power cannot be considered a dispatchable power source, but is generated as available. It is doubtful that consents would be easily available at Tweed Sands for conventional 90m tall wind towers, so any wind energy installed there would probably be very small scale.

Feasibility: Wind power generation is not considered to be viable as a power source for TSB.

6.2.7 Hydrogen

Recent developments in hydrogen fuel cell technology have led to renewed interest in this as an alternative fuel source, especially when linked to renewable energy production. Difficulties in transporting and storing hydrogen due to its low density have to date discouraged the uptake of hydrogen as a fuel, but recently the CSIRO has announced the development of a membrane technology which could allow hydrogen to be safely converted to ammonia for safe transport. It is hoped this would enable the hydrogen to be used as a mass production energy storage.

While it is understood that the technology has sparked expressions of interest from Japan, South Korea and Europe, it is not currently operating commercially and will require more investment and development before it can be considered a viable alternative energy source.

Feasibility: Hydrogen-powered generation is not considered to be viable as a power source for TSB.

6.3 Alternative Energy Source Strategy

6.3.1 Recommended Option

All the options explored in **Section 6.2** (except solar photovoltaics in conjunction with battery storage) will require significant feasibility study to determine for their suitability for use in this project. They will also probably face environmental and permitting issues. In most cases, they are either not yet proven technologies or have no fuel resource.

Therefore, only the solar photovoltaic option is considered to warrant further consideration for use for the Tweed Sand Bypass system.

6.3.2 Implementation

A photovoltaic power supply can be implemented at the TSB JMPS site by installing:

- A 40kW photovoltaic panel array on the roof of the control building
- A battery bank of approximately 105kWh capacity.

This system would supply about 65% of the instantaneous non-pumping power demand of the site. The combination of battery storage and varying actual power load means that the percentage of total non-umping power demand supplied form the solar/battery system would likely exceed 65%. The balance of the power demand would need to be drawn from the grid supply.

To enable all non-pumping power demand to be supplied by a photovoltaic+battery system, a large area of solar panels would be needed. These would need to be located on the maintenance building and/or in ground-mounted arrays on the site.

6.3.3 Cost

The estimated cost of providing a 40kW solar power supply for the TSB JMPS control building is $0.3m. A breakdown of this estimate is provided in **Appendix A**.

7. Conclusions and Recommendations

7.1 Conclusions

The following conclusions have been determined in this study:

Sand Trapping/Transfer Efficiency

- Based on SANDTRAP modelling of the JMPS, the impact on sand trapping efficiency will be as follows:
  - Operating five jet pumps at once (instead of four) will have negligible impact.
  - Modifying the jet pump stop-start trigger points will provide a very minor improvement.
  - Reducing the spacing between jet pumps will provide a very minor improvement.
  - Extending the jetty seaward by 60m and adding two extra jet pumps will provide a minor improvement.
  - Lowering the jet pumps by one metre jet pumps will provide moderate improvement.
- The most significant observation to be made from this data is that the actual average density of the slurry being transferred by the TSB system is only about 1.20 t/m^3 compared with a design density of 1.46 t/m^3.
- A 18% reduction in average slurry density from 1.46 to 1.20 t/m^3 results in a 60% reduction in sand transferred (from 1001tph to 400 tph) and a 106% increase in power consumption per cubic metre of sand transferred (from 1.02 to 2.10 kWh/m^3). The most effective means of increasing the energy use efficiency of the system will be to increase the slurry density. Other solutions will all involve increasing the capacity of the existing system (eg: higher flow, more jet pumps etc) which will involve significant cost and disruption to modify the existing TSB system.
- Based on the outcomes of a multi criteria assessment and cost estimates prepared for a number of options, the following options were concluded to be worth pursuing based on their likely effectiveness (in improving sand transfer efficiency), implementation cost, and potential lower power use:
  - Modifying the pump start-stop trigger points (negligible cost, and possible minor improvement)
  - Modification of the seabed fluidising system (low cost, and potential large improvement).
  - Lowering of the jet pumps by one meter *(only if this does not result in the need to re-pile the jetty)* (low cost, and potential minor/moderate improvement).

Energy Efficiency Improvement Options

- Constraining operation of the TSB system to off-peak times could reduce the scheme’s cost by 38%. Note however this would not achieve any reduction in energy consumption and would constrain (ie: probably reduce) the volume of sand transferred.
- Increasing the slurry density by 17% from 1.2 to 1.25 t/m^3 could improve power usage efficiency by 24% (in terms of volume of sand transferred per kWh of energy used).

Energy Source Options

- Solar energy (photovoltaic cells) in conjunction with battery storage is considered to be a viable alternative source of energy for the non-pumping TSB system power demand.
- Use of photovoltaics is not considered to be feasible for TSB system pumps power supply because the demand is very high and very large photovoltaic arrays would be required (which significantly exceed the area available on the existing TSB site).
- Mains power would need to be retained as a back-up power source if photovoltaic power supply is installed for the TSB system.
- Other alternative energy sources were evaluated (wave energy, wind energy, tidal energy and hydrogen fuel cells), however none of these are considered to be feasible for implementation for the TSB system due to a combination of scaling/size constraints, unproven commercial viability and inability to operate as a dispatchable/baseload power supply.

7.2 Recommendations

The following actions are recommended on the basis of the findings of this study:

1. Undertake testing of modifications to the seabed fluidising system at each jet pump (to increase slurry density) and implement on all jet pumps if demonstrated to be feasible.
2. Experiment with modifying the pump operations (start/stop trigger points, frequency of pump cycling etc) to determine an optimum operating regime for the system,
3. Undertake a detailed feasibility assessment of the potential for lowering the level of the jet pumps to determine the scope of works required (particularly whether the existing jetty piles would need to be deeper when the jet pumps are lowered).
4. Undertake detailed 3D modelling of the offshore sand movement processes to more reliably determine the the potential sand transfer efficiency improvements this strategy might achieve.
5. Undertake a detailed feasibility assessment of the potential for providing photovoltaic power supply and battery units to reduce grid power us by the non-pumping components of the TSB facility.
6. Reprogram SCADA to extract individual jet pump data. This will enable assessment of the performance for each individual pump (compared with the current data which applies to the system as a whole).
7. Validate Sandtrap tool outputs against ADCP and SCADA data and the 3D sand transport model results (Recommendations 4 and 6 must be implemented first).
8. Monitor the shape of sand drawdown cones in conjunction with jet pump performance data (implement in conjunction with Recommendation 6).

8. References

BMT WBM, 2011. Reassessment of Long Term Average Annual Net Sand Transport Rate. Ref: R.B17328.002.02.doc, September 2011

BMT WBM, 2016. Reassessment of Long Term Average Annual Net Sand Transport Rate 2015. Ref: R.B21627.001.00.doc, April 2016.

BMT WBM, 2017. Currumbin Coastal Process Assessment, R.B22132.001.01, June 2017 (in Draft)

Cardno Lawson Treloar, 2009, Tweed River Entrance Sand Bypassing System Review of Operations Coastal Processes Modelling. Ref: 790198/R2528, 5 May 2009.

Cardno, 2015. Gold Coast Seaway Sand Bypassing System – Energy Efficiency Studies Report. Ref 7904/02. For Gold Coast Waterways Authority, Version 2, 6 March 2015.

Jacobs, 2017. Tweed Quantified Conceptual Sediment Transport Model, Ref: IH123200-3200-RPT-1001, Rev 1, 01 Dec 2017.

Little, K Tweed River Entrance Sand Bypassing System – Review of Operations. K Little Engineering.

Kamphuis, J.W. 1991. Alongshore sediment transport rate. Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 117, 624-640

KBR, 2006. Tweed River Entrance Sand Bypassing Project. Jetty Efficiency Study – Supplement No. 3 – February 2004 to July 2005. Prepared for McConnell Dowell (Constructors) Pty Ltd. Ref BEJ304-W-DO-003, Rev 0, 10 March 2006.

KBR, 2007. Tweed River Entrance Sand Bypassing Project. Five-Year Review Report. Prepared for Tweed River Entrance Sand Bypassing Company. Ref BEJ704-W-REP-001, Rev 1, 6 November 2007.

NSW Department of Commerce, 2007. Asset Valuation. Tweed River Entrance Sand Bypassing Project Infrastructure, June 2007.

SMEC, 2017. Gold Coast Waterways Authority Seaway Sand Bypass System – Renewable Energy Study, Rev 5, 06 July 2017.

Van Rijn, L.C., 1987. Mathematical modelling of morphological processes in the case of suspended sediment transport. Doc. Thesis, Delft University of Technology, Delft, The Netherlands

Water Technology, 2007. Review of Sand Bypassing Efficiency Tweed River Entrance, Report No. J622/R01, Rev 3, October 2007

Appendix A. Cost Estimates

A.1 Basis of Estimates

A.1.1 Scope

Cost estimates prepared for this report are intended only to provide a cost comparison between options. They are not suitable for budgeting; estimates suitable for this purpose would require more detailed design consideration.

A.1.2 Capital Cost

Infrastructure capital cost estimates for each strategy have been determined on the basis of cost curves developed from actual costs of similar infrastructure on other projects in Australia.

The following items are excluded from the estimates:

- Owner's costs (typically 5-10% of capital expenditure).
- EPCM costs (typically 30% of capital costs depending on the complexity of the work)
- Contingency allowances.

Actual costs of infrastructure projects can vary significantly depending on a wide range of factors, including:

- Prevailing construction market conditions.
- Site specific constraints (e.g. accessibility difficulty, security risks).
- Schedule urgency – fast-tracked project cost more
- Commodity and materials prices.
- Shortfalls in particular services or key inputs (e.g. labour, power supply).

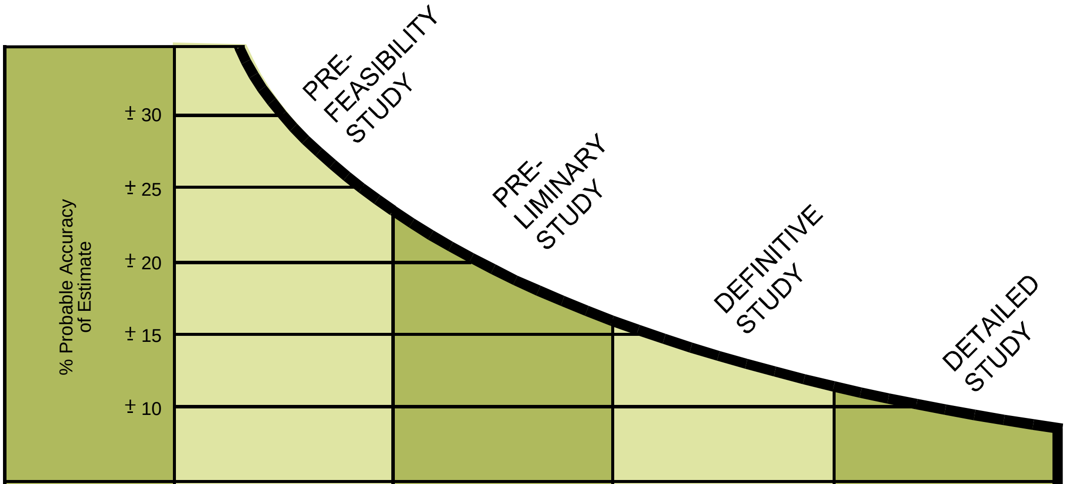
A.1.3 Estimate Accuracy

The cost estimates produced for this report have been determined by a combination of factoring and basic quantity take off. As such, they are considered to be a "Pre-feasibility" level estimates as defined by **Table 23** and have an accuracy of approximately ± 50%.

However, it is important to note that the estimates are based on a generic standard design approach and the cost may change significantly when shortlisted options are investigated in more detail and designs are developed in later studies.

The purpose of these estimates is primarily for cost comparison of options, and it is strongly recommended that the cost estimates be treated with caution, particularly if they are used for informing budget estimates. Use of appropriate cost risk assessment to determine contingency allowances is recommended.

Table 23 Definition Chart for Engineering Cost Estimates



Type of Estimate	Order of Magnitude	Preliminary	Definitive	Detailed
Provided Documentation	• Product capacity and Location • Cost Data on Similar Projects • Major Equipment List	• Preliminary Equipment List • Engineering Line Diagram • Plant Outline General Arrangement • Maps and Surveys • Bench Test Results • Nature of Facilities	• Equipment Specifications and Vendor Quotations • Construction Schedule • Electrical One Lines • Piping and Instrumentation Flow Diagrams • Soil Data and Architect Features • Site Survey and Labour Complete	• Bulk Material Specifications and Vendor Quotes • Construction Specification and Sub Contractor Quotations • Engineering Advanced Approximately 10%
Definition of Scope of Work	Conceptual	Approximate	Clearly Described Essentially Complete	Complete. Well Detailed
Estimating Procedure	Factoring	Combination of Factoring and Quantity Take-Off	Most Quantity Take-Off. Very little Factoring	Complete Quantity Take-Off
Use of Study	Comparison/ Rejection	Final Feasibility	Budget	Funding

Capital Cost Estimate

Option 1 - Increased Pump Capacity

IH145900 TSB Efficiency Study

Revision	B
Revision Date	11/02/2019
Print Date	13/02/2019 0:50

Item	Description	Unit	Qty	Rate $/unit)	Amount $
1	**Raw Water Pump Station Upgrade**				
1.1	Replace Pump	EA	1	140,000	140,000
1.2	Upgrade electrical system	LS	1	150,000	150,000
1.3	Modify pump jetty	LS	1	75,000	75,000
1.4	Modify pipework	LS	1	50,000	50,000
	Item Sub-Total				**415,000**
2	**High Pressure Pump Upgrade**				
2.1	Replace Pump	EA	1	530,000	530,000
2.2	Upgrade electrical system	LS	1	350,000	350,000
2.3	Modify pump mounts	LS	1	100,000	100,000
2.4	Modify pipework	LS	1	150,000	150,000
	Item Sub-Total				**1,130,000**
2	**High Pressure Pump Upgrade**				
2.1	Replace Pump	EA	1	30,000	30,000
2.2	Upgrade electrical system	LS	1	75,000	75,000
2.3	Modify pump mounts	LS	1	20,000	20,000
2.4	Modify pipework	LS	1	30,000	30,000
	Item Sub-Total				**155,000**
3	**Overflow Upgrade**				
3.1	Stilling Basin Extension	LS	1	200,000	200,000
3.2	Overflow Chamber Extension	LS	1	100,000	100,000
3.3	Outlet pipe upgrade	m2	75	750	56,250
	Item Sub-Total				**356,250**
	Sub-Total				**2,056,250**
	Survey, Geotech and approvals			5.0%	102,813
	Design			10.0%	205,625
	Project Management			10%	205,625
	Contingency			25%	514,063
	Total				**3,084,375**
	Estimated Capital Cost				**3,090,000**

Capital Cost Estimate
Option 3 - Lower Jet Pumps
IH145900 TSB Efficiency Study

Revision	B
Revision Date	11/02/2019
Print Date	13/02/2019 0:50

Item	Description	Unit	Qty	Rate $/unit)	Amount $
1	**Jetty Modifications**				
1.1	Pile Extensions 457OD	EA	30	20,000	600,000
	Pile Extensions 610OD	EA	40	40,000	1,600,000
	Pile Extensions 762OD	EA	20	80,000	1,600,000
1.2	Pile headstock replacement	EA	46	22,500	1,035,000
1.3	Temporary deck modifications during installation	EA	46	40,000	1,840,000
	Item Sub-Total				**6,675,000**
2	**Booster Pump Upgrade**				
2.1	Replace Pump Impeller	EA	1	20,000	20,000
	Item Sub-Total				**20,000**
3	**Pipework Modifications**				
3.1	Jet pump pipework extensions (1m)	EA	10	10,000	100,000
3.2	Stilling basin discharge modification	LS	1	60,000	60,000
	Item Sub-Total				**160,000**
	Sub-Total				**6,855,000**
	Survey, Geotech and approvals			5.0%	342,750
	Design			10.0%	685,500
	Project Management			10%	685,500
	Contingency			25%	1,713,750
	Total				**10,282,500**
	Estimated Capital Cost				**10,290,000**

Capital Cost Estimate

Option 4 - Pump Spacing Reduction

IH145900 TSB Efficiency Study

Revision	B
Revision Date	11/02/2019
Print Date	13/02/2019 0:50

Item	Description	Unit	Qty	Rate $/unit)	Amount $
1	**Jetty Modifications**				
1.1	Structural modifications at extra pump locations	EA	8	75,000	600,000
1.2	Additional Pump platforms	EA	8	125,000	1,000,000
	Item Sub-Total				**1,600,000**
2	**Additional Jet Pumps**				
2.1	Supply header connections	ea	8	13,000	104,000
2.2	Flume discharge connections	ea	8	13,000	104,000
2.3	Jet pump pipework assesmbly	ea	8	550,000	4,400,000
2.4	Density meters	ea	8	15,000	120,000
2.5	Stilling basin discharge modification	LS	1	30,000	30,000
	Item Sub-Total				**4,758,000**
3	**EIC**				
3.1	Control panel upgrade	LS	1	150,000	150,000
3.2	Instrumentation install and wire	LS	1	100,000	100,000
3.3	Control system programming	LS	1	20,000	20,000
	Item Sub-Total				**270,000**
	Sub-Total				**6,628,000**
	Survey, Geotech and approvals			5.0%	331,400
	Design			10.0%	662,800
	Project Management			10%	662,800
	Contingency			25%	1,657,000
	Total				**9,942,000**
	Estimated Capital Cost				**9,950,000**

Capital Cost Estimate
Option 5 - Extend Jetty Seaward
IH145900 TSB Efficiency Study

Revision	B
Revision Date	11/02/2019
Print Date	13/02/2019 0:50

Item	Description	Unit	Qty	Rate $/unit)	Amount $
1	**Jetty Modifications**				
1.1	Piling - 762 OD	EA	12	245,000	2,940,000
1.2	Pile caps/beams - supply & install	EA	6	22,500	135,000
1.3	Deck - supply & install	m2	220	3,100	682,000
1.4	Ballustrades - supply & install	m2	125	310	38,750
1.5	Connect to existing jetty	LS	1	30,000	30,000
1.6	Additional Pump platforms	EA	2	125,000	250,000
	Item Sub-Total				**3,795,750**
2	**Jet Pumps**				
2.1	Header pipework 508OD	ea	60	2,400	144,000
2.2	Flume discharge pipework 610OD	ea	60	3,100	186,000
2.3	Flume dilution pipework DN250	ea	60	1,400	84,000
2.4	Header pipework connections	ea	2	40,000	80,000
2.5	Flume pipework connections	ea	2	20,000	40,000
2.6	Flume dilution pipework connections	ea	2	10,000	20,000
2.7	Jet pump pipework assesmbly	ea	2	550,000	1,100,000
2.8	Density meters	ea	2	15,000	30,000
2.6	Stilling basin discharge modification	LS	1	60,000	60,000
	Item Sub-Total				**1,744,000**
3	**EIC**				
3.1	Control panel upgrade	LS	1	150,000	150,000
3.2	Instrumentation install and wire	LS	1	75,000	75,000
3.3	Control system programming	LS	1	20,000	20,000
	Item Sub-Total				**245,000**
	Sub-Total				**5,924,750**
	Survey, Geotech and approvals			5.0%	296,238
	Design			10.0%	592,475
	Project Management			10%	592,475
	Contingency			25%	1,481,188
	Total				**8,887,125**
	Estimated Capital Cost				**8,890,000**

Capital Cost Estimate

Option 6 - Modify Seabed Fluidising System

IH145900 TSB Efficiency Study

Revision	B
Revision Date	11/02/2019
Print Date	13/02/2019 0:50

Item	Description	Unit	Qty	Rate $/unit)	Amount $
1	**Modify Jet Pump Fluidising system**				
1.1	Pipework modifications	ea	10	35,000	350,000
1.2	Actuated valves	ea	10	10,000	100,000
	Item Sub-Total				**450,000**
2	**EIC**				
2.1	Control panel upgrade	LS	1	50,000	50,000
2.2	Instrumentation install and wire	LS	1	50,000	50,000
2.3	Control system programming	LS	1	20,000	20,000
	Item Sub-Total				**120,000**
	Sub-Total				**570,000**
	Survey, Geotech and approvals			0.0%	0
	Design			10.0%	57,000
	Project Management			10%	57,000
	Contingency			25%	142,500
	Total				**826,500**
	Estimated Capital Cost				**830,000**

Capital Cost Estimate
40kW Photovoltaic Power Supply
IH145900 TSB Efficiency Study

Revision	A
Revision Date	27/11/2018
Print Date	13/02/2019 0:50

Item	Description	Unit	Qty	Rate $/unit)	Amount $
1	**Photovoltaic Power Supply System**				
1.1	Roof-mounted solar power cell array	kW	40	2,000	80,000
1.2	Battery Bank	LS	1	84,000	84,000
2.1	System integration	LS	1	20,000	20,000
	Item Sub-Total				**184,000**
	Sub-Total				**184,000**
	Survey, Geotech and approvals			5.0%	9,200
	Design			10.0%	18,400
	Project Management			10%	18,400
	Contingency			25%	46,000
	Total				**276,000**
	Estimated Capital Cost				**280,000**

Appendix B. Results of Sand Trapping Efficiency Modelling

Table 24 Summary of results of SANDTRAP simulations – 'Modified pump triggers' scenario

Longshore sand transport rate	Modelled volume trapped by sand trap (m^3)	Trapping efficiency (% of LST through jetty)	Sand leakage through jetty (% of total LST)	Sand leakage offshore of jetty (% of total LST)	Total Sand leakage (% of total LST)	Modelled annual northward LST (m3/year)	Calculated annual leakage (m^3/year)
1,000m3/day	956	93.3%	6.7%	0.0%	6.7%	90,351	6,046
2,000m3/day	1,536	77.1%	22.9%	0.0%	22.9%	117,852	26,971
3,000m3/day	2,004	70.9%	27.6%	5.0%	32.6%	76,069	24,810
4,000m3/day	2,554	70.4%	25.1%	15.0%	40.1%	62,114	24,924
5,000m3/day	2,789	65.0%	28.0%	20.0%	48.0%	108,729	52,162
10,000m3/day	4,514	63.1%	25.8%	30.0%	55.8%	95,588	53,364
15,000m3/day	5,374	53.6%	30.1%	35.0%	65.1%	24,428	15,910
20,000m3/day	5,707	52.6%	28.5%	40.0%	68.5%	83,112	56,891
Other	n/a	n/a	n/a	n/a	n/a	-11,075	-71,368
Total						**647,169**	**189,710**

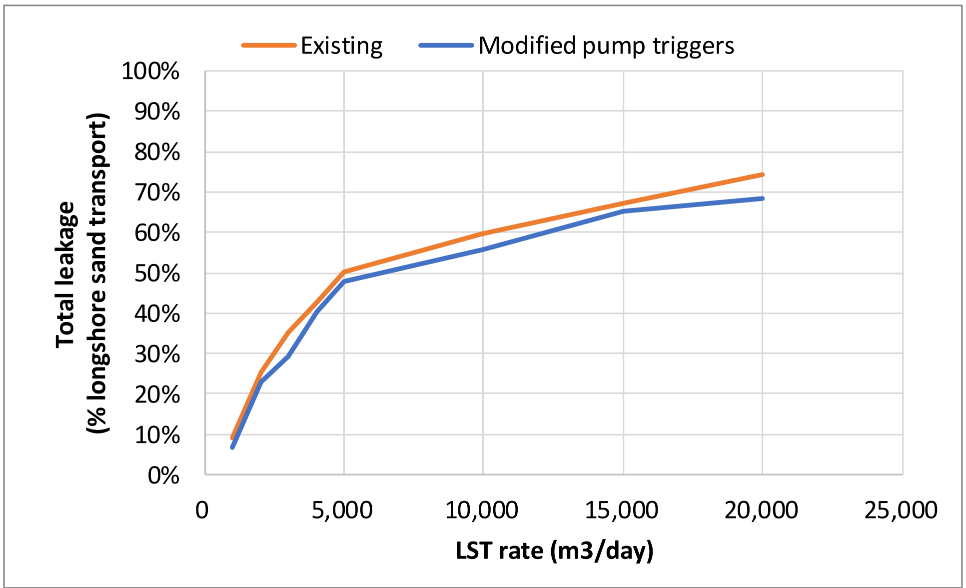


Figure 26 Modelled total sand leakage – 'Modified pump triggers' scenario vs. 'Existing Operations'

Table 25 Summary of results of SANDTRAP simulations – 'Increased Pump Capacity' scenario-

Longshore sand transport rate	Modelled volume trapped by sand trap (m^3)	Trapping efficiency (% of LST through jetty)	Sand leakage through jetty (% of total LST)	Sand leakage offshore of jetty (% of total LST)	Total Sand leakage (% of total LST)	Modelled annual northward LST (m3/year)	Calculated annual leakage (m^3/year)
1,000m3/day	933	91.0%	9.0%	0.0%	9.0%	90,351	8,156
2,000m3/day	1,500	74.6%	25.4%	0.0%	25.4%	117,852	29,980
3,000m3/day	1,971	67.8%	30.6%	5.0%	35.6%	76,069	27,055
4,000m3/day	2,355	67.2%	27.9%	15.0%	42.9%	62,114	26,642
5,000m3/day	2,521	61.1%	31.1%	20.0%	51.1%	108,729	55,544
10,000m3/day	4,226	59.0%	28.7%	30.0%	58.7%	95,588	56,121
15,000m3/day	4,933	49.7%	32.7%	35.0%	67.7%	24,428	16,540
20,000m3/day	5,971	49.1%	30.5%	40.0%	70.5%	83,112	58,614
Other	n/a	n/a	n/a	n/a	n/a	-11,075	-71,368
Total						**647,169**	**207,284**

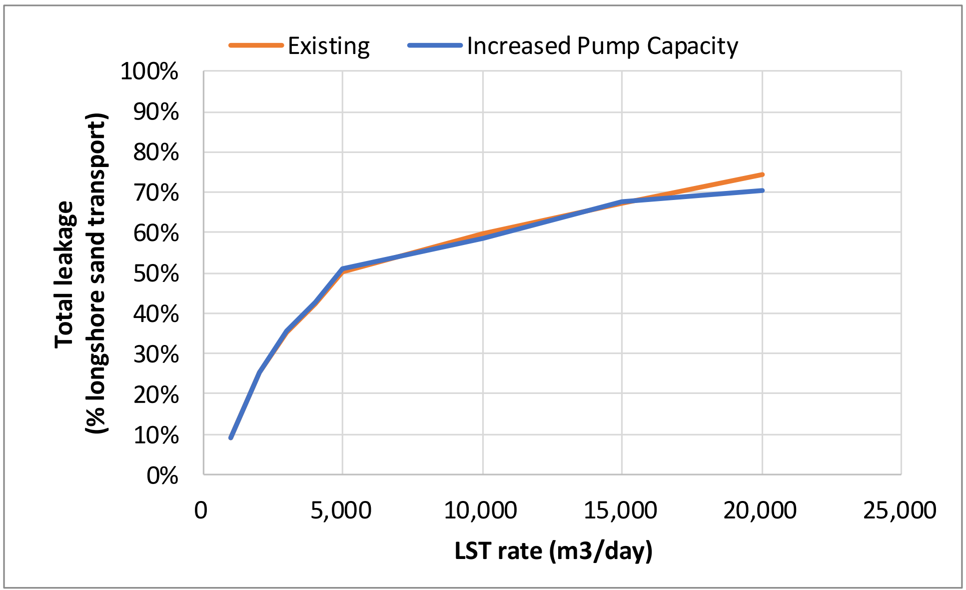


Figure 27 Modelled total sand leakage – 'Increased Pump Capacity' Scenario vs. 'Existing Operations'

Table 26 Summary of results of SANDTRAP simulations – 'Lowering of Jet Pumps' scenario

Longshore sand transport rate	Modelled volume trapped by sand trap (m^3)	Trapping efficiency (% of LST through jetty)	Sand leakage through jetty (% of total LST)	Sand leakage offshore of jetty (% of total LST)	Total Sand leakage (% of total LST)	Modelled annual northward LST (m3/year)	Calculated annual leakage (m^3/year)
1,000m3/day	1,011	98.9%	1.1%	0.0%	1.1%	90,351	1,012
2,000m3/day	1,868	90.3%	9.7%	0.0%	9.7%	117,852	11,392
3,000m3/day	2,480	86.0%	13.3%	5.0%	18.3%	76,069	13,900
4,000m3/day	2,927	86.0%	11.9%	15.0%	26.9%	62,114	16,734
5,000m3/day	3,262	81.4%	14.9%	20.0%	34.9%	108,729	37,940
10,000m3/day	5,752	81.6%	12.9%	30.0%	42.9%	95,588	40,964
15,000m3/day	7,177	73.0%	17.6%	35.0%	52.6%	24,428	12,841
20,000m3/day	8,927	73.4%	15.9%	40.0%	55.9%	83,112	46,491
Other	n/a	n/a	n/a	n/a	n/a	-11,075	-71,368
Total						**647,169**	**109,905**

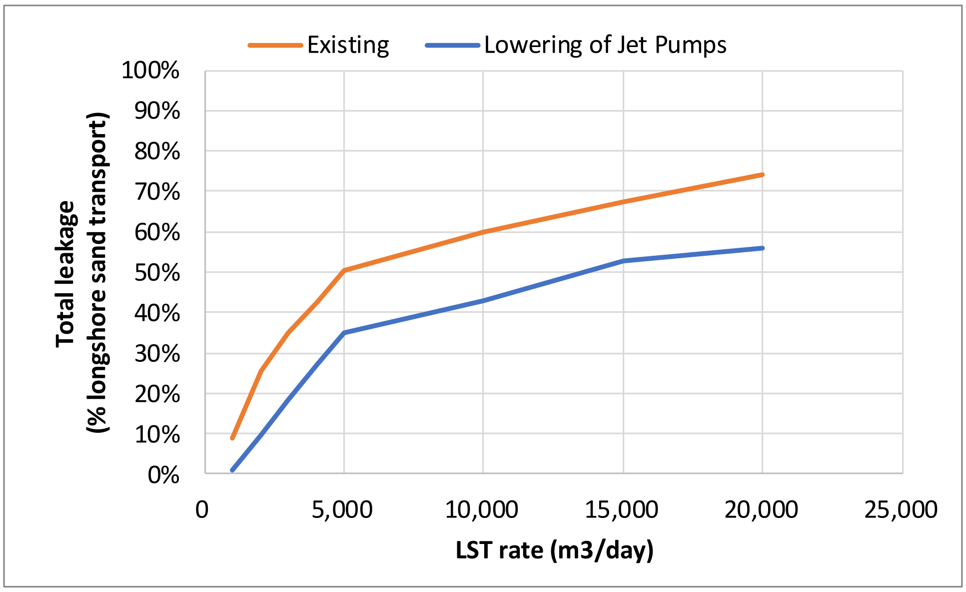


Figure 28 Modelled total sand leakage – 'Lowering of Jet Pumps' Scenario vs. 'Existing Operations'

Table 27 Summary of results of SANDTRAP simulations – 'Reduced Jet Pump Spacing' scenario

Longshore sand transport rate	Modelled volume trapped by sand trap (m^3)	Trapping efficiency (% of LST through jetty)	Sand leakage through jetty (% of total LST)	Sand leakage offshore of jetty (% of total LST)	Total Sand leakage (% of total LST)	Modelled annual northward LST (m3/year)	Calculated annual leakage (m^3/year)
1,000m3/day	971	94.8%	5.2%	0.0%	5.2%	90,351	4,682
2,000m3/day	1,617	78.7%	21.3%	0.0%	21.3%	117,852	25,151
3,000m3/day	2,129	72.7%	25.9%	5.0%	30.9%	76,069	23,538
4,000m3/day	2,495	72.4%	23.5%	15.0%	38.5%	62,114	23,893
5,000m3/day	2,707	66.7%	26.6%	20.0%	46.6%	108,729	50,674
10,000m3/day	4,566	64.5%	24.8%	30.0%	54.8%	95,588	52,420
15,000m3/day	5,524	55.4%	29.0%	35.0%	64.0%	24,428	15,632
20,000m3/day	6,526	53.2%	28.1%	40.0%	68.1%	83,112	56,565
Other	n/a	n/a	n/a	n/a	n/a	-11,075	-71,368
Total						**647,169**	**181,186**

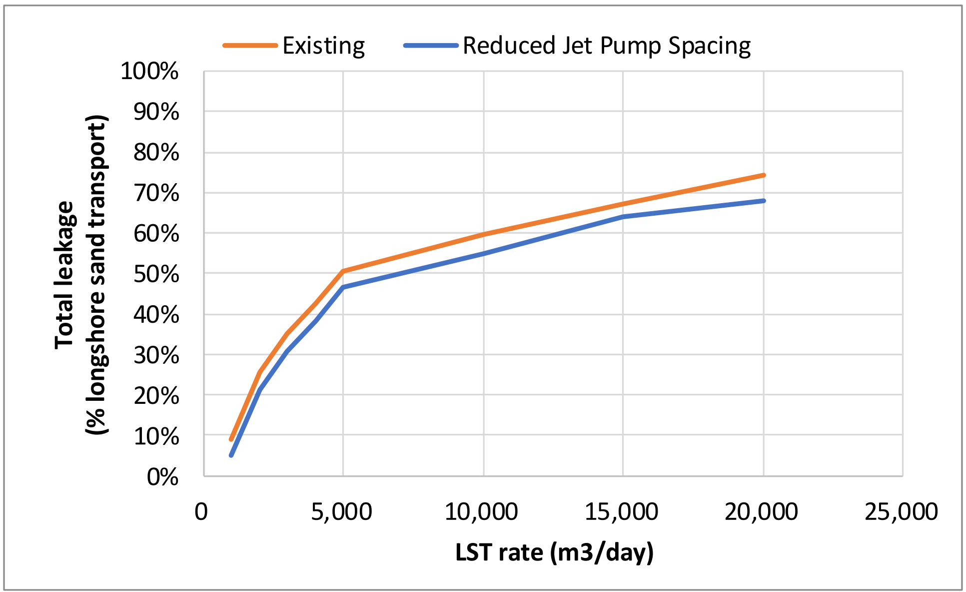


Figure 29 Modelled total sand leakage – 'Reduced Jet Pump Spacing' Scenario vs. 'Existing Operations'

Table 28 Summary of results of SANDTRAP simulations – 'Extend Pumping Jetty' scenario

Longshore sand transport rate	Modelled volume trapped by sand trap (m^3)	Trapping efficiency (% of LST through jetty)	Sand leakage through jetty (% of total LST)	Sand leakage offshore of jetty (% of total LST)	Total Sand leakage (% of total LST)	Modelled annual northward LST (m3/year)	Calculated annual leakage (m^3/year)
1,000m3/day	933	91.0%	9.0%	0.0%	9.0%	90,351	8,156
2,000m3/day	1,500	74.6%	25.4%	0.0%	25.4%	117,852	29,980
3,000m3/day	2,093	67.8%	32.2%	0.0%	32.2%	76,069	24,479
4,000m3/day	2,737	67.5%	32.5%	0.0%	32.5%	62,114	20,166
5,000m3/day	3,158	63.3%	35.9%	2.2%	38.1%	108,729	41,473
10,000m3/day	5,599	64.8%	30.1%	14.4%	44.5%	95,588	42,568
15,000m3/day	7,000	58.3%	33.1%	20.6%	53.7%	24,428	13,115
20,000m3/day	8,532	57.7%	31.0%	26.7%	57.7%	83,112	47,934
Other	n/a	n/a	n/a	n/a	n/a	-11,075	-71,368
Total						**647,169**	**156,503**

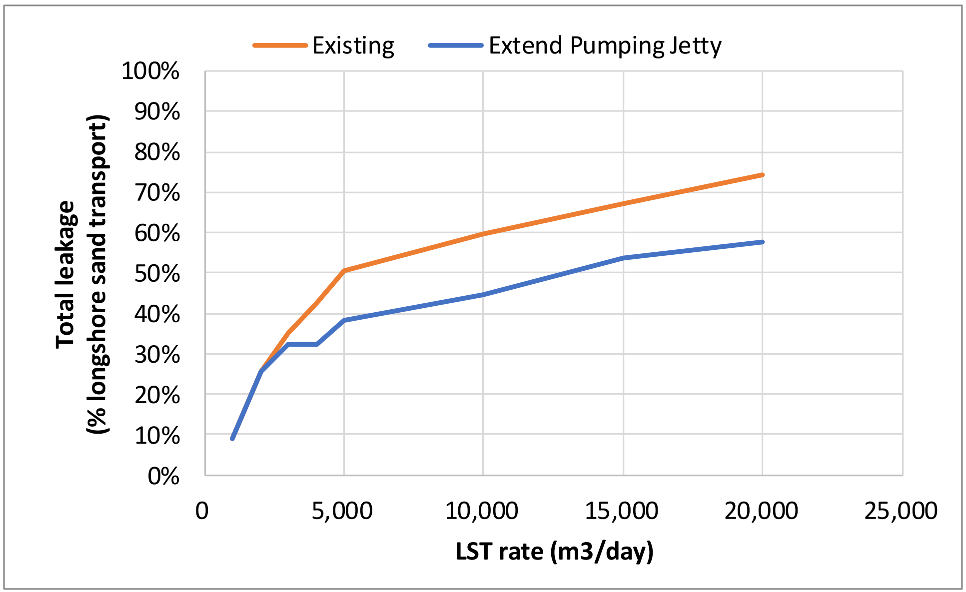


Figure 30 Modelled total sand leakage – 'Extend Pumping Jetty' Scenario vs. 'Existing Operations'

Appendix C. Results of Longshore Sand Transport Modelling

Table C-1 Modelled net annual longshore transport for selected wave conditions (m3/year)

	Peak Direction (deg TN)																	
Hs	**<30**	**30 to 40**	**40 to 50**	**50 to 60**	**60 to 70**	**70 to 80**	**80 to 90**	**90 to 100**	**100 to 110**	**110 to 120**	**120 to 130**	**130 to 140**	**140 to 150**	**150 to 160**	**160 to 170**	**170 to 180**	**<180**	**Total**
0 to 0.5	-1		-9	-5	-7	11	87	133	174	246	145	19						795
0.5 to 1.0	-586	-1,106	-970	-673	-921	703	6,702	14,899	17,573	18,612	9,169	1,466	61	2	2	0	0	64,934
1.0 to 1.5	-1,639	-2,779	-2,200	-1,742	-3,802	3,707	31,597	54,330	55,474	48,953	21,637	3,134	95					206,764
1.5 to 2.0	-334	-1,218	-1,025	-1,931	-7,526	5,854	33,852	52,250	45,712	28,880	8,440	715	16					163,684
2.0 to 2.5	-36	-245	-411	-2,431	-5,784	4,146	29,014	43,651	26,283	11,830	2,422	202						108,639
2.5 to 3.0			-208	-1,276	-3,777	3,318	22,770	23,045	5,255	542	98							49,767
3.0 to 3.5			-216	-1,655	-3,619	3,356	14,566	11,620	2,917									26,970
3.5 to 4.0			-336	-1,152	-2,548	2,095	10,217	5,004	332									13,611
4.0 to 4.5				-717	-1,154	2,786	11,378	1,141	443									13,877
4.5 to 5.0				-497	-3,126	-184	8,501											4,693
5.0 to 5.5				-625	-1,814	1,698	5,328											4,587
5.5 to 6.0					-3,133	-364												-3,497
6.0 to 6.5				-3,234	-3,138													-6,373
> 6.5				-1,238														-1,238
Total	**-2,596**	**-5,348**	**-5,374**	**-17,177**	**-40,349**	**27,124**	**174,011**	**206,072**	**154,164**	**109,064**	**41,911**	**5,536**	**171**	**2**	**2**	**0**	**0**	**647,213**

Ve+ transport towards North

Table C-2 Modelled average daily longshore transport for selected wave conditions (m3/day)

	Peak Direction (deg TN)																	
Hs	**<30**	**30 to 40**	**40 to 50**	**50 to 60**	**60 to 70**	**70 to 80**	**80 to 90**	**90 to 100**	**100 to 110**	**110 to 120**	**120 to 130**	**130 to 140**	**140 to 150**	**150 to 160**	**160 to 170**	**170 to 180**	**<180**	**Total**
0 to 0.5	-30		-221	-211	-99	59	142	178	187	187	169	133						
0.5 to 1.0	-250	-294	-300	-315	-275	92	478	666	759	745	657	503	281	97	209	8	6	
1.0 to 1.5	-624	-723	-783	-921	-903	272	1,305	1,847	2,148	2,131	1,876	1,409	756					
1.5 to 2.0	-1,672	-2,029	-2,796	-3,566	-2,566	619	3,011	4,312	4,987	4,741	4,084	3,065	1,867					
2.0 to 2.5	-4,377	-4,900	-7,051	-7,481	-4,787	1,468	6,353	8,939	9,825	9,528	8,806	8,075						
2.5 to 3.0			-8,321	-12,764	-8,392	2,844	11,627	15,195	17,044	13,018	11,780							
3.0 to 3.5			-25,885	-22,062	-15,510	5,516	17,655	23,241	26,927									
3.5 to 4.0			-40,295	-34,561	-21,844	7,855	29,193	35,321	39,812									
4.0 to 4.5				-43,002	-27,700	17,593	47,082	45,632	53,179									
4.5 to 5.0				-59,601	-41,686	-4,424	56,671											
5.0 to 5.5				-75,013	-54,410	50,929	71,038											
5.5 to 6.0					-75,198	-43,704												
6.0 to 6.5				-129,374	-75,321													
> 6.5				-148,564														
Total																		