Tamar Lake Longterm Sedimentation Study

Technical Report

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Synopsis	Tamar Lake Inc. has commissioned BMT to assess the long-term sedimentation impacts of the Tamar Lake concept.

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Amendment Record

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1	15 August 2022	Tamar Lake Inc	Revised draft (addressing comments)

Executive Summary

Tamar Lake Inc. has proposed that a barrage be built across the Tamar Estuary at Point Rapid, changing the majority of the Tamar Valley tidal estuary into a freshwater system. The proposal has been developed as a regional development initiative, resulting in the likely improvement of navigational access and public amenity which have declined because of sedimentation in the upper estuary.

The concept presents a significant challenge for decision makers, stakeholders, and the community due to the scale of the project, and its impact on the regional economic, social and environmental inventory. One area of concern which is inadequately understood at present relates to the impact of the barrage on the downstream remnant estuary.

To address these questions, Tamar Lake Inc. has commissioned BMT to undertake an assessment of the long-term (multi-decadal) sedimentation impacts of the Tamar Lake concept. The long-term sedimentation impacts of the Tamar Lake concept have been assessed using a 3D hydrodynamic, water quality and sediment transport model of the Tamar Estuary. Base and lake (developed) scenario simulations were undertaken for a 10-year period from 2004 to 2014, which included a range of dry to wet years. The sensitivity of the predicted impacts to climate change related sea level rise was also modelled.

Model outputs were interrogated to assess the predicted impacts to water levels, tidal prism, bed shear stress, silt transport, sand transport, net sedimentation rates and Particle Size Distributions within the lake upstream of the barrage and in the downstream remnant estuary.

Conclusions regarding sedimentation impacts upstream of the barrage are consistent with previous studies (BMT WBM, 2016); that is, there would be a net loss of sediment from the Home Reach in combination with an ongoing accumulation of fluvial sediment in the deeper (channel) of the lake system downstream of Newnham. Under the lake scenario it is predicted that 80% of the fluvial sediment load is retained upstream of the reservoir and 20% is bypassed downstream.

The model predictions downstream of the barrage were interpreted in the context of a new equilibrium state in the remnant estuary, along with the timeframe for this equilibrium to be reached. Considering both the rate of fluvial sediment supply bypassing the barrage and the post-barrage marine sediment supply rate, the timescale for the system to reach a new equilibrium was assessed to be of the order 5,000 years.

Changes to the sedimentological character of the remnant estuary would be expected to be observed within decades of the barrage construction, with a trend towards a more fluvial character due to a relative increase in the supply of fluvial sediment combined with a weakening in the marine sediment supply pathway.

Due to the long timescales involved in the downstream sedimentation response, the risk of the predicted sedimentation impacting on port infrastructure and operations is considered to be low in the context of a typical 50-year planning horizon. Infrastructure located in Long Reach immediately downstream of the barrage would be at the highest risk of experiencing problematic levels of sedimentation under the lake regime, with sedimentation episodes most likely to occur following large flood events.

The results of this modelling can be used to underpin studies into the other potential impacts associated with the Tamar Lake proposal including ecological and biogeochemical processes.

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1 Introduction

Tamar Lake Inc. has proposed that a barrage be built across the Tamar River at Point Rapid, changing the majority of the Tamar Valley tidal estuary into a freshwater system. The proposal has been developed as a regional development initiative, one benefit of which is the likely improvement of navigational access and public amenity associated with sedimentation in the upper estuary.

The concept presents a significant challenge to decision makers, stakeholders, and the community due to the scale of the project, and its impact on the regional economic, social and environmental inventory.

One area of concern which is inadequately understood at present relates to the impact of the barrage on the downstream remnant estuary. It is acknowledged that such a barrage:

1. Reduces the tidal prism, with a pre barrage tidal prism of around 200 GL/ebb tide at Low Head, reducing to about 100 GL/ebb tide post barrage construction.

2. While releasing daily river flows on the ebb tide only, these would represent a small proportion of the residual tidal prism. A mean river flow of 70 m^3/s (2,200 GL/year) would deliver a flow of only 3.0 GL/ebb tide, i.e. 3% of the residual tidal prism at Low Head

Tamar Lake Inc. has commissioned BMT to assess the long-term sedimentation impacts of the Tamar Lake concept using the 3D hydrodynamic, water quality and sediment transport model previously developed for Launceston City Council (BMT WBM, 2009) and NRM North (BMT WBM, 2016) on behalf of Tamar Estuary stakeholders. This model has been used in earlier technical assessments of Tamar Lake hydrodynamic, water quality and sedimentation impacts (BMT WBM, 2016). The previous sedimentation studies were limited to relatively short-term simulations of a few months and therefore the current study has involved modification of the existing model to allow for long term predictions.

This study seeks to provide specific advice on:

- How the lake sedimentation regime both upstream and downstream of the proposed barrage compares to the existing tidal regime.
- The ultimate (equilibrium state) bathymetry for the remnant estuary (under the lake scenario).
- The manner in which the remnant estuary bathymetry is expected to transition to its ultimate state and how this occurs over time.
- Potential areas of significant sediment accretion and/or erosion.
- Predictions for commercial shipping navigation channel and port berth depths within the remnant estuary.
- How future expected Sea Level Rise (SLR) will impact on sedimentation predictions.

The scope of the long-term sedimentation study does not include assessment of risk to ecological character of the Tamar Estuary.

2 Locality Description

For reference Figure 2.1 to Figure 2.3 provide an overview of the Tamar Estuary, adjacent townships and landmarks. The Tamar Estuary extends for some 70km from its mouth into Bass Strait at Low Head to Launceston, where the North and South Esk Rivers join. The estuary is tidal to First Basin on the South Esk and to St Leonards on the North Esk.

The proposed Tamar Lake concept would construct a tidal barrage at Point Rapid (Figure 2.1) which is located approximately 22km upstream from the mouth at Low Head, creating a 400GL freshwater reservoir between Point Rapid and Launceston.

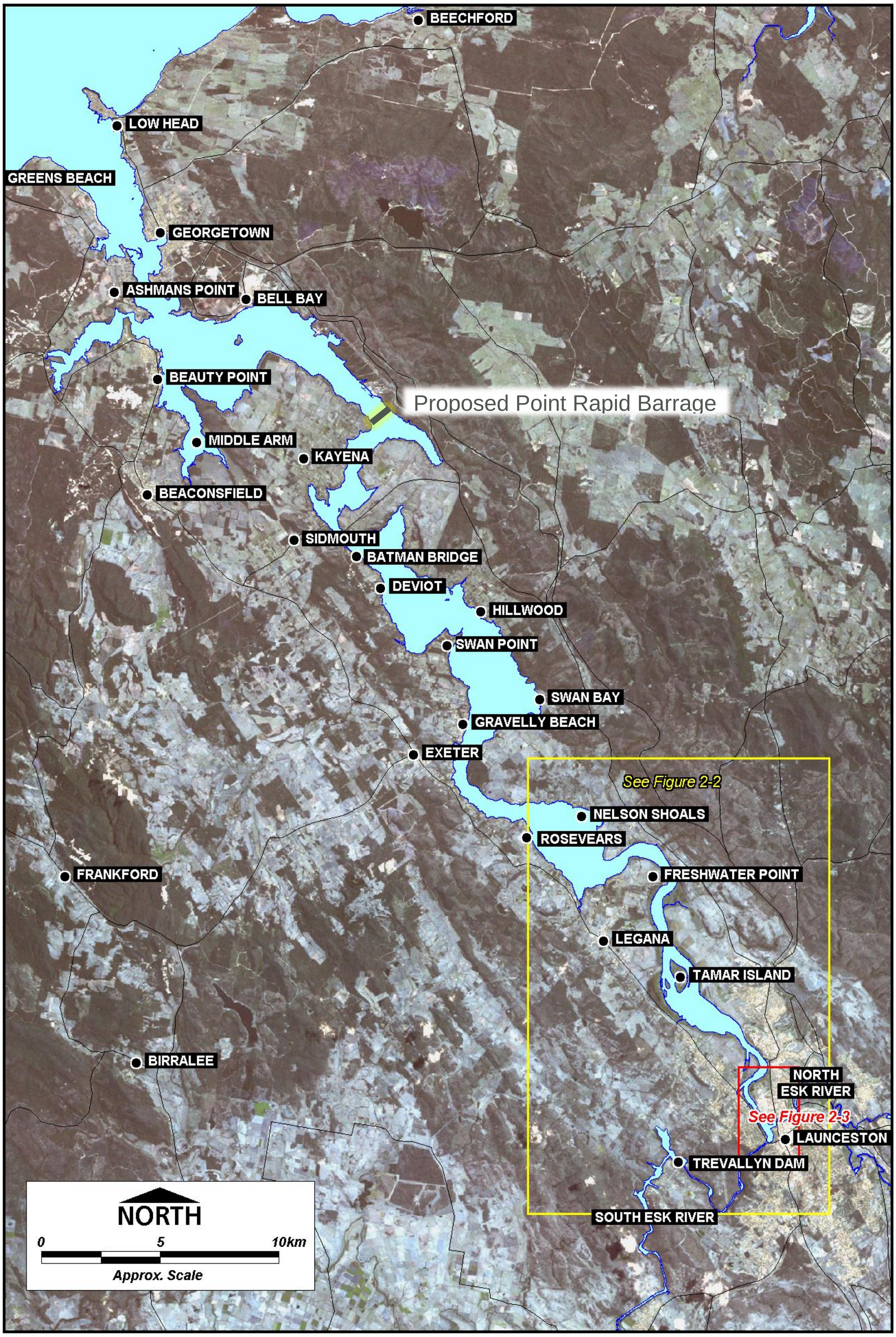

Figure 2.1 Tamar Estuary Overview / Locality Plan

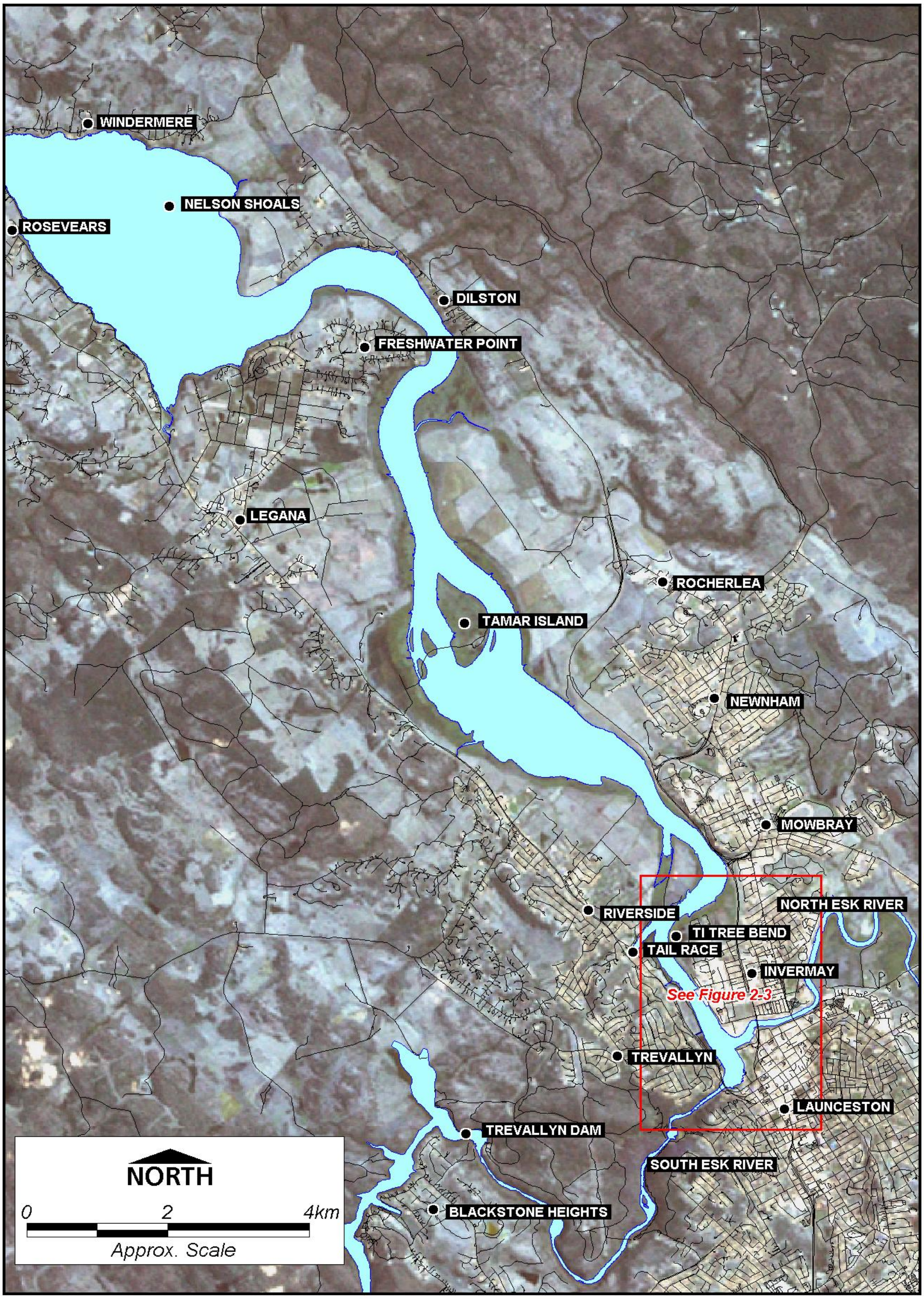

Figure 2.2 Upper Tamar Estuary Locality Plan

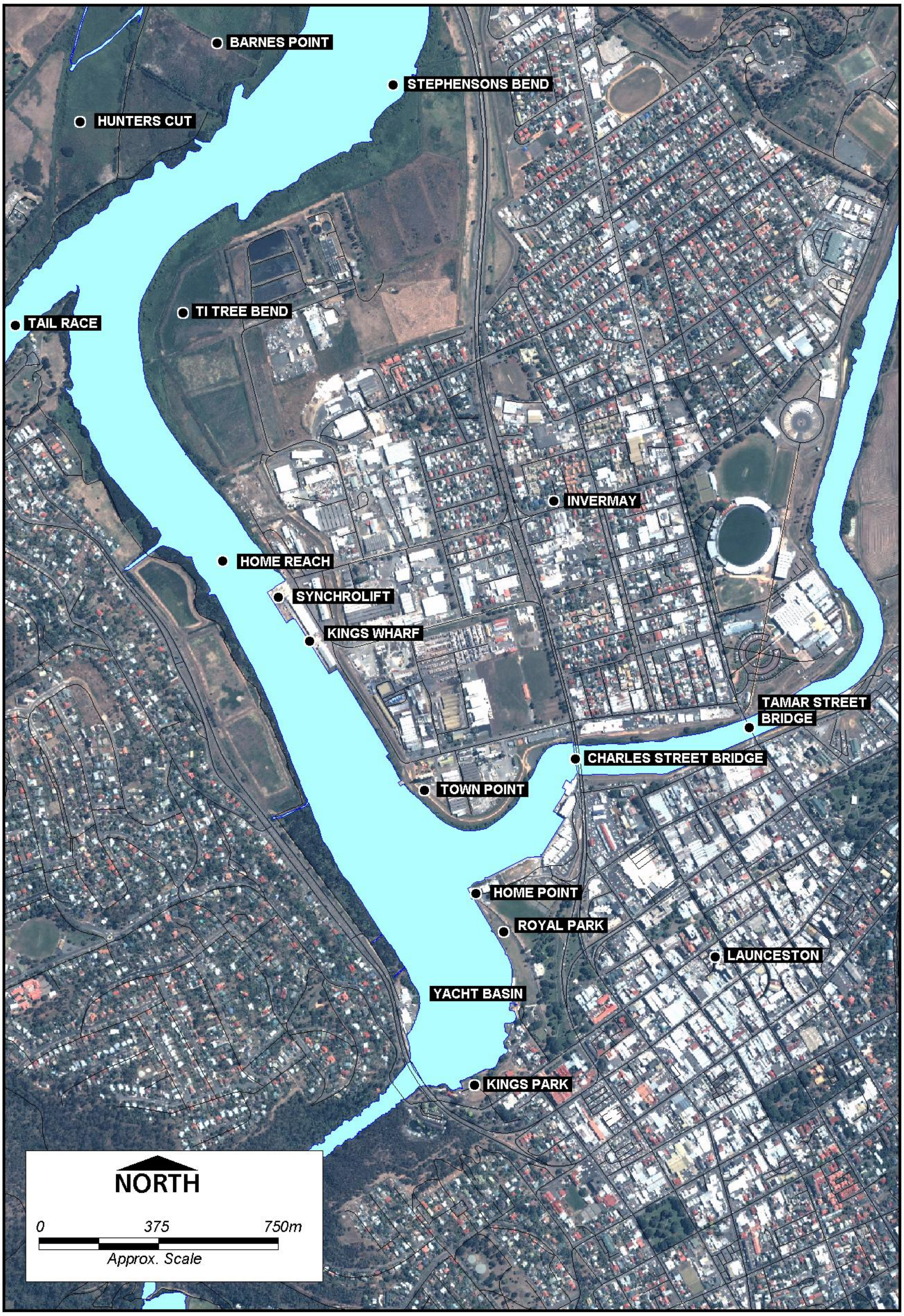

Figure 2.3 Tamar Estuary near Launceston Locality Plan

3 Methodology

This study has used a 3D hydrodynamic and sediment transport numerical model, which is based on the model developed for NRM North (BMT WBM, 2016) and used in previous Tamar Lake technical studies (BMT WBM, 2016). In these earlier modelling studies, a high-resolution computational mesh was used, with simulations reported to achieve a runtime ratio of around 50:1 (i.e. 50 hours of simulation was completed in a 1 hour run). This 50:1 runtime ratio typically constrained the Tamar estuary simulation periods to approximately 1 year.

Advances to both computer hardware and software in the last 5 years has enabled the Tamar estuary 3D model used in this study to achieve runtime ratios of around 800:1. To achieve this runtime performance, a reduced resolution version of the numerical model computation mesh has been used in conjunction with the simulations being run on a High Performance Computing (HPC) facility with a Nvidia A100 Tensor Core GPU.

The increased runtime performance allows the model for the first time to be used for quantitative modelling assessments of hydrodynamic, water quality and sedimentation processes over multi-year timescales, thereby providing the ability to assess system response to inter-annual variability and to simulate multi-year trends and impacts.

The following section describes the model software, computation mesh, boundary conditions, sediment transport module, barrage schematisation and model scenarios used to assess the long-term sedimentation impacts.

3.1 Numerical Model Description

The numerical modelling has been undertaken using the TUFLOW FV software, which is developed in-house by BMT and is made available commercially as part of the TUFLOW suite of products (http://www.tuflow.com). TUFLOW FV is a modern and extensively validated three-dimensional hydrodynamic modelling package that has been successfully applied and proven across floodplain, riverine, estuarine, coastal and ocean environments both domestically and overseas.

TUFLOW FV solves the three-dimensional Non-Linear Shallow Water Equations (NLSWE) on a "flexible" (unstructured) mesh comprising triangular and quadrilateral cells. This unstructured mesh approach has significant benefits when applied to study areas involving complex bathymetric features, flow paths and hydrodynamic processes, such as is the case for this this study.

The software was running in a fully three-dimensional (3D) configuration, including baroclinic (variable water density) coupling required to resolve the vertically stratified "salt wedge" regime that occurs in the Tamar estuary. The TUFLOW FV Sediment Transport Module (STM) was fully coupled with the hydrodynamic simulations to allow for the tracking of silt and sand sediment fractions.

3.2 Computational Mesh

The reduced resolution mesh, previously developed for undertaking Water Quality (WQ) model calibration (BMT WBM, 2016), was used as the basis for the long-term sedimentation simulations in the Tamar Estuary. The 2016 study conducted checks to confirm that the reduced resolution mesh was replicating the key hydrodynamic processes.

The model domain (shown in Figure 3.1) extends from Low Head to the upper tidal reaches of the Tamar and North Esk Rivers. The computational mesh has 3,800 mesh elements with an average cellsize of 150m. The vertical mesh is discretised into 11 equal sigma layers, and are approximately 41,000 3D computational cells.

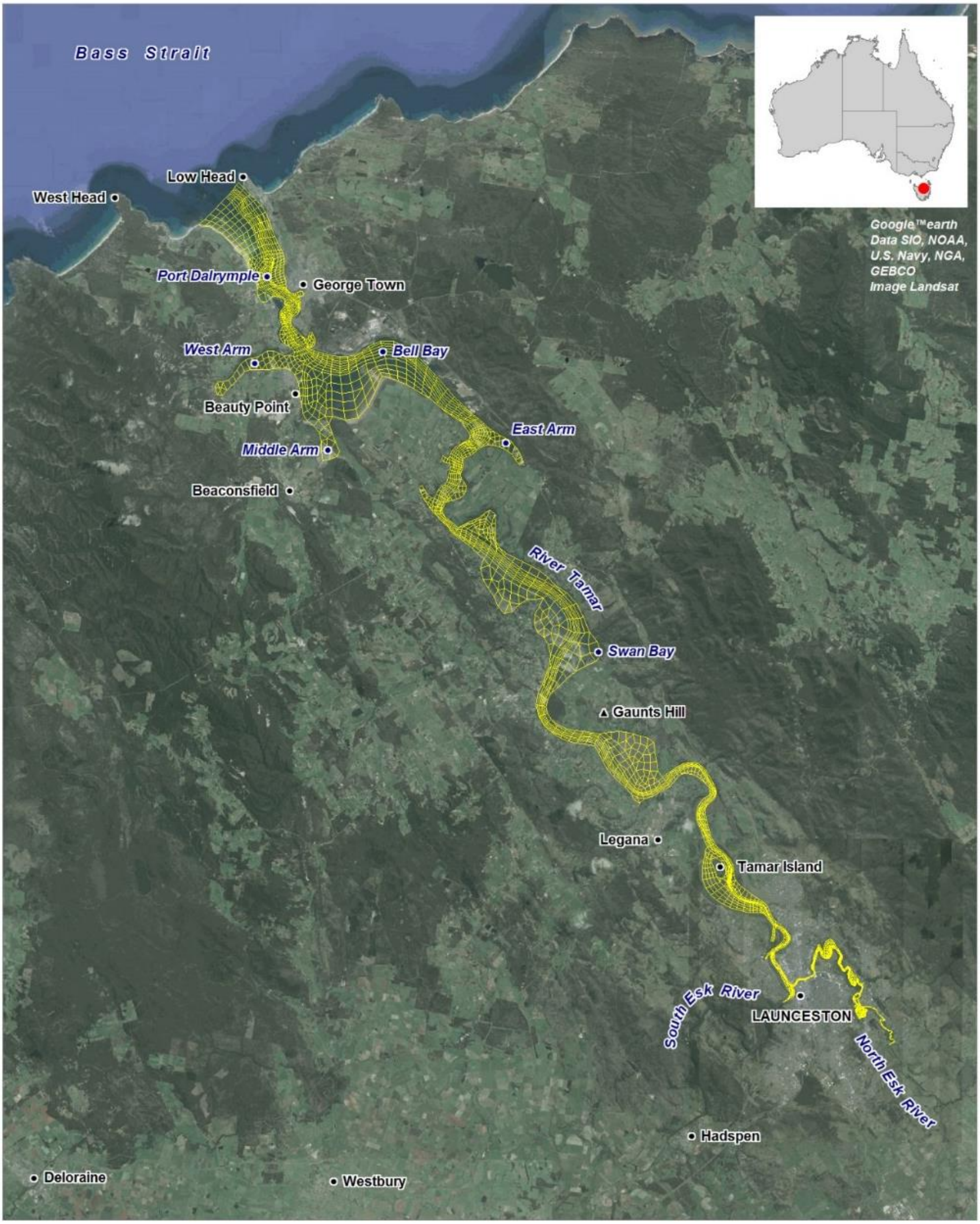

Figure 3.1 Tamar Estuary model mesh used in this study

3.3 Sediment Transport Module (STM)

The TUFLOW FV STM is used to simulate the advection, dispersion, flocculation, settling, deposition and resuspension of multiple sediment fractions from wave and current forcing coupled with the 3D hydrodynamic scheme. Morphological feedback from the STM to the hydrodynamic scheme was enabled in this study.

Surface sediments in the upper Tamar Estuary (south of Deviot) are entirely fluvial and predominantly within the fine-grained cohesive sediment classification. The lower estuary is comprised of a mixture of fluvial sediment and marine sand, with Particle Size Distribution varying by location based on sediment pathways and exposure to current and wave energy, with dominant silt sized sediment (d_{50}<75 µm) in low energy zones and dominant sand size sediment (d_{50}>150 µm) in higher energy zones. In this study the mobile sediment in the Tamar Estuary is represented by two fractions:

- Cohesive fluvial sediment (nominally silt)
- Non-cohesive marine sand

Salt wedge hydrodynamics is an important process driving the asymmetric tidal (upstream dominant) sediment transport in the upper Tamar Estuary. Cohesive sediment settling velocity is parameterised using a relationship that accounts for salinity-dependant flocculation, with the clear water settling velocity assumed to be 2.0e-4 m/s in freshwater and an order of magnitude higher once salinity exceeds around 3 ppt.

3.4 Model Boundary Conditions

Ocean (Bass Strait) Boundary

An open water level boundary along with salinity and temperature is specified at Low Head. The water level timeseries is based on data from the Low Head tide gauge, operated by TasPorts and data supplied by the Bureau of Meteorology's (BoM)'s National Tide Centre.

Atmospheric Forcing

Data from the National Center for Atmospheric Research's (NCAR) Climate Forecast System Reanalysis (CFSR) and CFSv2 were used to force climate conditions in the model. CFSR data covers the period from 1979-2011 and CFSv2 the period from 2011-present. Data streams used for the current study include hourly:

- Wind speed and direction,
- Short wave radiation,
- Downward long wave radiation,
- Relative humidity,
- Air temperature,
- Rainfall.

Wave Forcing

A wave prediction model was run in order to predict the wind-generated wave conditions within the estuary. A 50 m resolution SWAN model covering the entire hydrodynamic model domain was run at hourly timesteps with forcing from the CFSR wind fields. The predicted wave fields were supplied as boundary conditions to the TUFLOW FV sediment transport model, with the wave-induced stresses on the inter-tidal banks being an important process in the Tamar Estuary sediment transport pathways.

Catchment runoff

The South Esk and North Esk river catchments are the major fluvial discharges into the Tamar Estuary. Flow time-series data for the North Esk River at Johnstone's Rd Bridge, the South Esk River downstream of Trevallyn Dam and the Trevallyn hydro-electric plant discharge were supplied by Hydro Tasmania for the modelling conducted by this study.

The South Esk and North Esk River flow time-series were derived predominantly by the application of appropriately calibrated catchment rainfall runoff models, with the inclusion of gauged data where appropriate. The Trevallyn hydroelectric plant (tailrace) discharge is measured by Hydro Tasmania.

A complete dataset of daily catchment inflows has been collated for the period from 2003 to 2014. Water temperature and Total Suspended Solids (sediment) concentration is also specified at the major catchment inflow boundaries.

The catchment inflow daily timeseries for the 2004-2014 period is shown in Figure 3.2. The Tailrace flow has a mean discharge of 47 m^3/s and maximum of 98 m^3/s. South Esk River (Cataract Gorge) discharge ranges between an environmental flow lower limit of 1.5-2.5 m^3/s up to maximum flood flows in excess of 1,000 m^3/s, with a mean discharge of 21 m^3/s. The unregulated North Esk River has a mean discharge of 8.4 m^3/s with flood flows in excess of 100 m^3/s.

The yearly total catchment flows for the period 2004-2014 are summarised in Figure 3.3. The average yearly total catchment flow is 2,427 GL, of which the Tailrace accounts for 61%, South Esk 28% and North Esk 11%.

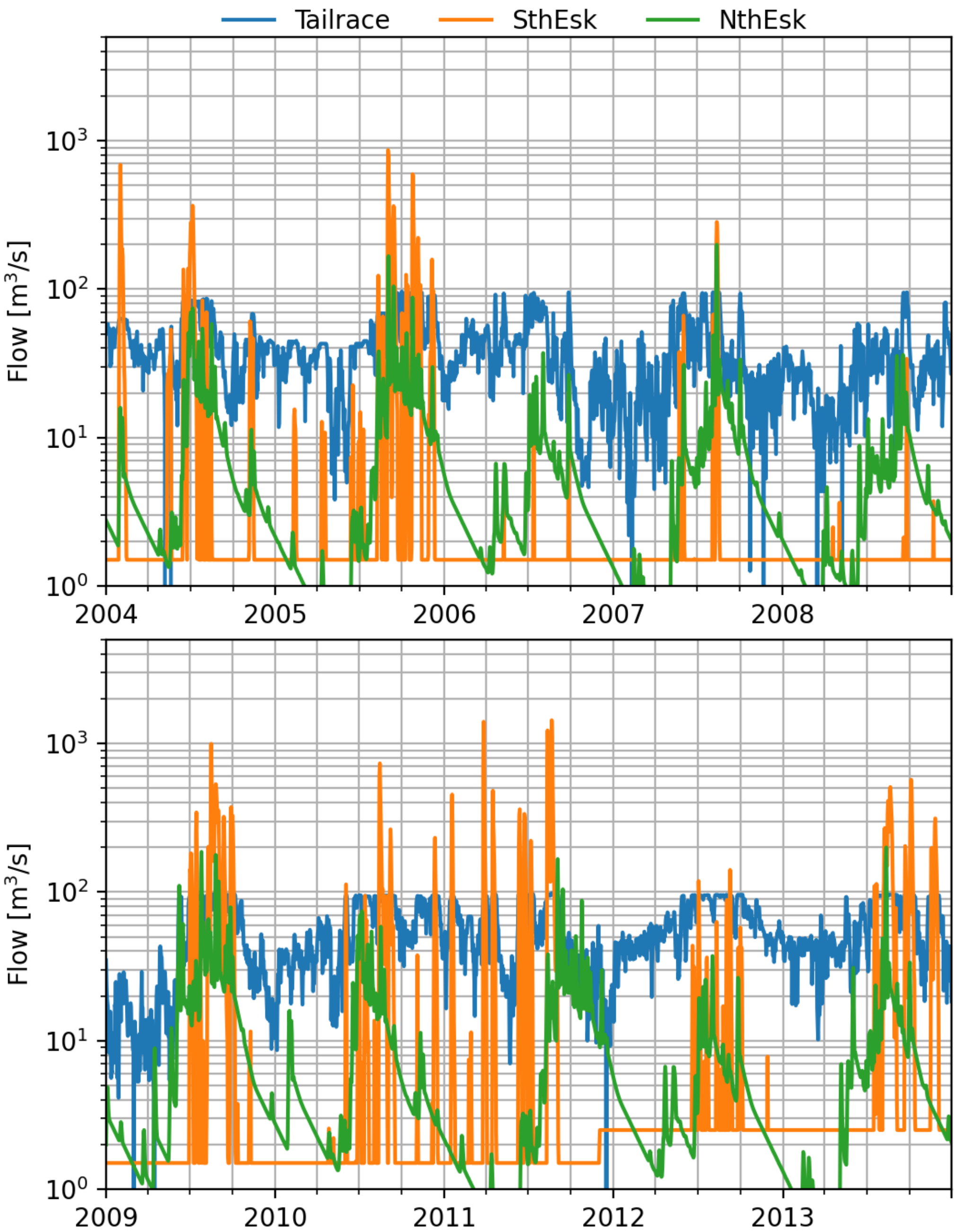

Figure 3.2 Major catchment inflow daily timeseries for 2004-2014.

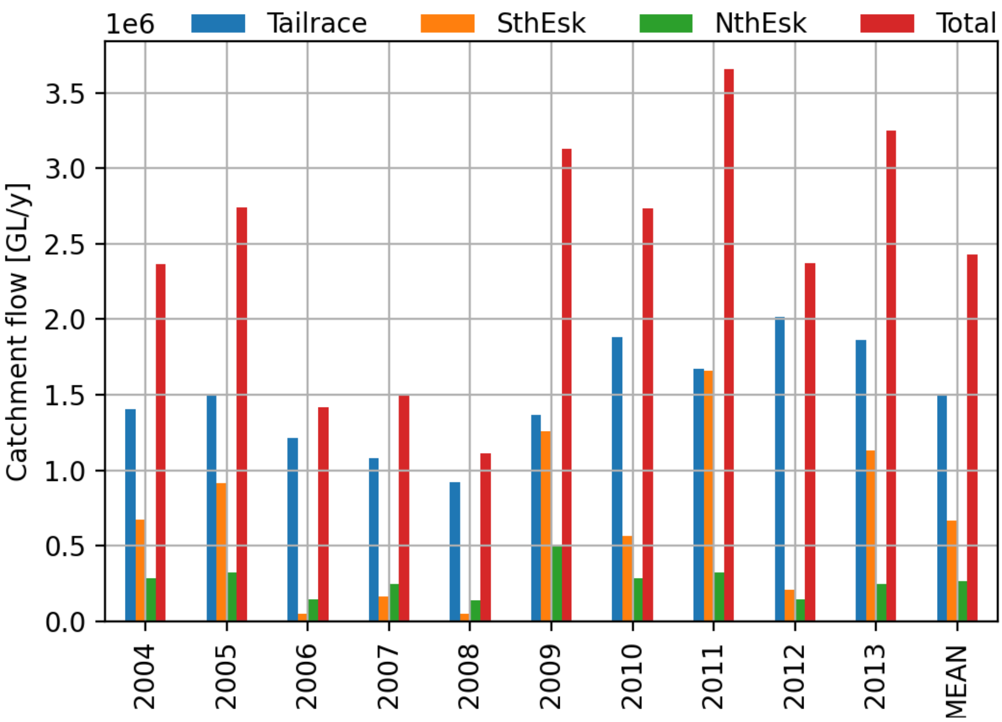

Figure 3.3 Major catchment annual flows for 2004-2014.

Catchment sediment load

Catchment sediment load boundary conditions are of primary importance to any quantitative long-term sedimentation study. The predominant contemporary contribution of sediments to the Upper Tamar Estuary is fine suspended load from the catchments. The Trevallyn Dam on the South Esk presently attenuates small flood flows and traps any coarser bed load while passing the suspended load. At Corra Linn on the North Esk, all suspended sediment load is also assumed to be in the fine silt category.

BMT WBM (2009) derived a relationship for TSS concentration in mg/L associated with South Esk River inflows (Cataract Gorge and the Tailrace) based on data presented in Foster (1986).

$$TSS = \max(0.30Q^{0.83}, \qquad 4.0)$$

where *Q* is the total flow from Trevallyn Dam via Cataract Gorge and the Tailrace (including the Poatina Diversion input).

A sediment discharge relationship provided in DPIWE (2003) was similarly re-arranged to obtain a relationship between inflow suspended sediment concentration and flow rate for the North Esk River (BMT WBM, 2009).

$$TSS = \max(1.3Q^{0.70}, \qquad 6.5)$$

Both the North Esk and South Esk sediment loads are assumed to be 100% comprised of cohesive sediment.

Daily sediment loads were calculated from the catchment flow and suspended sediment concentration relationships. The daily sediment load timeseries were aggregated into annual sediment loads for the period 2004-2014, which are shown in Figure 3.4. Total annual sediment load varies from 7,300 t in a dry year up to 150,000 t in a wet year with an average annual load of 54,000 t. Sediment loads to the estuary occur mainly from the South Esk catchment during flood conditions.

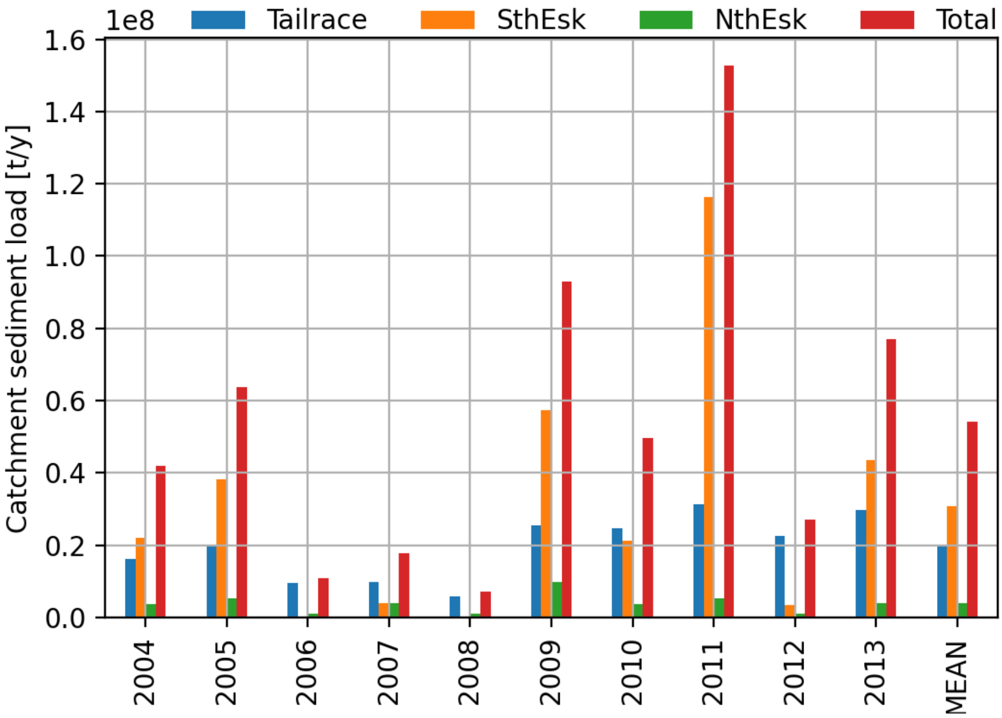

Figure 3.4 Major catchment annual sediment loads for 2004-2014.

3.5 Barrage schematisation

The proposed Tamar Lake Barrage at Point Rapid was schematised as a gated weir structure with a crest elevation at –2.0 m AHD. The gated weir mechanism is operated to maintain a normal lake operating level of +0.8 m AHD, with the gates shut during downstream flood tides or whenever downstream water levels exceed the lake operating level. The gates are sufficiently opened during downstream ebbing tides to pass the temporarily stored catchment inflows.

3.6 Initial Conditions

The model hydrodynamics are “warmed up” over a series of simulations, which is undertaken separately for the base and lake case scenarios. The lake case scenarios are warmed up with the barrage in place so that the lake initial condition is already completely fresh.

The sediment transport model initial condition is also “warmed up” from a crude initial distribution of the fluvial silt and marine sand fractions comprising the seabed. The crude initial distribution is 50% sand and 50% silt in the lower reaches and 100% silt in the upper reaches. The sediment distribution in the model is then warmed up over multiple 12-month simulations in combination with a “morphological acceleration” factor in order to converge towards a state that is in dynamic equilibrium with local hydrodynamic conditions and catchment sediment supply (Figure 3.5). The North Esk river was initialised without mobile sediment in the bed and accumulated silt from fluvial load and tidal resuspension over the course of the warm up.

Both the base case and lake case scenarios were run from the same bed warmup initial condition, allowing for the difference in subsequent sediment evolution trends between these two cases to be predicted.

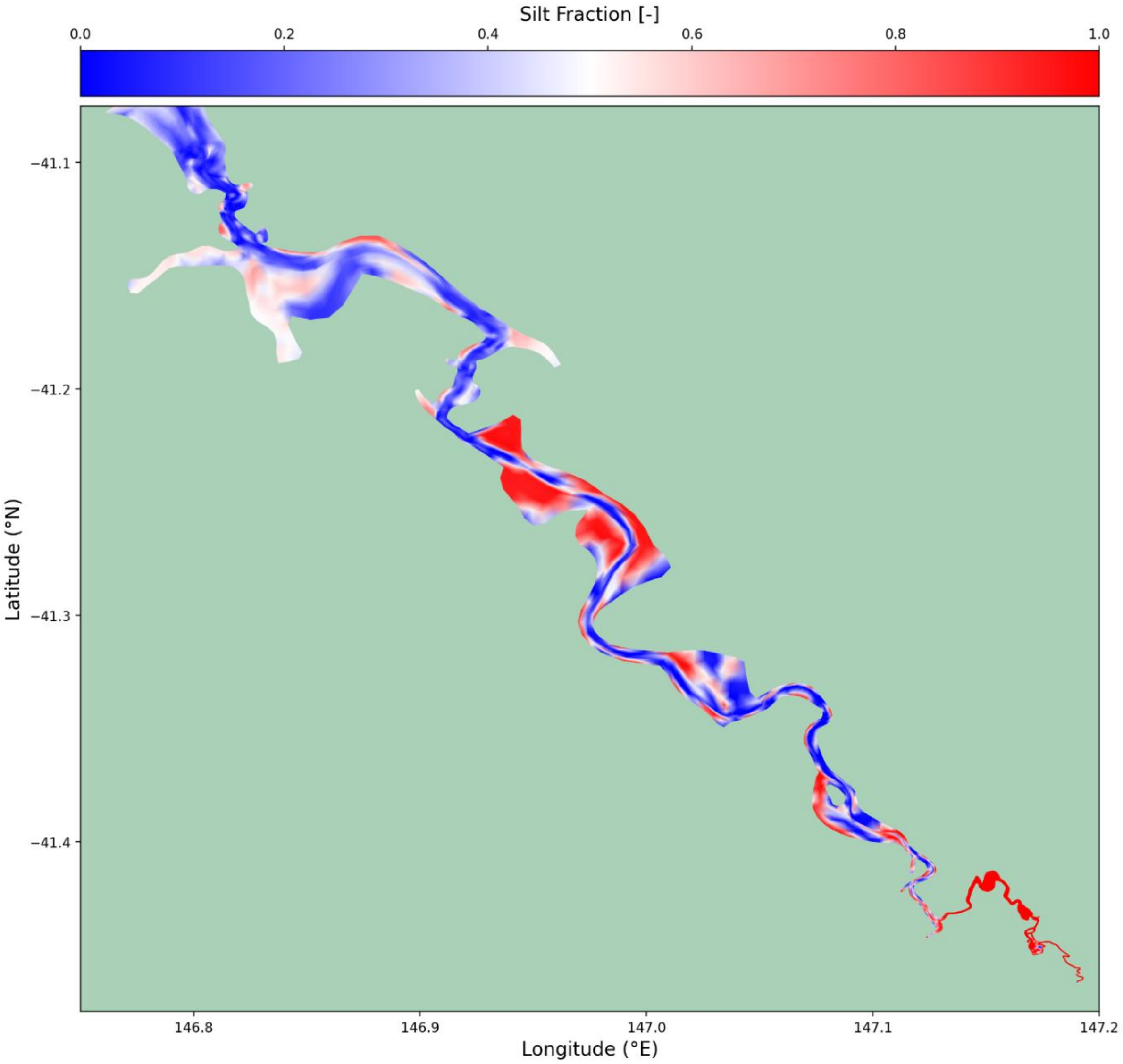

Figure 3.5 Proportion of silt in the bed following the warm up process. Silt fractions ~0.0 can be due to the bed being mainly comprised of sand, or in the upper estuary indicates that the bed has been scoured down to an erosion resistant rock or consolidated sediment layer.

3.7 Model Scenarios

The hydrodynamic and sediment transport model prepared for this long-term sedimentation study provides a 16-times increase in runtime ratio compared with the previous version, allowing for multi-year scenarios to be run for the first time. A 10-year model scenario takes approximately 5-days to complete on the Tesla-A100 HPC.

The potential use of a “morphological acceleration factor” (MORFAC) was investigated early in this study as a mechanism to further increase the effective period of morphological evolution simulated during a model scenario. For instance, a MORFAC of 10 would accelerate the morphological response such that a 10-year hydrodynamic simulation would approximate 100-years of morphological evolution. However, it was found that the MORFAC approach was unreliable (potentially inaccurate) in the context of the present study due to the propensity to exaggerate the response of the system to flood events.

Based on the availability of complete boundary condition datasets, the 10-year period from 1/1/2004 to 1/1/2014 has been selected as the basis for the following primary model scenarios:

- Base Case, 2004-2014
- Lake Case, 2004-2014

The 10-year scenario results have been used to infer longer term sedimentation response patterns and timescales as discussed in Section 5.1.

A sensitivity assessment was also undertaken assuming a 0.4 m sea level rise (SLR), which is a mid-range value for 2070 based on the IPCC AR5 RCP 4.5. The SLR sensitivity scenarios involved a 12-month simulation based on the 2011 calendar year:

- Base Case + 0.4m SLR, 2011
- Lake Case + 0.4m SLR, 2011

The sensitivity of predicted impacts to potential future climate change induced changes to catchment runoff has been interpreted from the inter-annual variation in annual flows captured over the 2004-2014 period.

4 Results

Model results relevant to the addressing the study objectives have been extracted from the long-term simulation outputs. In general, the base and lake scenario are directly compared so that impacts due to the lake proposal can be clearly identified. Impacts to the hydrodynamic regime are presented first as these are the drivers for the morphological evolution impacts that this study is principally interested in.

4.1 Water Level

Water level percentile statistics (10%, 50% and 90%) were derived along the Tamar Estuary from Low Head (Chainage 0 km) to the Home Reach Yacht Basin (Chainage 68km). The barrage at Point Rapid is located at Chainage 22km. The water level long section results are plotted in Figure 4.1.

Water level impacts downstream of the barrage show a slight increase in high tide levels around chainage 10km (Beauty Point) and a slight increase in low tide levels immediately downstream of the barrage.

Upstream of the barrage the macro-tidal regime is replaced by a nearly static water level that occasionally rises due to the passage of flood events through the lake storage (typically <0.5m). The highest water levels in the lake during simulated flood events remain well below the base case highest water levels. The low water levels do not drop below 0.8 m AHD.

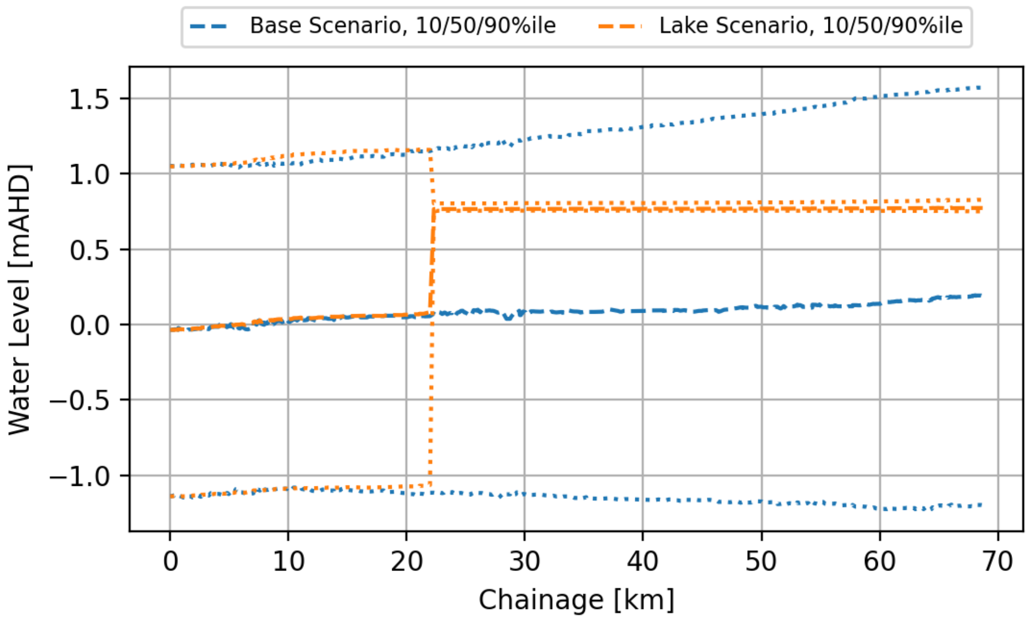

Figure 4.1 Long section of water level percentiles from Low Head to Launceston.

4.2 Tidal Prism

Tidal prism is a measure of the volume of water exchanged through a cross-section during a typical low to high (or high to low) range. Tidal prism corresponding to a Mean High Water Spring (MHWS) tidal range were derived along the Tamar Estuary from Low Head to the Yacht Basin. The tidal prism long section results are plotted in Figure 4.2. Reductions in tidal prism are expected to be matched by similar percentage reductions in tidal current speeds.

As expected, the construction of a barrage at Point Rapid completely removes the tidal prism upstream of the barrage in the lake scenario. As discussed in the introduction section, the downstream tidal prism is also very substantially reduced by the barrage. At Low Head the tidal prism is reduced from 230 GL to 100 GL (57% reduction).

At the proposed barrage location at Point Rapid (Chainage 22km) the base case tidal prism is 137 GL and under the Lake scenario this tidal exchange is replaced by an ebb tide release regime, with an average release of 3.0 GL per tidal cycle (98% reduction). At Bell Bay (Chainage 15km) the base case tidal prism is 155 GL and this is reduced to 20 GL under the lake scenario (87% reduction).

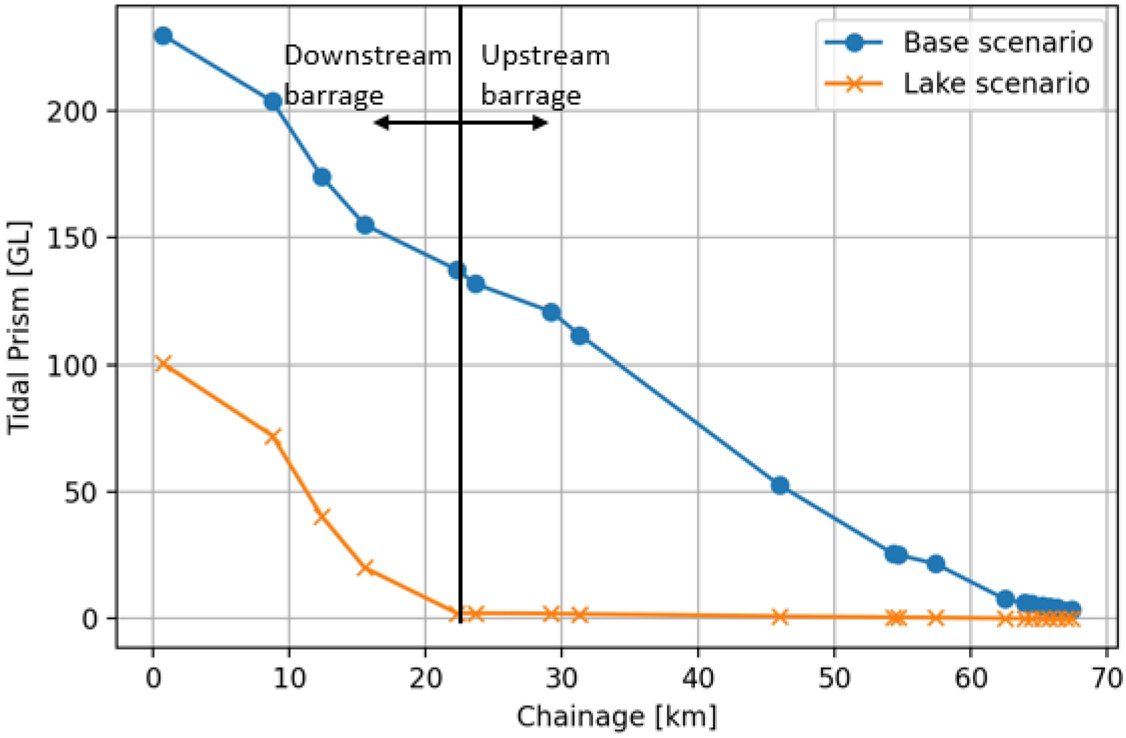

Figure 4.2 Long section of MHWS tidal prism from Low Head to Launceston.

4.3 Salinity

Depth-averaged salinity percentile statistics (10%, 50% and 90%) were derived along the Tamar Estuary from Low Head (0 km chainage) to the Home Reach Yacht Basin (70km chainage). The salinity long section results are plotted in Figure 4.3.

Upstream of the proposed barrage the base scenario estuarine salinity regime is replaced by a freshwater lake regime.

Downstream of the barrage, depth-averaged salinities are seen to reduce by up to 5 ppt under the lake scenario (compared with the base scenario). The predicted salinity reductions reflect the substantial reductions in tidal prism while the freshwater discharge volumes are maintained.

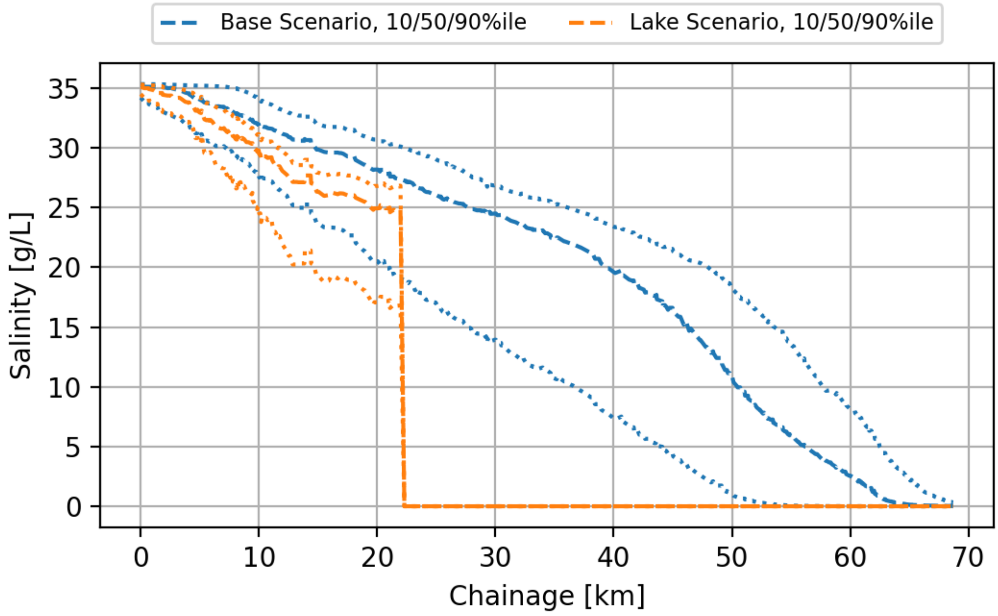

Figure 4.3 Long section of depth-averaged salinity percentiles from Low Head to Launceston.

4.4 Bed Shear Stress

Wave and current induced bed shear stress percentile statistics (10%, 50% and 90%) were derived along the Tamar Estuary. Bed shear stress greater than 0.2 N/m^2 is likely to drive sediment resuspension, while values greater than 0.05 N/m^2 will limit the ability for cohesive sediment to settle and consolidate. The bed shear stress long section results are plotted in Figure 4.4. A log-scale axis is used to better show the several orders of magnitude variations in bed shear stress.

Under the base case scenario, 50th-percentile bed shear stress magnitudes are consistently greater than 0.1 N/m^2 and 90th-percentile magnitudes are consistently greater than 0.2 N/m^2; values which represents an energetic tidal resuspension regime along the entire estuary.

Upstream of the proposed barrage in the lake scenario, the tidal bed shear stress regime is replaced by a relatively quiescent (low current speed) lake regime, with 90th-percentile bed shear stress magnitudes reduced by 2-orders of magnitude immediately upstream of the barrage and by more than 1-order of magnitude within the Home Reach.

Downstream of the barrage in the lake scenario, the bed shear stress magnitudes are also predicted to reduce by around 80%, which is expected due to the substantial tidal prism reductions (Section 4.2). Settling and consolidation of fine sediment introduced downstream of the barrage would be expected to occur under this reduced bed shear stress regime.

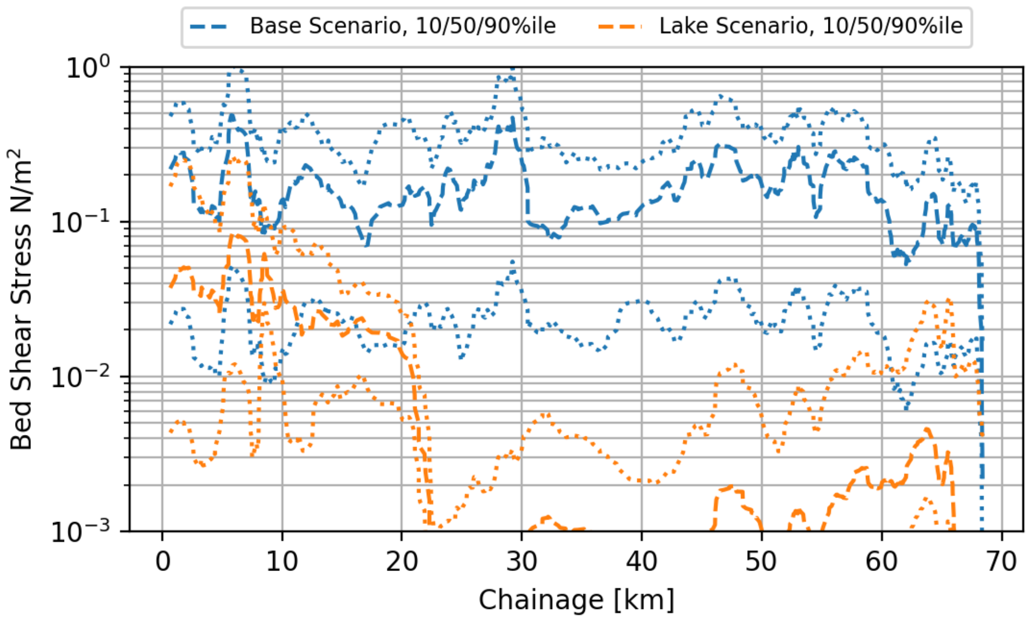

Figure 4.4 Long section of wave/current bed shear stress percentiles from Low Head to Launceston.

4.5 Silt Transport

Replacement of the macro-tidal estuarine regime with a relatively quiescent lake also represents a major shift change in the silt transport regime in the upper estuary. The following notable changes are expected under the lake regime:

- Freshwater conditions will reduce silt flocculation, which occurs when saline and freshwaters mix in estuaries. This would slow the potential settling of silt.
- Quiescent conditions will prevent silt resuspension except under flood conditions upstream of Newnham (Figure 2.2).
- Silt re-suspended by flood flows will be transported downstream, to either deposit within the lake system or to be discharged through the barrage into the remnant lower estuary
- Mechanisms for upstream tidal transport of sediment is absent from the lake system, meaning that sediment scoured from the upper Tamar Estuary during flood events cannot be subsequently recycled back upstream to re-deposit in the Home Reach.

The base case scenario results indicate that almost 100% of the fluvial silt load is retained in the upper-estuary (south of Deviot) with only the two largest flood events (2009 and 2011) resulting in any bypassing of silt downstream of the Whirlpool Reach. This result is illustrated in Figure 4.5, which shows the cumulative silt flux (in tons) calculated through a cross-section at the proposed barrage location (Point Rapid). The 2009 and 2011 flood events are circled for the base case, showing a positive deviation (downstream transport) due to the flood events in an otherwise slightly negative (upstream transport) trend during non-flood conditions. Considering just the downstream mass transported during the two flood events, the total downstream bypassing of sediment over the 10-year simulation is 17,000 t or equivalently 1,700 t/y, which is just 3% of the average catchment load of 54,000 t/y. According to the base scenario predictions, the remaining 97% of fluvial sediment load is retained in the upper estuary where it is mobilised and re-distributed by the tidal transport regime.

Figure 4.5 also shows the cumulative sediment flux at the barrage location for the lake scenario. Under this scenario, sediment is bypassed more efficiently to the downstream estuary under flood events. This is evidenced by the more frequent and larger magnitude positive sediment flux episodes in the lake scenario timeseries. During non-flood periods there is a negligible sediment load in the discharge over the barrage. The average rate of downstream silt bypassing predicted for the lake scenario is equal to 11,000 t/y, which is 20% of the average catchment load. The remaining 80% of the fluvial sediment load or 43,000 t/y is predicted to deposit and remain in the lake.

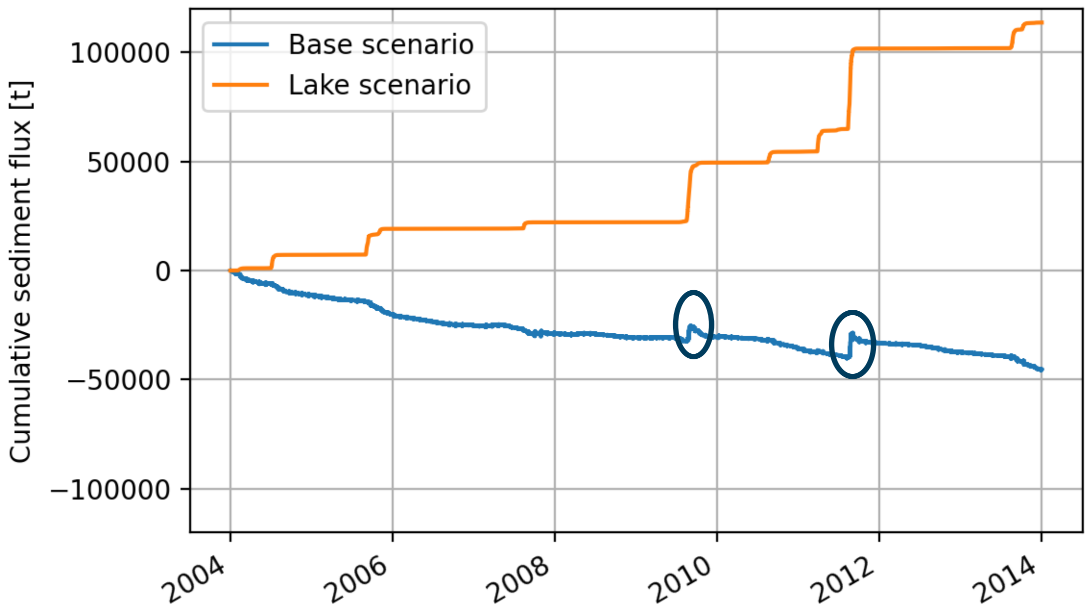

Figure 4.5 Cumulative silt flux through a cross-section at the proposed barrage location under both the base and lake scenarios. Positive sediment flux is in the downstream direction. The 2009 and 2011 flood events are circled for the base case. More frequent and efficient downstream bypassing of sediment is evident in the Lake scenario timeseries.

Depth-averaged Total Suspended Solids (TSS) percentile statistics (10%, 50% and 90%) were derived along the Tamar Estuary for both the base and lake scenario. The quantity of suspended sediment is strongly correlated with water clarity or turbidity. The TSS long section results are plotted in Figure 4.6. A log-scale axis is used to present the several orders of magnitude variations in TSS more clearly.

In the upper estuary, the base case predictions show the TSS/turbidity maxima located around Tamar Island. Typical (50^{th}-percentile) TSS levels under the base case tidal regime are around 20 mg/L and 90^{th}-percentile TSS concentrations are around 90 mg/L.

Under the lake scenario, TSS is predicted to be highest where the catchment flows enter the system in the Home Reach and reduce with distance downstream as sediment disperses and slowly settles within the lake system. Under typical (50^{th} percentile) conditions the lake TSS is approximately 7 mg/L where the tailrace flow enters the Home Reach and reduces both upstream and downstream. Under higher flow (90^{th} percentile) conditions the TSS in the Home Reach is in the 10-20 mg/L range but reduces further downstream in the lake.

TSS levels just upstream of the barrage range from <1 mg/L under typical conditions up to 5 mg/L for the 90^{th} percentile.

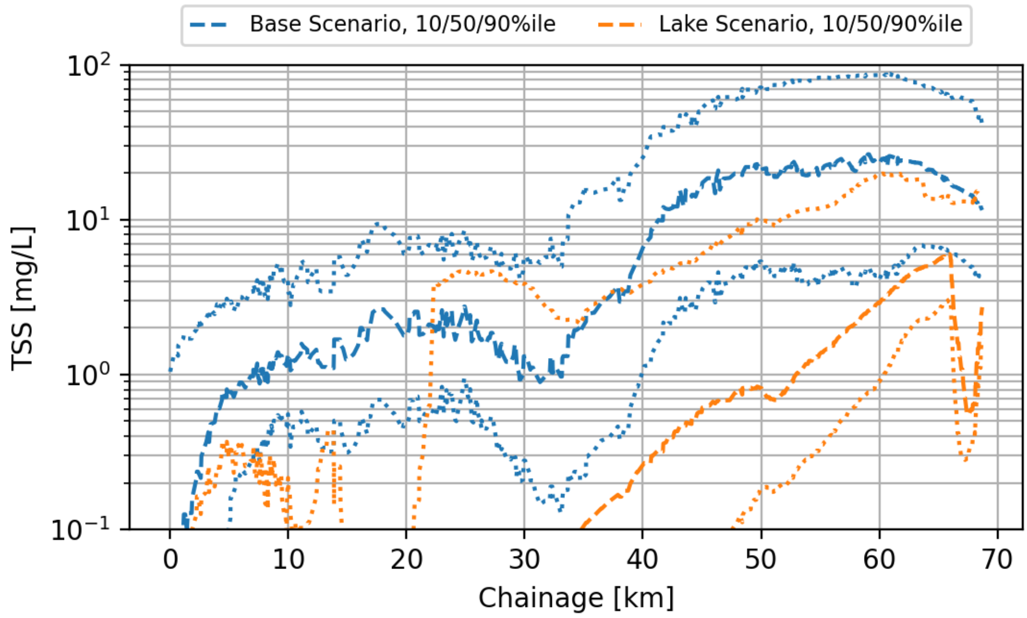

Figure 4.6 Long section of depth averaged TSS percentiles from Low Head to Launceston.

4.6 Sand transport

Transport of the marine sand fraction occurs in the lower estuary under wave and tide forcing. There is a net upstream sediment transport potential in the lower estuary as illustrated by the negative cumulative sediment flux through a cross-section at Clarence Point boat ramp (Figure 4.7). The magnitude of net upstream sand transport potential (760 t/y) is much lower compared to the fluvial sediment load in the upper estuary.

The reduced lower estuary tidal prism under the lake scenario results in a very significant reduction in sand transport potential compared with the base scenario. Under the lake scenario, the net upstream sand transport at Clarence Point is only 55 t/y which is a 93% reduction from the base case.

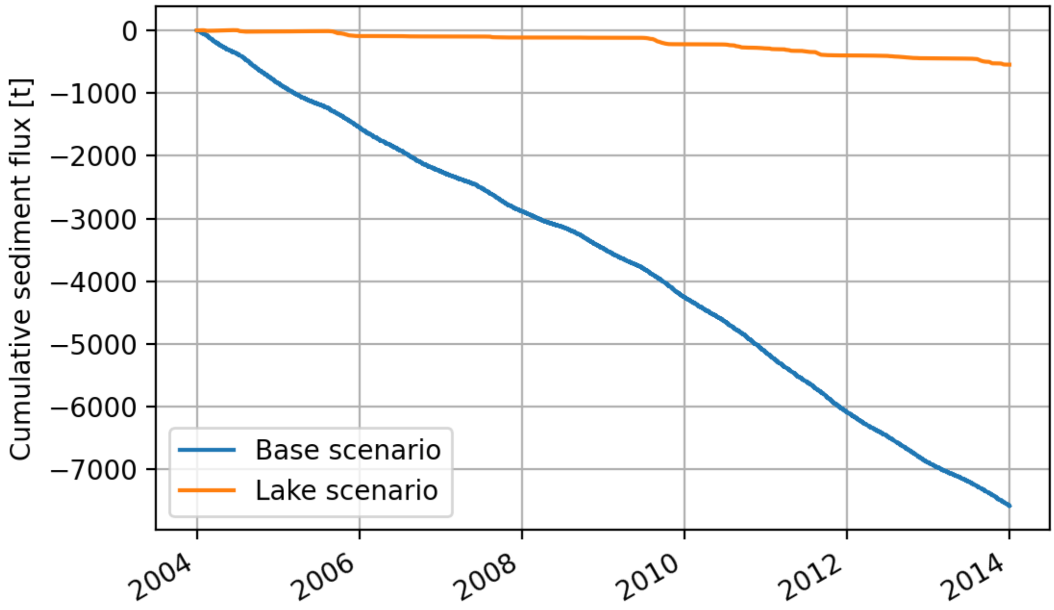

Figure 4.7 Cumulative sand flux through a lower estuary cross-section at Clarence Point. Positive sediment flux is in the downstream direction indicating that net sand transport potential is upstream in the lower Tamar Estuary.

4.7 Sedimentation Rates

Bed elevation changes over the course of the 10 year lake scenario simulation are shown in Figure 4.8. Erosion of sediment from the Home Reach is driven by flood events under both the base and lake scenarios. However, under the Lake scenario there is no upstream recycling of sediment back into the Home Reach, as occurs under the existing (base scenario) tidal regime. Under the lake scenario scouring of the Home Reach would occur during the first few major flood events and would eventually be limited as the cross-section area increases and more consolidated and erosion resistant sediment becomes exposed.

Erosion of the North Esk riverbed was limited in the model by the initial bed warmup condition (refer Section 3.6) which allowed for only limited erosion to occur during catchment runoff events. Under the lake scenario sediment scoured from the North Esk River during flood events would be transported downstream and would not be recycled back upstream as occurs under the tidal regime.

The ongoing fluvial supply and any sediment mobilised from the Home Reach is predicted to disperse and settle in relatively deep areas downstream of Stephenson's Bend. The area of the lakebed between Point Rapid and Launceston is approximately 48 million m^2. Based on the average fluvial sediment load retained in the lake (43,000 t/y) the average sedimentation rate per unit area would be only 0.90 kg/m^2/y. Assuming a dry density value for silt of 500 kg/m^3, this equates to an average annual sedimentation depth of 1.8 mm/y.

Immediately downstream of the barrage at Point Rapid there is a zone of enhanced sedimentation driven by flocculation of silt-laden water discharged from the lake during flood events and mixing with saline water in the lower estuary (Figure 4.8). Due to the reduced tidal prism and less energetic bed shear stress regime, silt is also predicted to deposit and accumulate more broadly in deeper areas of the lower estuary.

The channel and inter-tidal area of the lower estuary downstream of Point Rapid is approximately 30 million m^2 and based on the average fluvial sediment load bypassed through the lake (11,000 t/y) the average sedimentation rate per unit area over the downstream area would be only 0.37 $kg/m^2/y$. Assuming a dry density value for silt of 500 kg/m^3, this equates to an average sedimentation depth over the lower estuary of 0.7 mm/y.

As mentioned above, the model predicts a higher rate of sedimentation in the zone immediately downstream of the barrage, which may include the Long Reach port facilities. Sedimentation rates predicted for the Bell Bay and Inspection Head port areas appear to be in keeping with the average sedimentation rate (<1 mm/y), which would be unlikely to pose a serious constraint to ongoing port activities.

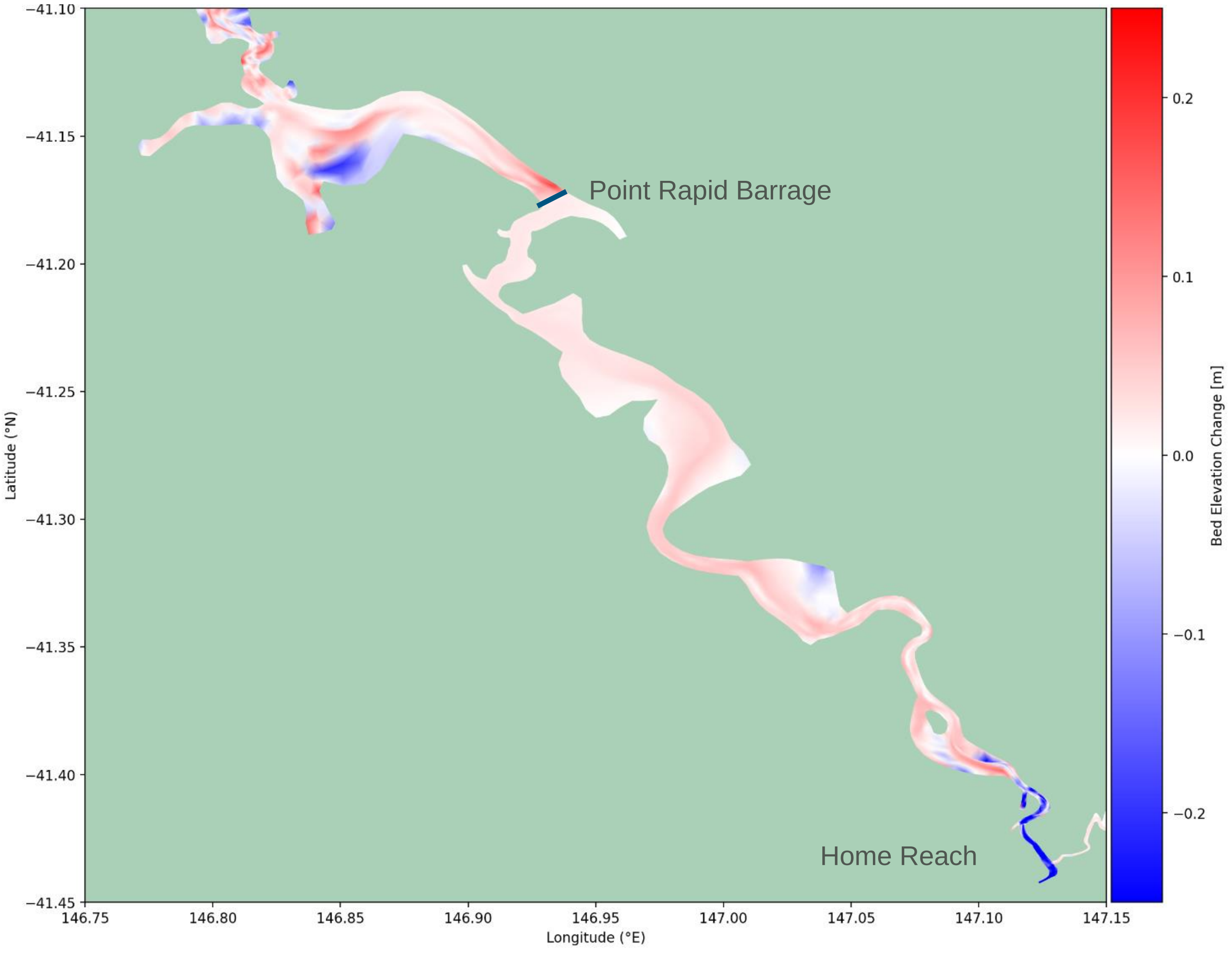

Figure 4.8 Modelled bed elevation change during the Lake Scenario 10 year simulation.

4.8 Particle Size Distributions

The potential for Particle Size Distribution (PSD) changes as a result of the lake proposal have been inferred by comparing the base and lake scenario predictions of the relative proportions of fluvial silt and marine sand sediment fractions (refer Figure 4.9). A map of impacts was derived from the difference between the lake and base scenario predictions. The impact plot indicates a tendency for increased silt deposition and accumulation in the deep channel areas within the lake system. There is also a tendency for the deeper areas downstream of the barrage to accumulate a higher proportion of silt under the lake scenario than occurred under the more energetic base scenario.

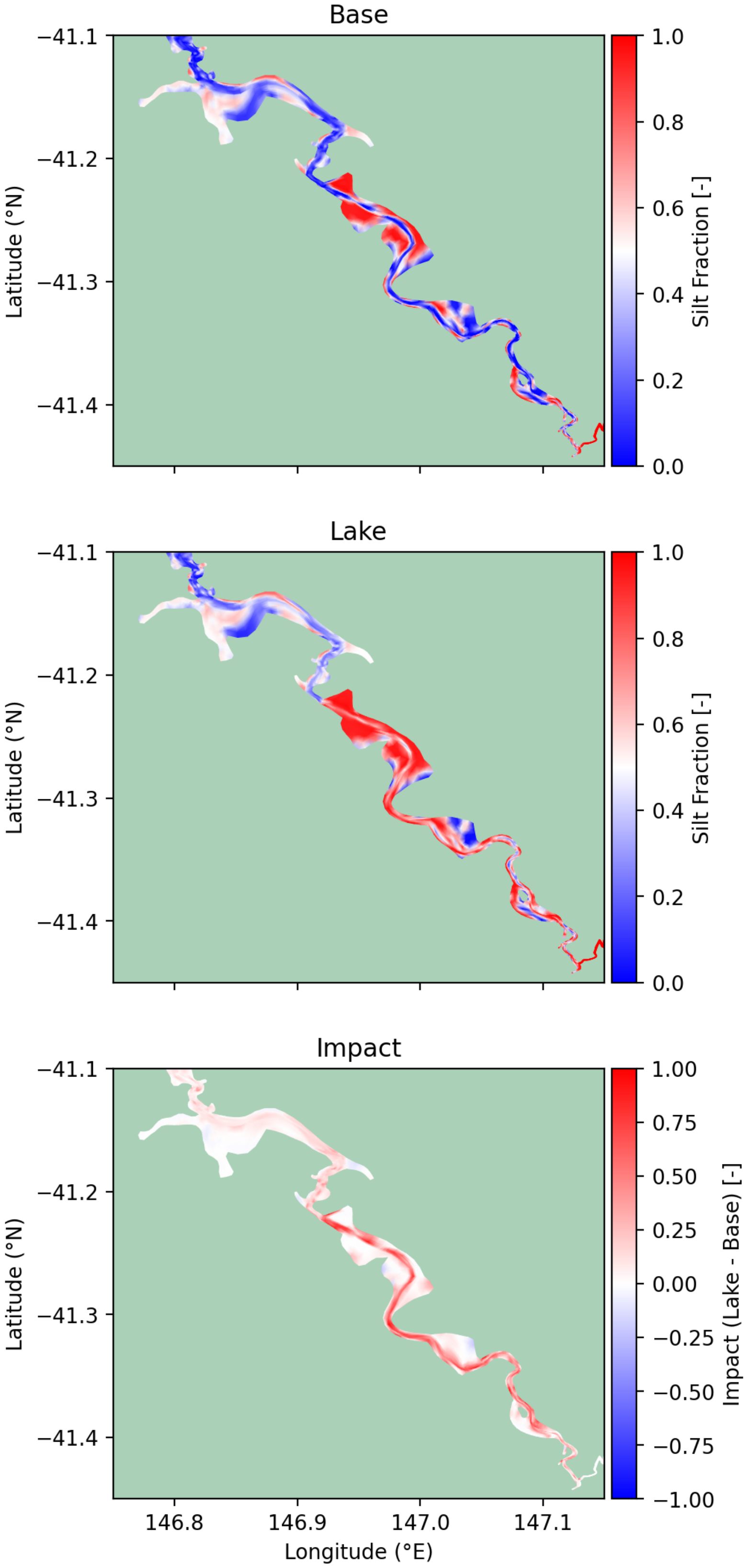

Figure 4.9 Model predictions of the proportion of silt in the seabed, showing base scenario (top), lake scenario (middle) and impact (bottom).

5 Discussion

A hydrodynamic and sediment transport numerical model has been applied in order to deterministically assess the potential for long-term sedimentation impacts from the proposed Tamar Lake barrage concept. The modelling simulated 10-years of morphodynamic evolution under both base and lake scenarios. Further interpretation of the model results is required to evaluate the morphodynamic evolution over multi-decadal and longer timescales.

5.1 Long-term sedimentation

Upstream of the barrage

The deterministic sediment transport modelling of a 10-year period has indicated that the vast majority of fluvial sediment load is retained and recycled in the upper estuary (south of Deviot) under existing (base scenario) conditions. This accumulating silt load (estimated to be around 52,000 t/y) contributes to the ongoing progradation of the extensive shallow and inter-tidal mudflats in the upper estuary. The Home Reach, Yacht Basin and Lower North Esk River exist in a highly dynamic state driven by the influences of tidal sedimentation, base catchment flows and episodic flood-driven scour (Foster, 1986, BMT WBM, 2009; TEER, 2021).

Under the lake scenario, slightly less of the fluvial sediment load is predicted to be retained within the lake system, however it is still expected to capture around 43,000 t/y of silt. Under a relatively quiescent lake regime, this silt will tend to deposit in the deeper channel areas rather than on the banks (refer Figure 4.8). With an overall lake volume of around 400 GL it would take approximately 46 years for the sedimentation to remove 1% of this capacity.

BMT WBM (2016) have previously undertaken water quality modelling of the Tamar Lake scheme, which highlighted some of the challenges that are likely to arise in a man-made lake system, such as thermal stratification and de-oxygenation of the water column. The ongoing accumulation and retention of fluvial sediments in the lake system is likely to be an important component of the overall nutrient cycle and water quality dynamics under a freshwater reservoir regime.

Downstream of the barrage

Stable tidal channels, unless otherwise geologically restricted or subject to strong external influences, such as input of sediments by other processes, have been shown to exhibit a well-defined relationship between the volume of tidal flow (tidal prism) and the cross-section area of the flow. As the tidal prism reduces in the upstream direction along the estuary, the regime equilibrium channel cross-section also reduces. This is a consequence of the fact that they tend to adjust their geometry until a certain regime equilibrium is achieved.

Previously Foster (1986) and BMT WBM (2009) have used regime equilibrium concepts to interpret the morphological response to historical dredging and contemporary sedimentation trends in the upper estuary, in particular the Home Reach at Launceston. The following regime equilibrium relationship between cross-section area below 0 m AHD (*A*) and Tidal Prism (*P*) has been derived using data from several Australian estuaries and is plotted with data points derived from along the Tamar Estuary between Low Head and Launceston. In general, data points for the base scenario estuary are seen to be in reasonable accordance with the empirical regime equilibrium relationship.

$$A = 3.1e^{-3}P$$

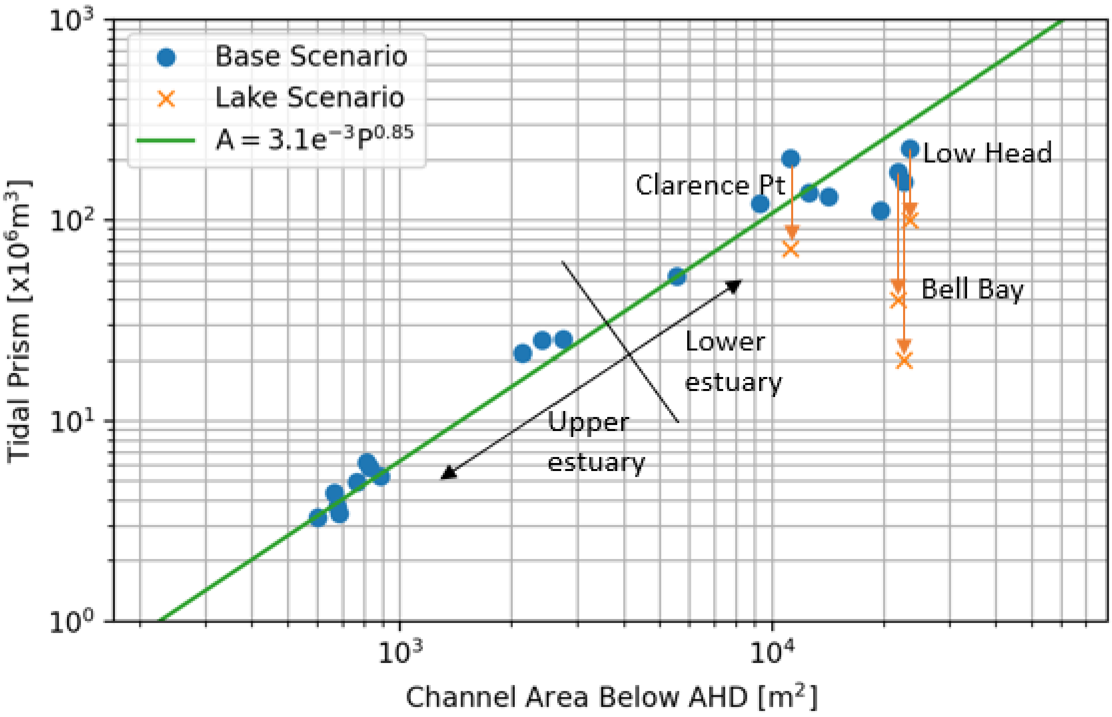

Figure 5.1 Empirical regime equilibrium relationship and data points for the Tamar River estuary from Low Head to Home Reach. For the lake scenario the shift in regime equilibrium for locations in the remnant estuary downstream of the Point Rapid barrage have also been plotted.

Some of the estuary cross-sections, notably at Clarence Point, sit above the regime equilibrium relationship, indicating that these sections are probably geologically restricted. Wave-dominated tidal inlet entrances with strong sediment supply will tend to plot well above the plotted regime equilibrium relationship for non-entrance estuary channels (O'Brien, 1969). Interestingly, there is a trend for the furthest downstream Tamar Estuary cross-sections to plot below the regime equilibrium relationship, which may indicate that there is a relatively weak marine sediment supply at the mouth of the Tamar Estuary.

As detailed in Section 4.2, the Lake scenario will substantially reduce the tidal prism in the remnant estuary downstream of the Point Rapid barrage. This is shown in the four (4) Lake scenario data points plotted in Figure 5.1. It is clear that the reduced tidal prism due to the barrage at Point Rapid would initially leave the remnant estuary in a regime that has much larger channel cross-sections than required for regime equilibrium. Under this scenario siltation of the remnant estuary would be expected, which is also consistent with the 10-year morphological modelling predictions (Section 4.7).

The trend towards a new regime equilibrium in the remnant estuary is illustrated in Figure 5.2. Based on the projected change in regime equilibrium under the lake scenario the channel cross-section areas in the remnant estuary are expected to decrease by approximately 9,000 m^2 on average, which ultimately equates to roughly 180 million m^3 of sedimentation over the 20km of remnant estuary. In percentage terms the remnant estuary is projected to ultimately decrease in waterway volume by 40 to 50% compared with its present configuration.

However, the regime equilibrium concept by itself does not assess the timescales for achieving equilibrium. The numerical model analysis on the other hand does provide quantitative estimates of both marine sand and fluvial silt supply rates to the remnant estuary, which can be used to infer timescales for the estuary to attain a new equilibrium following barrage construction.

Fluvial sediment load to the lower estuary is predicted to increase under the lake scenario to an average rate of 11,000 t/y (from 1,700 t/y in the base scenario). In contrast the rate of marine sediment supply is predicted to substantially decrease to an average rate of just 55 t/y (from 760 t/y in the base scenario). Based on these estimated supply rates, the timescale for infilling of the lower estuary to approach regime equilibrium is likely to be of the order 5,000 to 10,000 years. Over these rather long timescales the remnant lower estuary would be expected to also evolve towards a more fluvial character than the existing case (base scenario).

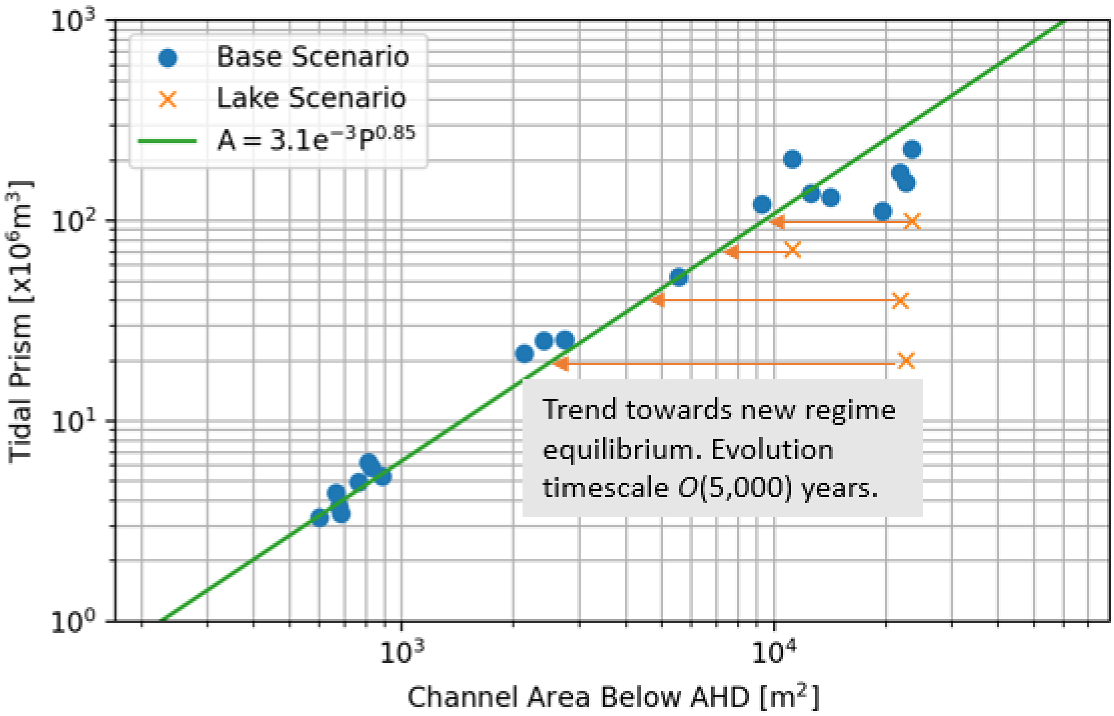

Figure 5.2 Trend towards smaller channel cross-sections under a new regime equilibrium in the remnant estuary. The timescale for evolution towards the new regime equilibrium has been assessed to be *O*(5,000) years.

5.2 Sensitivity to Climate Change

The sensitivity of the predicted response to projected climate change induced SLR was assessed by simulating the base and lake scenarios in combination with a 0.4 m SLR allowance. Only the 2011 calendar year was simulated for the SLR sensitivity assessment.

The relative contribution of SLR to modifying the morphological evolution trends was assessed by firstly considering the fluvial sediment load at the proposed Point Rapid barrage location (Figure 5.3). The contribution of SLR to the tidal base scenario is to reduce the downstream bypassing of fluvial sediment during the 2011 flood event by around 30%.

In contrast, the contribution of SLR to sediment bypassing under the lake scenarios is negligible as the water levels, currents and sediment transport upstream of the barrage are relatively insensitive to the 0.4 m projected increase in ocean water level.

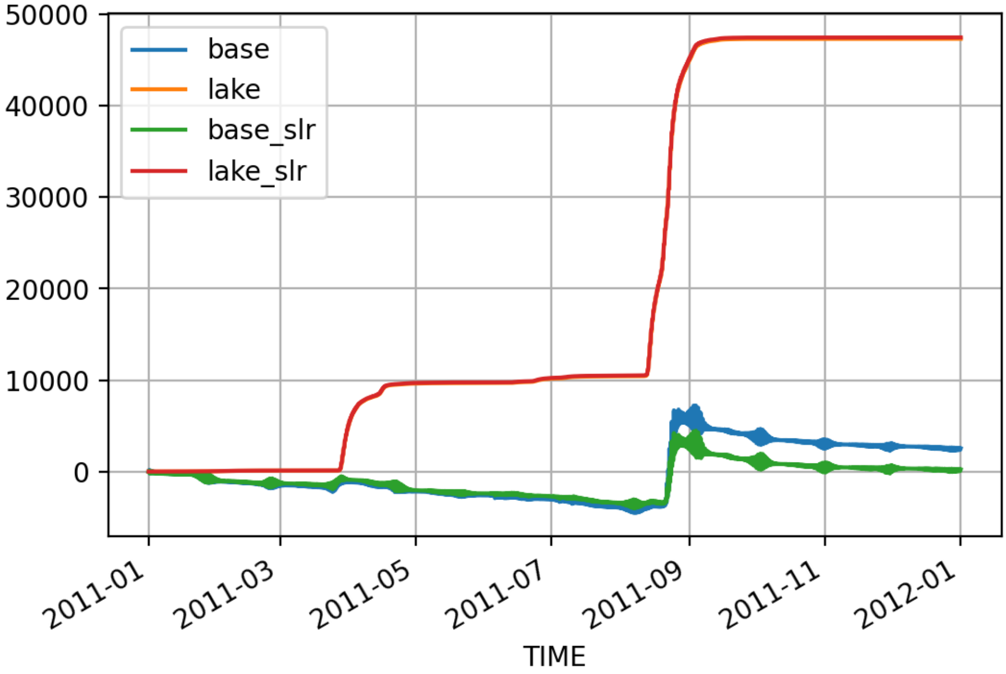

Figure 5.3 Cumulative silt flux through a cross-section at the proposed barrage location under base and lake scenarios with and without 0.4 m SLR.

The marine sediment transport near the mouth of the estuary (Clarence Point boat ramp) was also assessed for the scenarios with and without SLR (Figure 5.4). These results show that the predicted contribution of SLR to modifying marine sediment ingress into the estuary is small compared with the substantial reduction that is predicted to occur with a barrage at Point Rapid reducing the lower estuary tidal prism.

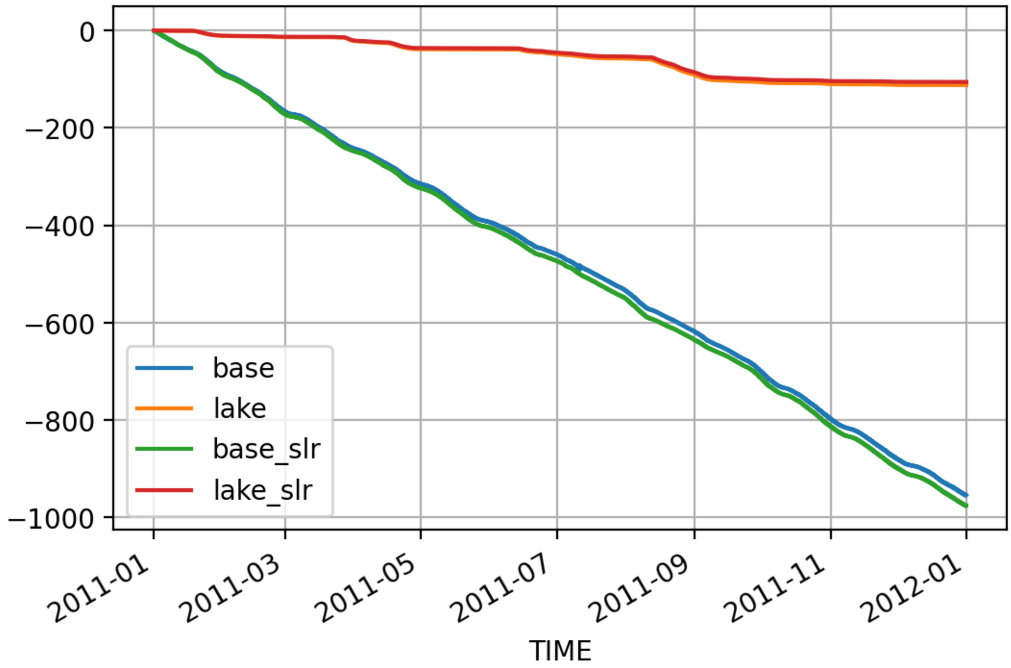

Figure 5.4 Cumulative sand flux through a lower estuary cross-section at Clarence Point.

Climate change projections for rainfall and catchment runoff (Bennett et al., 2012) are less clear than the projections for temperature and SLR. The majority of climate change models predict decreased rainfall, but the trends are found to be spatially variable. Changes are expected to the frequency and severity of extreme weather events. Rainfall intensity and associated flooding is projected to increase across Tasmania, with longer dry periods in between heavy downpours. Due to the non-linear relationship between catchment sediment load and catchment flow, a slight decrease in average rainfall combined with an increase in extreme flood events would most likely result in an increase in catchment sediment load.

The lake scenario was predicted to be more efficient at bypassing fluvial sediment into the lower estuary than the base scenario. Potential future increases in catchment sediment load would be expected to have a more pronounced effect on the lower estuary under the lake scenario compared with the base scenario. Under the lake scenario, the lower estuary would be expected to slowly evolve towards a more fluvial character (i.e. higher proportion of fluvial sediments) and this trend could be accelerated under a climate change scenario with higher catchment sediment loads.

5.3 Model Uncertainty

This study has undertaken deterministic numerical modelling of hydrodynamic and sediment transport processes in order to assess the potential impacts of the Tamar Lake concept. Any numerical model system relies on a number of input datasets and calibration parameters. While every effort has been made to use the most accurate input data and to calibrate the model predictions to match observations, there will be a level of uncertainty in the model predictions.

The expected uncertainty ranges in some of the model inputs and outputs of primary significance to addressing the objectives of the long-term sedimentation study are summarised in Table 5.1. The most important model prediction to meet the study objectives relates to the broad scale sediment transport pathways and in particular the relative differences under both the base and lake scenarios. While the prediction of absolute quantities may be uncertain, in no small part due to significant uncertainty in the catchment sediment load model input, the model's ability to predict relative differences in broad-scaled transport pathways and sediment budgets between the base and lake scenarios is considered to be sufficiently robust and fit for purpose to address the objectives of this study.

Table 5.1 Assessment of modelling uncertainty

Study predictions	Model input / output	Level of uncertainty
Catchment flows	Input	Moderate (±50%) uncertainty.
Catchment sediment loads	Input	High (±100%) uncertainty (limited sediment load gauging data and high variability in data)
Estuary hydrodynamics	Output	Low to moderate (±20%) uncertainty. Tamar Estuary model has been validated again in-situ observations in earlier studies demonstrating a good level of predictive skill (BMT WBM, 2015).
Lake hydrodynamics	Output	Low to moderate (±20%) uncertainty. Modelling platform used in this study has been proven in other studies to accurately reproduce lake/reservoir hydrodynamics.
Broad scale estuarine sediment transport	Output	Moderate (±50%) uncertainty in relative impacts. Model predictions of broad-scale sediment transport pathways in the Tamar Estuary is consistent with general understanding of Tamar River geomorphology (Foster, 1986).
Broad scale lake sediment transport	Output	Moderate (±50%) uncertainty. The potential accuracy of the model to predict the relative proportion of sediment retained in a large freshwater lake system is reasonable and sufficient to meet objectives of this study.
Fine scale sediment transport	Output	High (±200%) uncertainty. Complex sediment transport processes occur in estuaries at fine scales (<*O*(1km)) and model predictions of fine scaled variability should be treated with some caution.

6 Conclusion

The long-term sedimentation impacts of the Tamar Lake concept have been assessed using a 3D hydrodynamic, water quality and sediment transport model of the Tamar Estuary. Base and lake (developed) scenario simulations were undertaken for a 10-year period from 2004 to 2014, which included a range of dry to wet years.

Model outputs were interrogated to assess the predicted impacts to water levels, tidal prism, bed shear stress, silt transport, sand transport, net sedimentation rates and Particle Size Distributions within the lake upstream of the barrage and in the downstream remnant estuary.

Conclusions regarding sedimentation impacts upstream of the barrage are consistent with previous studies (BMT WBM, 2016); that is, there would be a net loss of sediment from the Home Reach in combination with an ongoing accumulation of fluvial sediment in the deeper (channel) of the lake system downstream of Newnham. Under the lake scenario it is predicted that 80% of the fluvial sediment load is retained upstream of the reservoir and 20% is bypassed downstream. This ongoing accumulation of fluvial sediment would contribute to some of the challenges related to maintaining a healthy water quality regime in the 400GL freshwater reservoir.

The model predictions downstream of the barrage were interpreted in the context of an estuary regime equilibrium analysis, in order to understand both the projected final equilibrium state of the downstream remnant estuary and also the order of magnitude timescale for the remnant estuary to reach its new equilibrium. Considering both the rate of fluvial sediment supply bypassing the barrage and the post-barrage marine sediment supply rate, the timescale for the system to reach a new equilibrium was assessed to be of the order 5,000 years.

Changes to the sedimentological character of the remnant estuary would be expected to be observed within decades of the barrage construction, with a trend towards a more fluvial character due to a relative increase in the supply of fluvial sediment combined with a weakening in the marine sediment supply pathway.

Due to the long timescales involved in the sedimentation response, the risk of the predicted sedimentation impacting on port infrastructure and operations is considered to be low in the context of a typical 50-year planning horizon. Infrastructure located in Long Reach immediately downstream of the barrage would be at the highest risk of experiencing problematic levels of sedimentation under the lake regime, with sedimentation episodes most likely to occur following large flood events.

In addressing the objectives of this study, an improved understanding of the predicted long-term sedimentation response of the Tamar Estuary system to the Tamar Lake proposal has been developed. The findings presented herein should allow for more informed risk assessments of the Tamar Lake proposal. The scope of this study does not include considerations of risk to (for instance) ecological character or social values attached to the Tamar Estuary, and the conclusions of this study do not represent an endorsement for (or against) the proposal.

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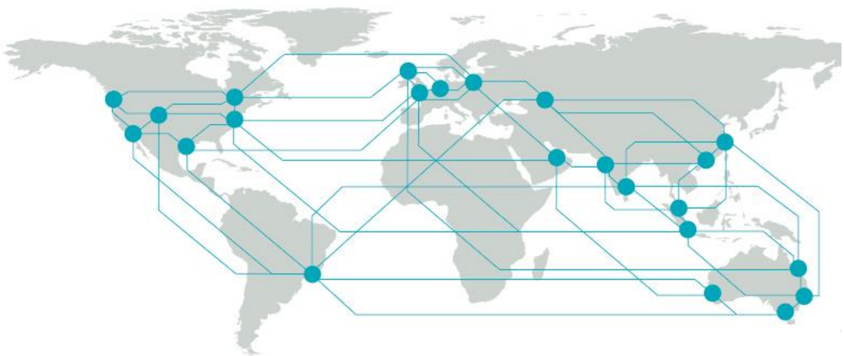

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