Trevallyn Flow Releases Study

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Synopsis:	**Report detailing the development and results of a model to study the impact of flow releases over Trevallyn Dam on the siltation in Home Reach and on the effects of silt-raking.**	

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Executive Summary

The natural variability of siltation patterns in the kanamaluka/Tamar River Estuary near Launceston has been a cause of community concerns for many decades. Periods of increased siltation can cause social and economic issues by impacting the amenity of these parts of the estuary. During large catchment rainfall events, high flows through Cataract Gorge serve as a natural mechanism for mobilising silt from the upper-estuary, scouring out a deeper channel and reducing the extent of the silt-flats. In the absence of such events (prolonged dry seasons and years of drought), silt accumulates in the upper-estuary. In recent years silt-raking has been the preferred management method for silt-mobilisation in zones of interest with dredging utilised prior to 2012. Silt-raking involves the agitation of sediments to mobilise them into the outgoing tide, with the aim of flushing them downstream. It has been suggested that planned (targeted) flow release of water from the Trevallyn Dam could serve as alternative method for sediment mobilisation.

This modelling study has sought to investigate the potential of targeted flow releases to manage sedimentation in the upper estuary, either on their own or as a combined strategy with silt-raking.

The key objectives for sediment management are:

- Reducing the extent of silt-flats on the banks of the estuary that are perceived as unsightly;
- Reducing the same silt-flats in areas that impinge on the amenity for rowing and paddling;
- Deepening channels that become silted and impact the navigability of watercraft; and
- Maintaining deep areas of mooring and access for watercraft.

The longer-term fate of upper-estuary mobilised sediments must also be considered for its potential impact on any areas that it is mobilised to. The location at which mobilised sediments settle out also influences the time over which those sediments might be transported back to the upper-estuary.

An additional goal of mitigating the potential severity of flood events has also been proposed, but this has not been assessed within the scope of this study.

Achieving these outcomes must also be balanced by any negative impacts on water quality by the increased entrainment of sediment in the water column. This study has only examined potential impacts on Total Suspended Solids (TSS) concentrations due to any interventions. Any associated water quality impacts due to other pollutants (both dissolved and those bound to sediments) are beyond this scope and would require further study.

Modelling has been conducted using a Three-Dimensional Hydrodynamic and Sediment Transport model of the kanamaluka/Tamar River Estuary using the TUFLOW FV software. This model has been previously validated and used for studies of the water quality in different reaches of the estuary.

The modelling conducted assessed a range of different Trevallyn Dam release flow rates, but with an equal total release volume equivalent to 100 m^3/s released for 24 hours (8,640,000 m^3, approximately the volume accessible via the spillway when the dam is full within operational constraints). A base case without flow releases (both with and without silt-raking) was also considered, as was a ‘natural spill’ event, corresponding to a typical (approximately annual) rainfall event that causes an elevated flow event through Cataract Gorge.

Overall, the modelling results indicate that targeted (planned) releases of water from Trevallyn Dam have a limited effect on silt-mobilisation in the upper estuary and are unlikely to serve as an effective

sedimentation management strategy on their own. Moreover, such releases come at a relatively high cost (approximately $100,000), in terms of the lost potential electricity generation.

Even the relatively high flow rates of the natural spill scenario that was assessed (peak flow down Cataract Gorge of 138 m³/s, relative to highest targeted flow release of 50 m³/s) shows only small scouring effects on the silt-flats and navigable channels (less than 1 mm of bed level change in practical terms).

The modelled silt-raking campaign has been shown to be effective at mobilising silt from within the immediate area of such operations (~40 mm lower bed in the shoals on average), coming at a cost of ~$90,000. However, the modelling also shows that the majority of silt mobilised by this silt-raking deposits on adjacent silt-flats and within adjacent channels (~20 mm bed level increase in channels on average). Therefore, silt-raking causes a trade-off in the objectives of silt-raking where an improvement can be achieved by reducing silt-flats in one area with a corresponding detriment to adjacent silt-flats and to the navigability of nearby channels.

Silt-raking during targeted flow releases increases the volume of silt-mobilised (up to 27% more sediment mobilised from within the target area, corresponding to an additional 10 mm decrease in shoal bed levels), but also causes more infilling of adjacent areas. Such a combined strategy is also costly, with the flow releases adding an additional ~$100,000, resulting in a significantly higher cost of ~$190,000.

Silt-raking during natural spill events shows the highest rates of silt-mobilisation (over 90 mm lower bed level in the shoals on average), but still creates an impact on the adjacent silt-flats and channels (relative to the stated objectives).

The modelled scenarios show that the majority of sediments that are mobilised remain within the upper-estuary, and consequently no change to the long-term siltation rate is expected.

Further conclusions drawn from the modelling investigation conducted are as follows:

- The magnitude of flow releases assessed does not cause any significant impact on the downstream TSS concentration beyond the timeframe of the flow release itself. However, the flows of the natural spill can cause a significant increase (with peak TSS concentrations twice as high as under the assessed ‘base case’ conditions);
- Silt-raking (with and without targeted flow releases) causes an increase in TSS conditions, though this is less than is observed during the natural spill event (without silt-raking);
- Silt-raking during a natural spill event causes the greatest increase in peak TSS concentrations immediately downstream of Launceston. It also causes a small increase in the TSS concentrations immediately downstream from Launceston for several weeks after the flows cease; and
- All increases in TSS concentrations due to increased flows or silt-raking (or both) return to normal levels shortly (within one tide cycle) after the flows and silt-raking cease.

Some recommendations arising from this modelling investigation include:

- Further study is needed on the silt-mobilisation effects of large flow events. The modelling shows that the natural spill scenario modelled is insufficient to achieve the desired outcomes, but much larger spill events do occur. Understanding of the magnitude of event required to achieve different levels of silt-mobilisation would help inform the likely need for silt management interventions in a given year.

- Further, the water quality impacts (both TSS and other pollutants) during large flow events (as well as silt-raking and other siltation management interventions) should be monitored to collect a broader dataset that can inform further water quality modelling, as well as decision making. The outcomes of this could also be used to prepare impact assessments of siltation management options and to inform the licence conditions of these.
- Lastly, additional investigations should be undertaken into the effects and impacts of silt-raking to better understand the effects relative to the desired outcomes. The modelled silt-raking uses broad approximations of silt-raking processes that limit the precision that can be achieved in comparing different silt-raking operations (operating at different rates and in different areas to minimise the negative effects). A planned extended monitoring program of silt-raking operations (with bathymetry surveys, deployed instruments including real-time backscatter transecting) would allow for better understanding of the immediate effects and the plume production relative to other operational constraints.

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1 Introduction

Siltation in the kanamaluka/Tamar River Estuary has been a consistent source of community concern since the early settlement in Launceston. Alluvial silt accretes in Zone 1 (from Launceston down to Legana, just past Tamar Island) where the mixing zone of fresh water to saline water causes fine sediments to flocculate and settle.

Within the estuary, the asymmetrical tidal currents and salt-wedge circulation combine to transport sediments (especially fine silt and clay particles) upstream where they are deposited in the relatively quiescent conditions around Launceston (noticeably on the banks and in the Yacht Basin). Catchment flows of sufficient magnitude will counter the upstream sediment transport and resulting upper-estuary siltation processes. However, catchment flows are highly variable across both years and seasons. Prolonged dry periods resulting in below average catchment flows correlate with elevated upper-estuary siltation rates.

The construction of Trevallyn Dam and the Trevallyn Power Station has contributed to the modification of the natural system by diverting a proportion of the South Esk catchment flows through the Tail Race, bypassing Cataract Gorge and the Home Reach. At the same time the Tamar River system now receives additional freshwater flows as a result of the Poatina diversion. High flow events overtop the Trevallyn Dam spillway and flow through Cataract Gorge. Large spill events are the dominant process driving the scour and removal of sediment from the Yacht Basin and Home Reach.

While the presence of transient intertidal silt-flats is part of the overall natural system, it has social and economic effects for the local community. Firstly, there is a perception that the silt-flats have a negative aesthetic and odour during low tides. Additionally, the navigation of both larger vessels in the main channels (such as tourist ferries) and smaller vessels near the banks (such as rowing craft) is hampered by the shallow depths. Finally, there is a perception within parts of the community that excessive siltation can contribute to the severity of flood impacts during large events.

In the absence of significant flow events, the dredging of Home Reach was historically used to manage navigational access for the Port Authority. This process began when Launceston catered to larger cargo ships requiring deep maintained navigational channels but continued in a reduced capacity long after these vessels moved to other ports. In more recent years, silt-raking has been the primary recourse for siltation management and was adopted to be a more cost-effective methodology for the present needs of the community.

Considering that large spill events can scour out silted areas, it has been proposed (by community and stakeholders) that targeted releases of water from Trevallyn Dam outside of natural flow events could be used as another method to mobilise silt in the upper estuary (both with and without concurrent silt-raking).

The key outcomes desired by any efforts of silt-mobilisation are:

- Removing silt-flats on the banks of the estuary that are perceived as unsightly;
- Removing same silt-flats in areas that impinge on the amenity for rowing and paddling;
- Deepening channels that become silted and impact the navigability of watercraft; and

- Maintain deep areas of mooring and access for watercraft.

An additional goal of mitigating the potential severity of flood events has also been proposed historically, but this has not been assessed within the scope of this study.

These outcomes must be considered in light of any negative impacts on water quality by the increased entrainment of sediment in the water column. The final fate of mobilised sediments must also be considered for its potential impact on any areas that it is mobilised to, and the likelihood of it quickly returning to the target areas.

Considering the above, the aim of this modelling study is to assess the impact of Trevallyn Dam flow releases on the sediment mobilisation in Zone 1, either on their own or as a combined strategy coupled with silt-raking.

An investigation has been undertaken with the following specific objectives of assessing:

- The potential impact of staged releases relative to no releases and to a natural spill event; how much silt mobilisation can be provided by practically achievable flow releases (and other associated impacts).
- The influence of release flow rate compared to duration; whether a shorter duration but higher magnitude flow is more or less effective at mobilising sediment than a lower flow over a longer duration.
- The influence of flow releases synchronised with silt raking operations; whether combining silt raking and targeted flow releases has a potential impact on silt management outcomes.

A series of scenarios have been developed that seek to address these objectives. The modelling scenario predictions have been assessed for their effects with respect to navigability, reduction of the silt flats and their relative costs. Impacts of silt mobilisation on potential flood mitigation benefits have not been assessed by this modelling investigation. Moreover, impacts on water quality (other than TSS) and on the estuarine ecology have not been assessed.

2 Historical Context

2.1 Flows

A set of assumptions to be used for developing the flow scenarios have been provided in the project brief by the working group (consisting of representatives of isNRM, IMAS, EPA, Hydro Tasmania, City of Launceston, Petuna, WTC and NRM North). These assumptions are as follows:

- Releasing water to mobilise sediment in Zone 1 would only make sense during moderately dry years that do not experience natural spills given that these would be expected to be much more effective at mobilising sediment than any targeted flow release;
- In extremely dry years (drought), water may not be available for such releases and would be preferentially retained for energy security and drinking water supply;
- Therefore, targeted flow releases should only occur during drier-than-average but not drought years;
- Flow releases would most likely take place after winter to ensure that no large natural spill events have occurred;
- Flow releases would also need to occur prior to November/December to avoid potential (or perceived) impacts on downstream aquaculture and the Australian Grayling migration; and
- Therefore, flow releases would be expected to occur in early Spring (September/October).

The past 10 years of Dam release data (provided by Hydro Tasmania, 1st January 2008 – 17th September 2018) was collated (incorporating the spillway, power station and environmental flows). An upstream inflow to Lake Trevallyn was inferred by the change in daily dam volumes (sourced from the Bureau of Meteorology) and the addition of the daily release data. It is noted that actual inflows to Lake Trevallyn are likely to be slightly higher than this due to evaporation, which is not quantified in this assumption. This dam inflow and dam release information was then analysed to assess the context of different flow assumptions and also to determine a suitable 'natural spill' event.

2.1.1 Average Flow Distributions

The distribution of flows coming from the Trevallyn Dam changes during different times of the year. Any increases in upstream flow up to 100 m³/s are able to be accommodated by the Trevallyn Power Station. This means that the vast majority of flows through Cataract Gorge are either the long-term environmental flow releases (set at 2.5 m³/s) or dam spillway releases due to natural flow events (which can range up to extreme floods, and are discussed further in section 2.1.2). There are occasional targeted dam releases for alternative purposes such as for recreational purposes in supporting kayaking in Cataract Gorge. Figure 2-1 shows timeseries of the flows through the Tail Race (from the hydro station) and the South Esk. Peaks of flow through the South Esk are marked also (representing event flow peaks).

In terms of inter-annual variability, the range of annual-average dam outflow (both through the South Esk and the hydro station) is from 30.7 m³/s in 2008 to 106.5 m³/s in 2016. Figure 2-3 shows the average flow rates for each year, as well as the average flow rate for the September/October period of that year (shown in lighter shade). These average flows are split to show the relative distribution of the flows through the Tail Race and the South Esk.

Most years experience concentrated periods of high flows, usually during the winter wet season, but occasionally with events outside of this. The outcome of this is that the Tail Race and South Esk flows are often elevated at the same time, with the long leading and trailing edges of an event being routed through the Tail Race and the peak flow conditions spilling down the South Esk. However, there are some outlying years (such as 2012), where the overall flow is more distributed, with the Tail Race flows experiencing an annual average flow rate in excess of 60 m^3/s, but with only a few small spill events in the South Esk.

In terms of expected monthly variations, the minimum and peak monthly average total inflow rates to Lake Trevallyn for the past 10-years were 12 m^3/s and 378 m^3/s, respectively. These two extremes correspond to a well-below average drought-like flow and a 'very wet' month, experiencing a flood event. As a conservative measure, for the purpose of developing the scenarios, it has been assumed that the average inflow to Lake Trevallyn (not including losses through evaporation) is 22.5 m^3/s. In terms of the corresponding outflows, this represents an average 2.5 m^3/s in environmental flows through Cataract Gorge and an average 20 m^3/s in hydro station flows (Tail Race). For context, the 20th percentile flow (exceeded 80% of the time) into Lake Trevallyn is 25.4 m^3/s and the median discharge at the Poatina Tail Race is 18 m^3/s. Therefore, it is highly likely that a Lake Trevallyn inflow (and outflow) rate of 22.5 m^3/s would be available, even during relatively dry years, for artificial releases.

Moreover, when considering the likely time of year for releases and silt-raking (September/October), this magnitude of inflows is likely to be conservative. Figure 2-3 shows that September/October periods tend to be 'wetter' (higher flow rates) than the average for the year. Overall, a flow rate of 22.5 m^3/s was available over 85% of the time throughout the past decade and was available at all times during September/October periods.

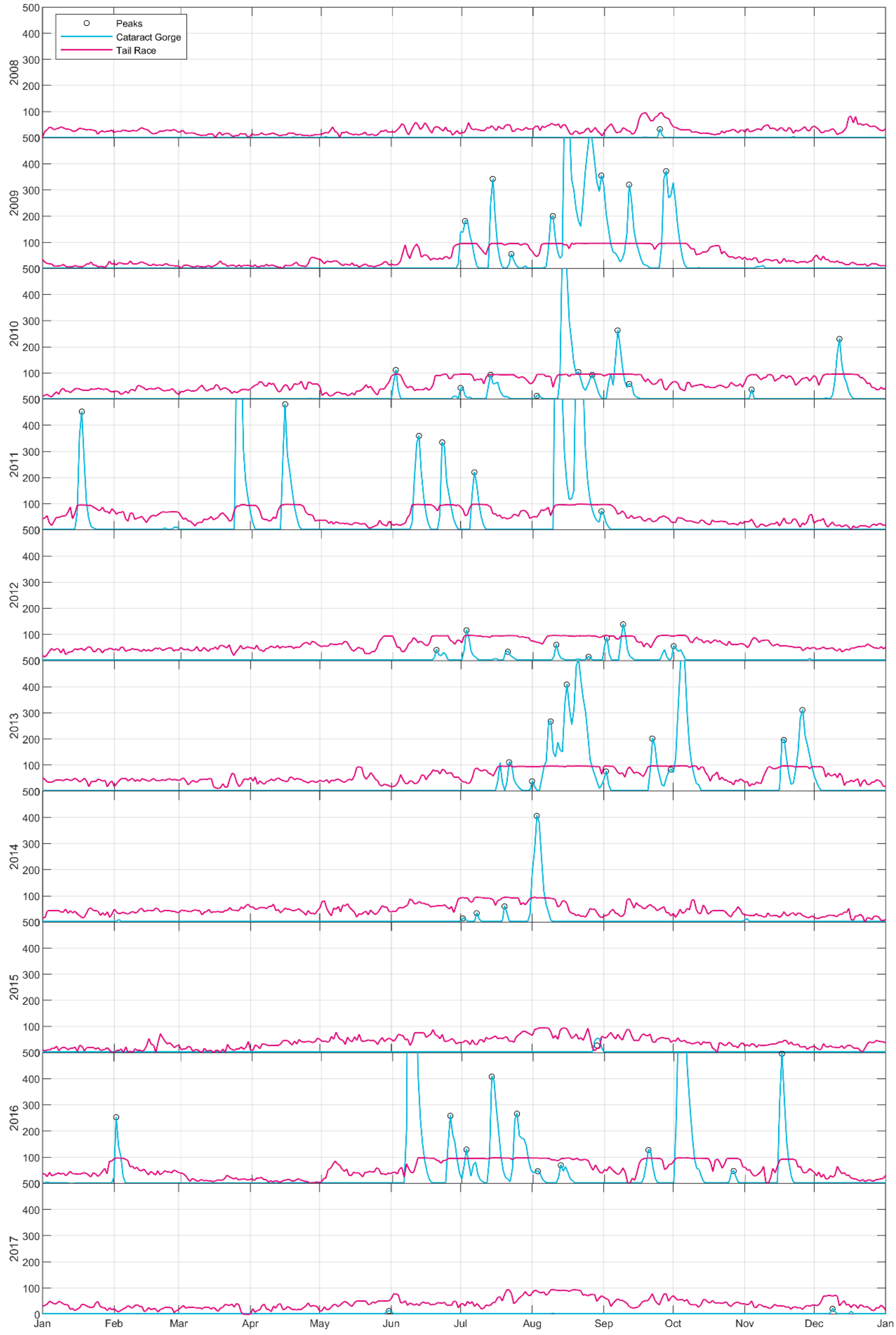


Figure 2-1 Annual Lake Trevallyn Outflow Comparisons (2008-2017)

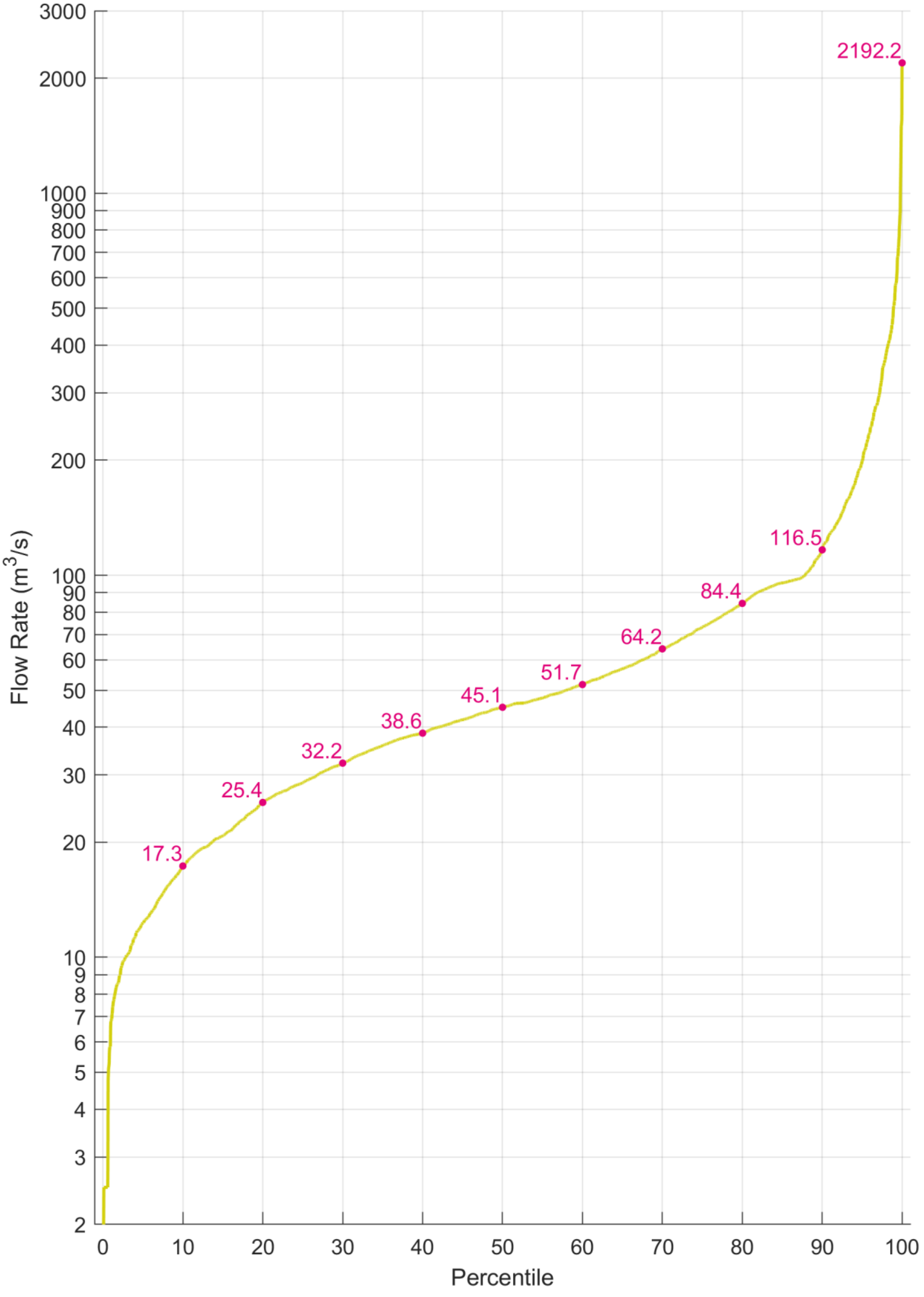


Figure 2-2 Percentiles of Total outflow from Lake Trevallyn (Jan 2008 – September 2018)

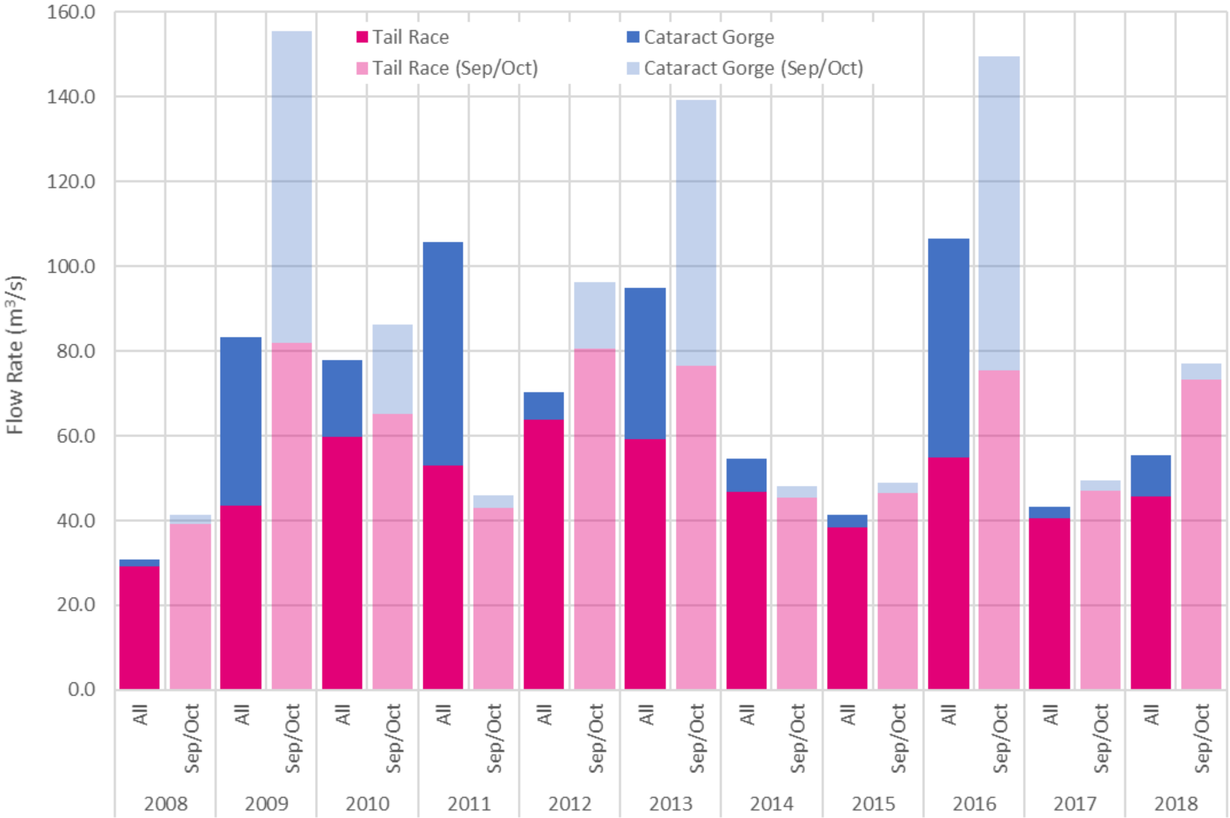


Figure 2-3 Average Flow Rates by Year

2.1.2 Peak Flow Analysis

In order to develop an appropriate natural spill event to compare to the targeted flow release scenarios, a representative hydrograph was selected. Ideally, the natural spill event would occur on average once per year. It is also important to consider the frequency of events given their relation to the frequency that targeted releases might be required.

Recent investigations of the flood frequency analysis (BMT, 2019) for the South Esk River at Lake Trevallyn Spillway are shown in Table 2-1, with the generalised extreme value distribution (GEV) in Figure 2-4 (note log scale on y-axis). As this is focussed on the occurrence of large flood events, the smallest AEP tabulated is the 20% (~5-year event). However, inspecting Figure 2-4 shows that 1 in 1.5-year AEP (66% chance of being exceeded in a year) is between 260 m^3/s and 650 m^3/s.

A natural flow event occurring in September 2012 with a peak flow rate of ~140 m^3/s was chosen to represent a natural spill scenario that could be expected to occur (or to be exceeded) on average approximately once per year. Only three years in the past ten (2008, 2015 and 2017) did not have flow events that exceed 140 m^3/s.

Table 2-1 South Esk River at Lake Trevallyn Spillway FFA Results

AEP	Expected Quantile (m^3/s)	90% Quantile Probability Limits	
20%	1,147	1,017	1,302
10%	1,594	1,381	1,878
5%	2,132	1,782	2,643
2%	3,034	2,389	4,086
1%	3,902	2,916	5,631
1 in 200	4,975	3,517	7,751
1 in 500	6,796	4,440	11,710
1 in 1000	8,559	5,245	16,009
1 in 2000	10,744	6,180	21,802

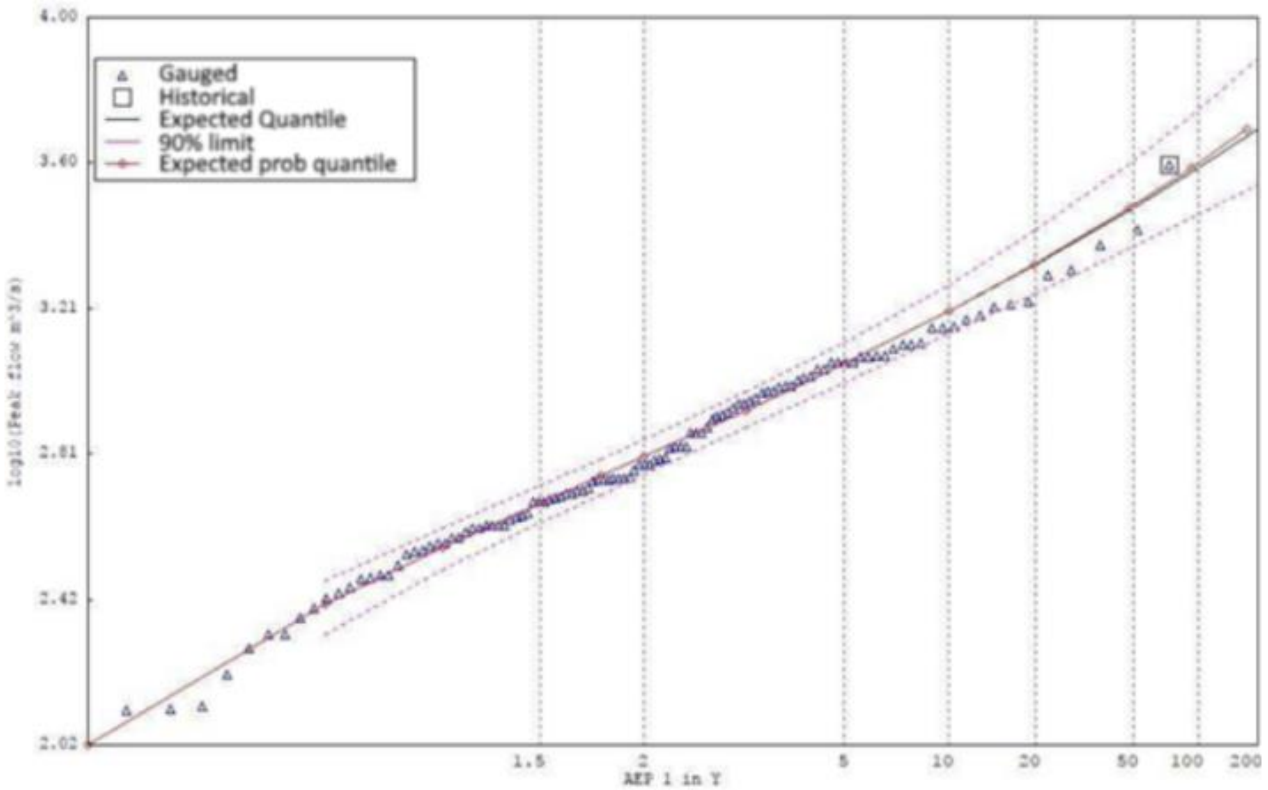


Figure 2-4 South Esk River at Lake Trevallyn Spillway GEV

2.2 Silt Raking and Siltation

The Launceston Flood Authority has conducted silt-raking as the preferred method of siltation management since 2012 due to its lower operational costs relative to dredging. Silt raking uses a large rake to pull sediments from the silt-flats into the main channel path. The goal of this method is to reduce the areas of sediment that are above the low-tide level, while ideally mobilising them in the outgoing tide to be washed downstream. It can also be used in the channels to mobilise bed sediments into the water column that would not be eroded by the natural currents.

Little is known about the exact rates of mobilisation of sediment due to the silt raking, and where the sediment is transported to afterwards. It is likely that some of the sediment that is mobilised will rapidly settle to the bed again in the nearby area, whereas the remainder can be entrained into the currents and settle elsewhere. This process is supported by the observations of the physical tracer study conducted by AMCS (2015), which suggests that the majority of sediments mobilised by silt-raking remain in the upper-estuary.

It is also unknown whether the effects of silt-raking depend on the speed that the rake is towed at, the depth that the rake is at and the direction that any sediments are raked towards. The influence of the sediment characteristics, such as the particle size distribution and consolidation of bed sediments, has also not been recorded for their effect on silt-raking effectiveness.

The main methodology for examining the impact of silt-raking has been to analyse the bathymetric surveys that are conducted every second month (sometimes more frequently during silt-raking campaigns). An existing Launceston Flood Authority (LFA) timeseries of the volume in the Yacht Basin is shown with silt-raking, dredging campaigns and upstream flows in Figure 2-5. This shows that during silt-raking campaigns the sediment volume can be reduced across the Yacht Basin. However, many of the larger sediment mobilisation episodes (reductions in Yacht Basin sediment volume) also occur during large flow events making it difficult to separate these influences.

The surveys show that silt-raking can be effective at mobilising sediment in localised areas (see mid-2015 silt-raking in the absence of significant flows). However, the survey data is not sufficient to determine where the mobilised sediment is relocated to.

Figure 2-5 also supports the hypothesis that the rate of siltation is positively correlated with catchment flow rates. Most of the periods between silt-raking campaigns experience low-flow conditions and exhibit similar rates of infilling in the Yacht Basin. During periods with no silt raking but moderately high flows (such as September 2016 or May-June 2012), there is a reduced rate of infilling.

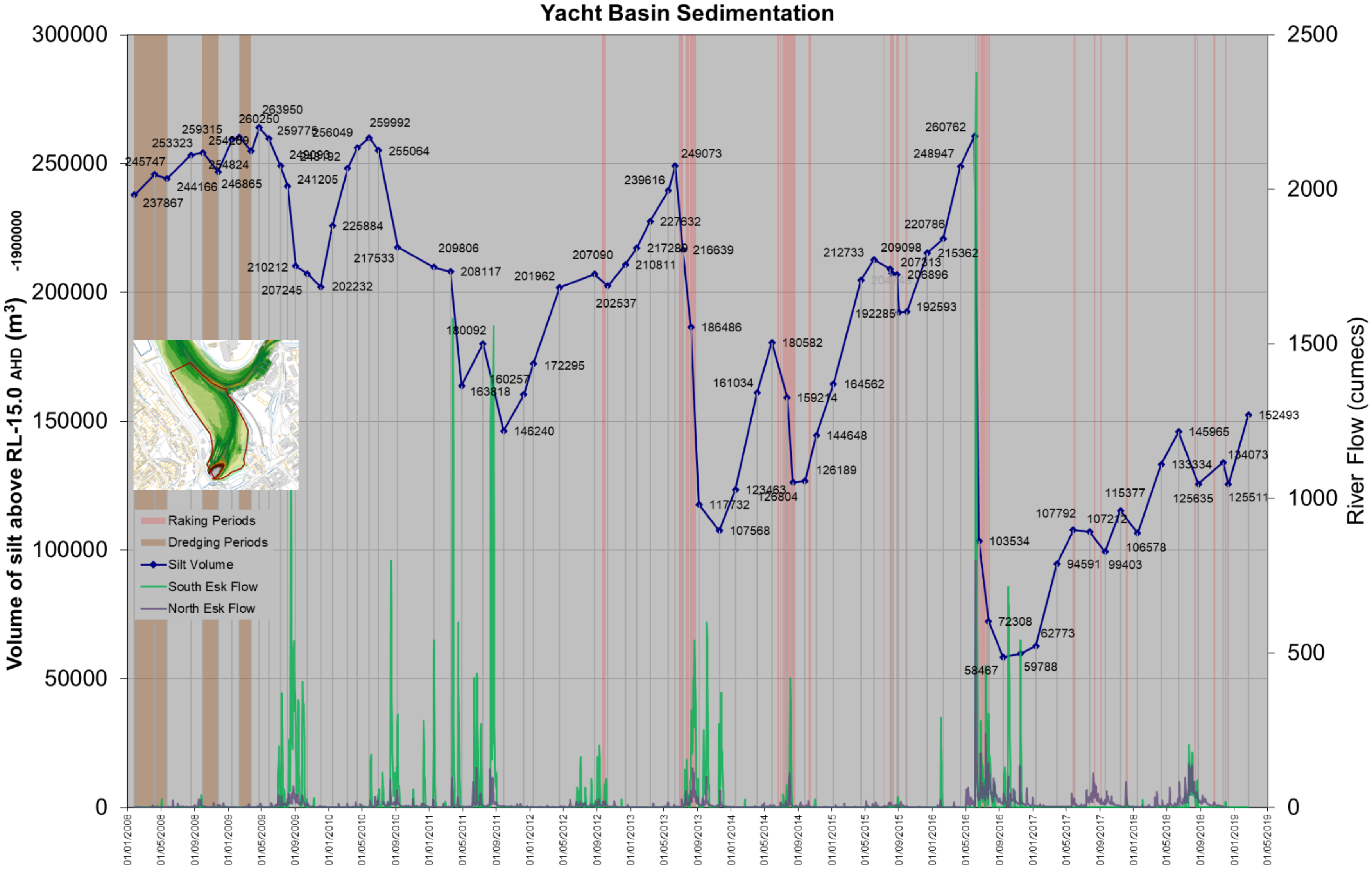


Figure 2-5 Yacht Basin Sedimentation Rates (provided by Launceston Flood Authority)

3 Model Configuration

3.1 Overview

This study makes use of the coupled modelling framework developed previously and described in BMT WBM (2015). The system uses a wave model based on the Delft University of Technology's (TUD) SWAN wave modelling package (Simulating WAves Nearshore) coupled with a TUFLOW FV 3D hydrodynamic and sediment transport model. The fully-coupled water quality model (AED2) is not used for this study.

3.2 Waves (SWAN)

While wave action in the Tamar is generally small, during stronger wind events and over the longer and more exposed reaches of the estuary, it can be a significant driver of sediment transport. Typically, the small waves in an estuary can increase the shear stresses at the bed in shallow regions, providing a mechanism for re-cycling of sediment from these shoals back into the main flow channels.

A SWAN model has been used to add additional wave energy to parts of the Tamar downstream from Launceston including the salt-wedge mixing zone. The extent of the SWAN model is shown in Figure 3-3 and it had a resolution of approximately 50 m. The SWAN model was forced by the wind field data from CFSv2 (Climate Forecast System version 2, obtained from the National Centers for Environment Prediction).

3.3 Hydrodynamics (TUFLOW FV)

The hydrodynamics are as developed previously in BMT WBM (2015), using BMT's in house TUFLOW FV 3D hydrodynamic model, which solves the three-dimensional Non-Linear Shallow Water Equations (NLSWE) on a 'flexible' (unstructured) mesh comprising of triangular and quadrilateral cells. A second-order numerical solution has been applied to both the horizontal and vertical calculations to accurately capture the discontinuities between different parts of the water column such as the salinity and temperature stratification and mixing that is an important feature of tidal estuaries.

Since 2014, additional resolution has been added to the mesh in the vicinity of Home Reach to accurately resolve the silt-raking regions. The model mesh is shown in Figure 3-3.

The hydrodynamics have been previously validated to flow and water level measurements collected in 2003. This validation has been confirmed for the latest mesh changes and is shown in Figure 3-1 and Figure 3-2.

As the silt-raking is likely to occur when siltation is at its highest, the bathymetry that has been adopted for the model is based on heavily silted conditions, based on surveys provided by the Launceston Flood Authority (LFA). The shallower levels of several surveys have been inspected for use as the bathymetry in this study. These have focussed on very high siltation levels both in the channels and on the silt flats on the West Tamar Shoal area (bathymetry shown in Figure 4-8.

3.4 Sediment Transport (TUFLOW FV)

The resuspension, dispersion and settling of the natural bed sediments throughout the study area was estimated using the TUFLOW FV ST module coupled with the calibrated wave and hydrodynamic models. Various assessments also simulated the additional resuspension, dispersion and settling of sediment released into the water column and placed on the bed by proposed silt-raking activities.

The ST module allows for the simulation of multiple sediment fractions in suspension and within the bed. Ambient sediments have been represented by two (2) fractions representing an alluvial silt and a non-cohesive sand fraction. Silt-raking related sediments have been represented by an additional two (2) fractions where applicable (same properties as the ambient sediments).

Bed shear stress is calculated in the ST model from the non-linear interaction of currents and waves using the procedure of Soulsby (1997). A Root-Mean-Square combined wave-current bed shear stress is used as the representative value in the sediment erosion and deposition calculations.

The modelled rate of sediment deposition, Q_d (g/m^2/s), is a function of the near-bed sediment concentration (TSS), the sediment settling velocity (w_s) and the bed shear stress (τ_b), according to Equation 3-1. As such, sediment settling may be reduced below its still water value by the action of bed shear stress and associated mixing in the water column. Non-cohesive sediment fractions were modelled without a critical shear stress for deposition, meaning that they can potentially settle at all times regardless of the bed shear stress. The settling velocity used is based on a constant rate assumed for each sediment class (shown in Table 3-1), that is modified by the processes of flocculation and hindered settling. Flocculation is the process by which high concentration plumes of cohesive sediments can flocculate into larger particles, increasing the effective fall velocity. This process depends on both the concentration of the plume and the salinity of the water, where plumes in saline environments experience more flocculation than in fresh water. Hindered settling is the effect of a reduced settling rate for higher concentration plumes due to the interactions of sediment particles and the effect of falling sediments on the turbulence within the water column.

$$Q_d = w_s . TSS . \max\left(0, 1 - \frac{\tau_b}{\tau_{cd}}\right)$$

Equation 3-1

The rate of erosion, Q_e (g/m^2/s), is calculated according to Equation 3-2. Erosion will occur in response to the combined wave-current driven bed shear stress (τ_b) when this exceeds a critical threshold (τ_{ce}).

$$Q_e = E . \max\left(0, \frac{\tau_b}{\tau_{ce}} - 1\right)$$

Equation 3-2

The sediment transport model has also been previously validated to measured turbidity observations down the Tamar, sediment flux estimations and siltation observations in Home Reach. The parameters that have been used (based on this calibration) are presented in Table 2-1. A limitation on the current modelling approach is that by utilising an assumption of a shallower (more heavily silted) bathymetry in the Home Reach/Yacht Basin areas, the infilling rate modelled is below average. The whole Yacht Basin area typically experiences infilling rates of between 200 and 400 m^3/day during low-flow conditions, however the model with its current configuration will only show infilling rates up to 80 m^3/day. The benefits of this are that the rates of silt-mobilisation are likely to be more realistic for these conditions when flows are present. The infilling rates of the model have been previously validated to collected survey data over the whole Home Reach area and was not specific to either the silt-flats or channel regions. Furthermore, updating the bathymetry to assess different configurations in response to sediment volume changes is not-practical for three-dimensional modelling and introduces other uncertainties and limitations. As discussed in the outcomes of this study, the recommendations and results have not been based on any aspects of the modelling that might be sensitive to these limitations and have used observed long-term average infilling rates for conclusions.

Table 3-1 Modelled Sediment Schematisation

Sediment Parameter	Silt Fraction	Sand Fraction
Settling Velocity [1]	0.001 m/s	0.02 m/s
Critical Shear Stress for Deposition	0.18 N/m^2	N/A
Critical Shear Stress for Erosion	0.20 N/m^2	0.20 N/m^2

[1] Settling velocity is modified by flocculation to be lower in fresh water and higher in salt water (settling velocities will be a factor 5 smaller in fresh water but reach the above values at a salinity of 10-15 PSU). It is modified to decrease for high concentration plumes due to hindered settling processes.

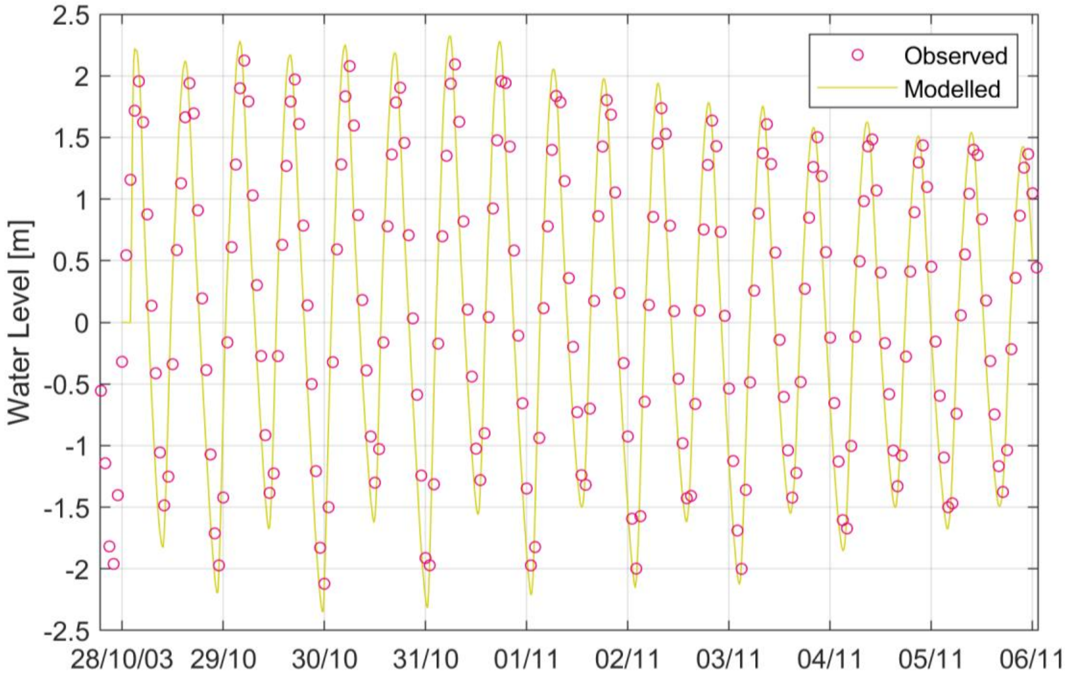


Figure 3-1 Water Level calibration at Tamar St Bridge

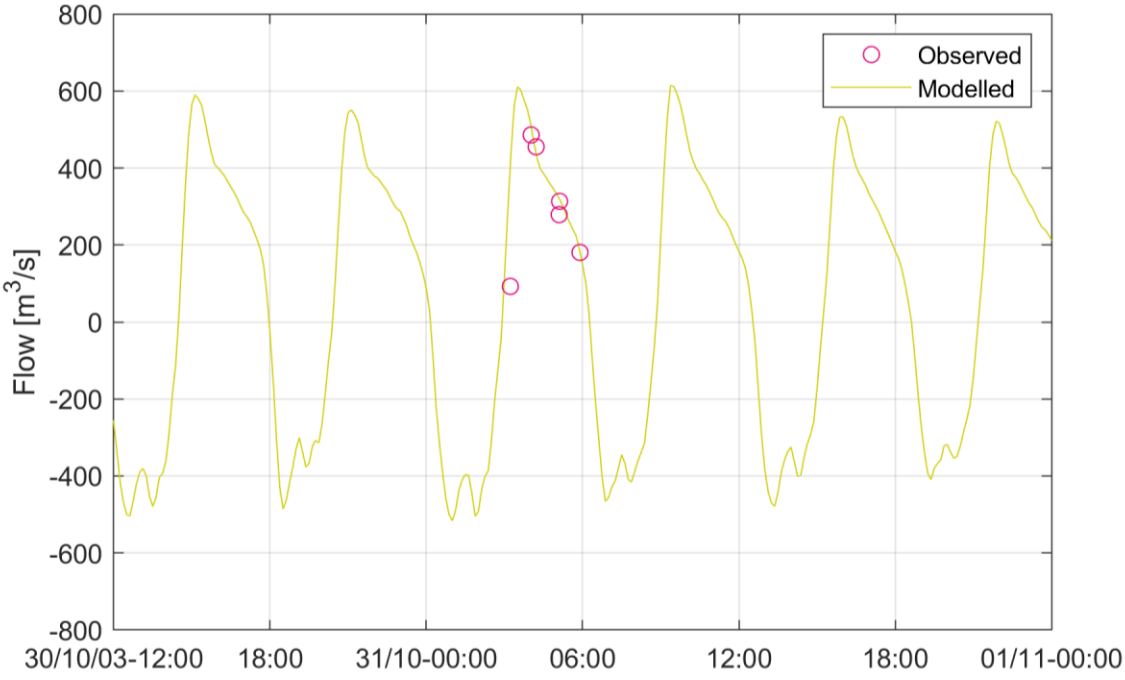
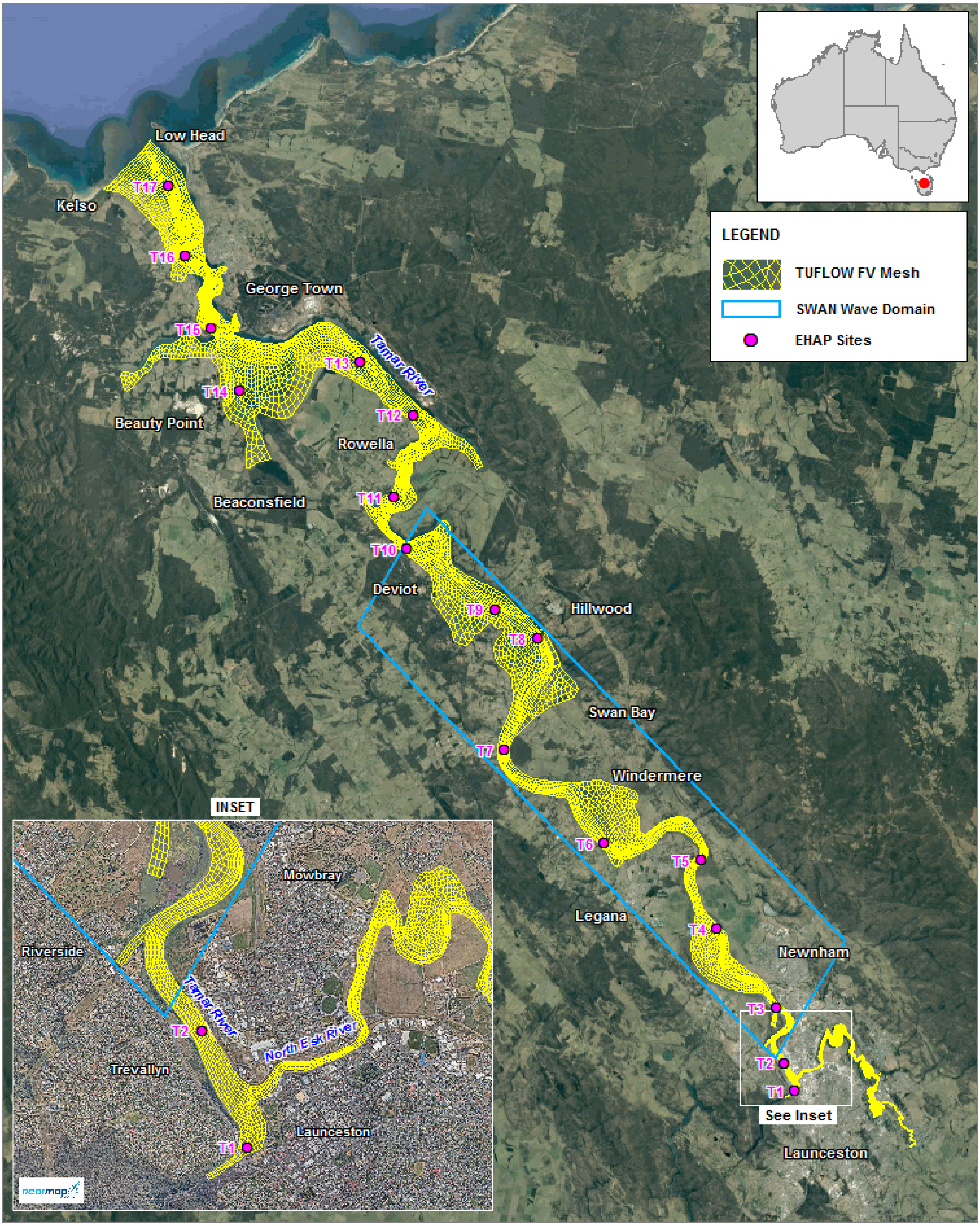


Figure 3-2 Flow Calibration near Tamar Cut



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Mesh and Localities

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4 Scenario Development

An overview of the modelled scenarios is presented in Table 4-1. A base case of consistent outflow from the Tail Race of 20 m^3/s and environmental flows down the South Esk of 2.5 m^3/s has been modelled to compare all scenarios against (“Base” in the table). The same flow scenario but with silt raking has also been used for comparative purposes (“Base SR”).

In total, 10 scenarios have been modelled, assessing a range of conditions including modifying the flow rate and duration of a flow release and the inclusion or otherwise of silt-raking. Not all flow conditions have been assessed without silt-raking (flows only) in order to reduce the overall number of scenarios. However, targeted flow releases with the largest and smallest peak flows have been assessed both with and without silt-raking in order to quantity the expected range of comparative conditions.

A detailed explanation of the range of flow rates and their context is provided in section 4.1. Furthermore, an explanation of the schematisation of silt-raking boundary conditions and the expected range of conditions is discussed in section 4.2.

Table 4-1 Scenario Configurations

Scenario	Silt Raking	Spill Period (not including warning flow)			Lake Recharge Period			Stable Operation	
		Tail Race (m3/s)	South Esk (m3/s)	Duration (days)	Tail Race (m3/s)	South Esk (m3/s)	Duration (days)	Tail Race (m3/s)	South Esk (m3/s)
0A (Base)	No	N/A	N/A	N/A	N/A	N/A	N/A	20	2.5
0B (Base)	Yes	N/A	N/A	N/A	N/A	N/A	N/A	20	2.5
1A (High Flow)	No	20	50	~1.3	0	2.5	~3.24	20	2.5
1B (High Flow)	Yes	20	50	~1.3	0	2.5	~3.24	20	2.5
1C (High Flow alt.)	Yes	0	50	~1.9	15	2.5	~10.15	20	2.5
2B (Low Flow)	Yes	20	20	~2.3	0	2.5	~2.13	20	2.5
3B (Medium Flow)	Yes	20	33.33	~1.7	0	2.5	~2.78	20	2.5
4B (Pulsing Flow)	Yes	20	50*	~3.9	0	2.5	~2.9	20	2.5
5A (Natural Spill)	No	Peak of 95	Peak of 138	6-day spill (Tail Race elevated for 12 days)	N/A	N/A	N/A	20	2.5
5B (Natural Spill)	Yes	Peak of 95	Peak of 138	6-day spill (Tail Race elevated for 12 days)	N/A	N/A	N/A	20	2.5

* Flows are split between 50 m^3/s on ebbing tides and 20 m^3/s on flooding tides.

4.1 Flow Rates

A key parameter that has been modified between subsequent scenarios is the flow rate of the targeted releases. An important consideration for the scenarios was that they all release the same total volume of water from Lake Trevallyn. The volume adopted for this study is 100 cumec-days (8,640,000 m^3), which has been based on the volume accessible by draining Lake Trevallyn as much as possible via the spillway in the absence of any upstream inflows.

Different flow rates have been selected (with different corresponding durations) to investigate the effects of peak flows as well as durations, ranging from 20 m^3/s up to a maximum of 50 m^3/s. One scenario (4B) models a tidal pulsing release flow that alternates between 50 m^3/s during the ebbing (outgoing) tide and 20 m^3/s during the flooding (incoming) tide.

All scenario releases have been preceded by a 6-hour 'warning flow' of 12 m^3/s as required for safety and operational purposes (Sarah Metcalf – Hydro Tasmania, *pers. comm.*). This warning flow forms part of the total available volume, reducing the volume available for the target spill rate to 8,380,800 m^3. Following the warning flow, the scenarios instantly reach the target flow rate, which is then maintained for as long as there is remaining volume available before returning to the environmental flow rate through Cataract Gorge (2.5 m^3/s).

A lake recharge period follows all targeted flows to allow for the recovery of water levels in the lake, which is drained by the releases. This recharge is facilitated by reducing the hydro station (Tail Race) flows for as long as required to replenish the lake volume. At all times the environmental flow release of 2.5 m^3/s is the minimum flow maintained down the South Esk.

All scenarios were configured to run over a two-week period, ending at the same time. The outcome of this is that for different scenarios the flow release may occur on different days (and therefore different tides) and at different times of the day (and therefore different stages of the tide).

Hydrographs (flow timeseries) for the South Esk and Tail Race flows for each scenario are shown against the tidal water level in Figure 4-1 to Figure 4-7.

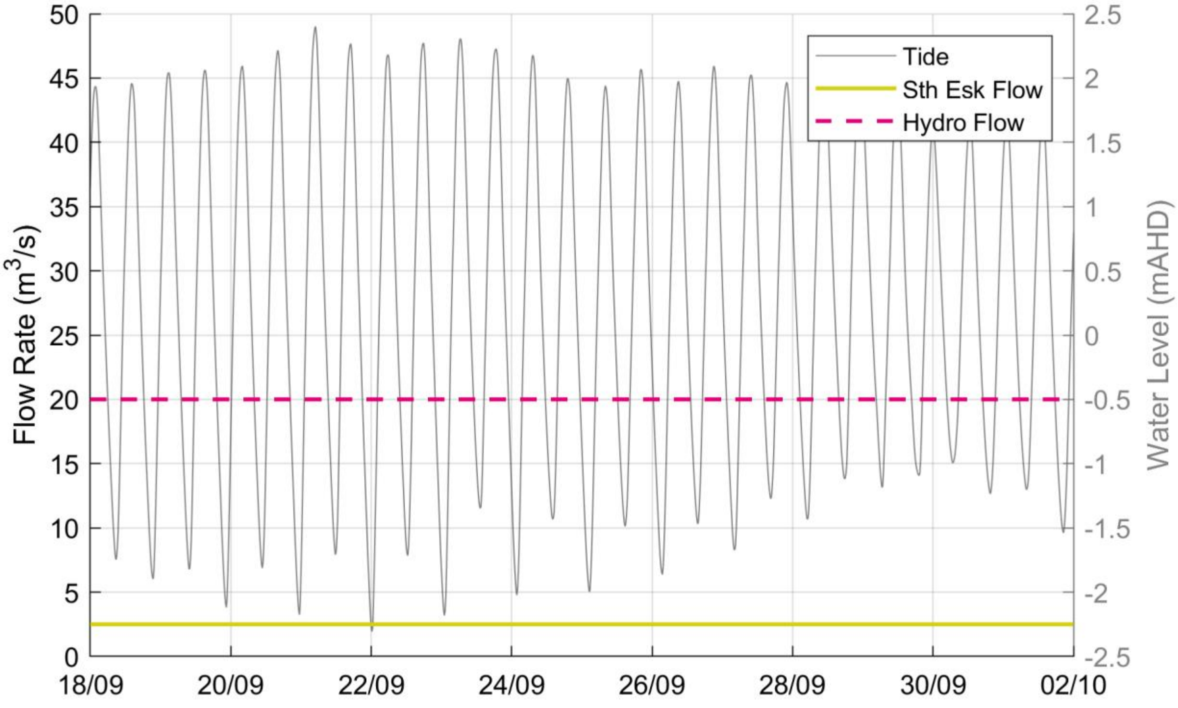


Figure 4-1 Scenario 0A and 0B (Base case) Flow Timeseries

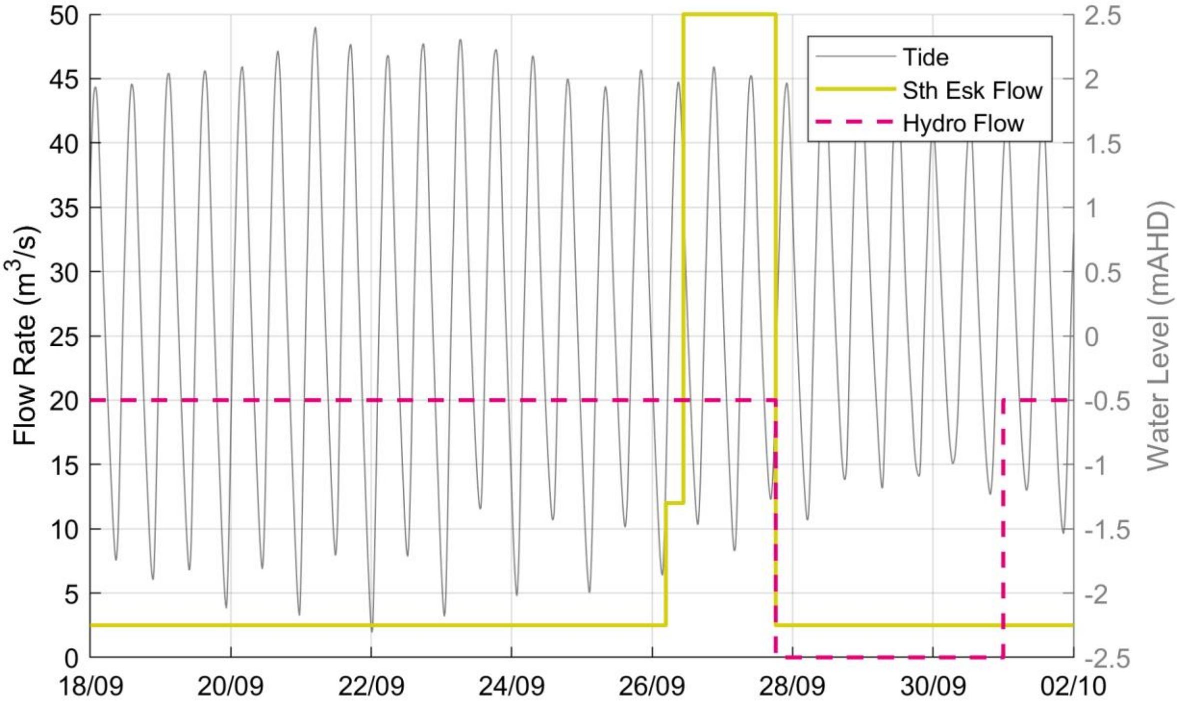


Figure 4-2 Scenario 1A and 1B (High flow) Flow Timeseries

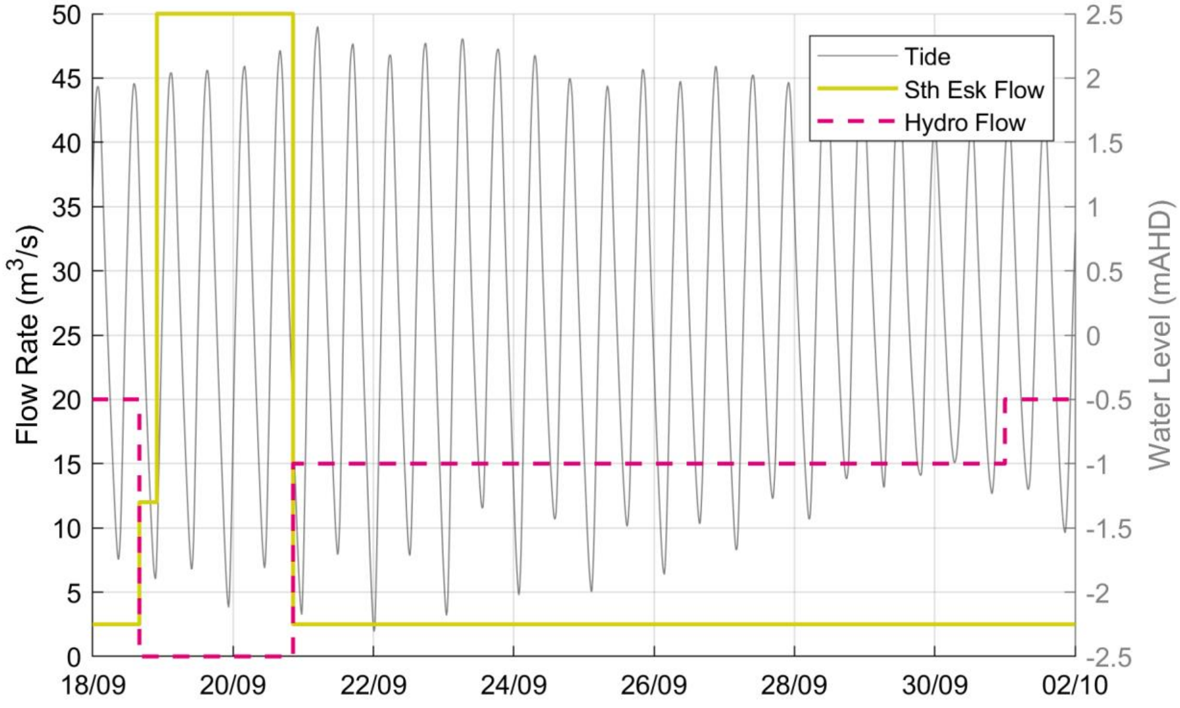


Figure 4-3 Scenario 1C (High flow) Flow Timeseries

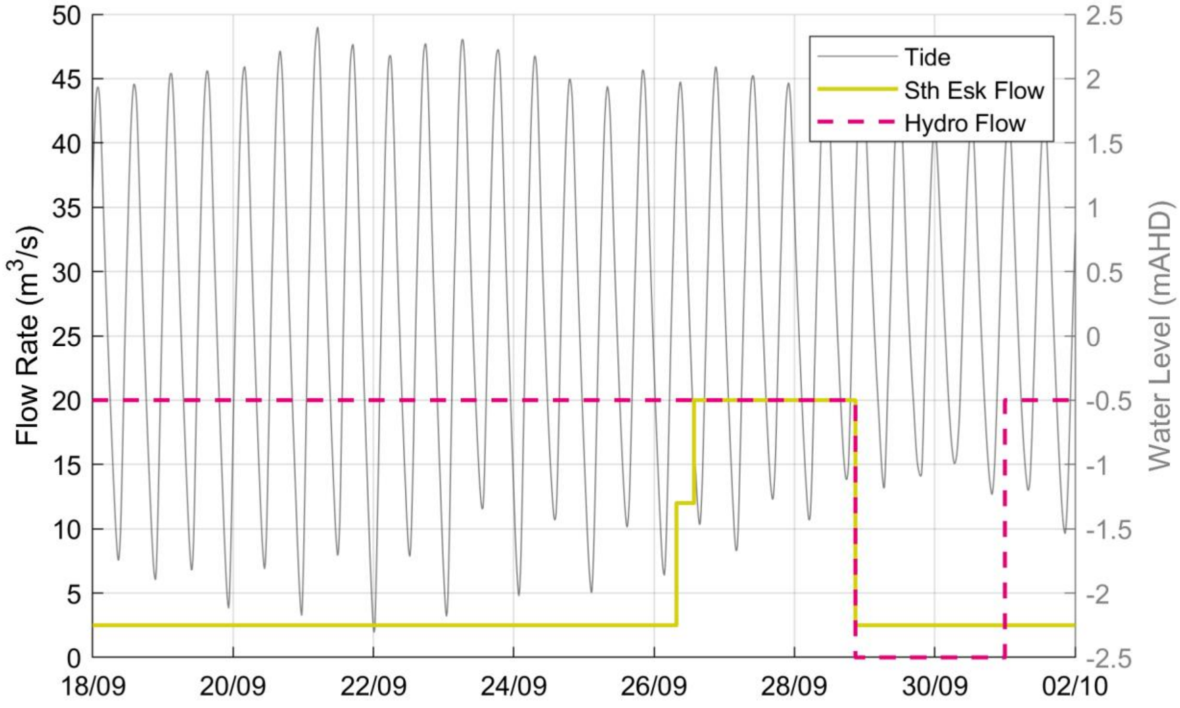


Figure 4-4 Scenario 2B (Low flow) Flow Timeseries

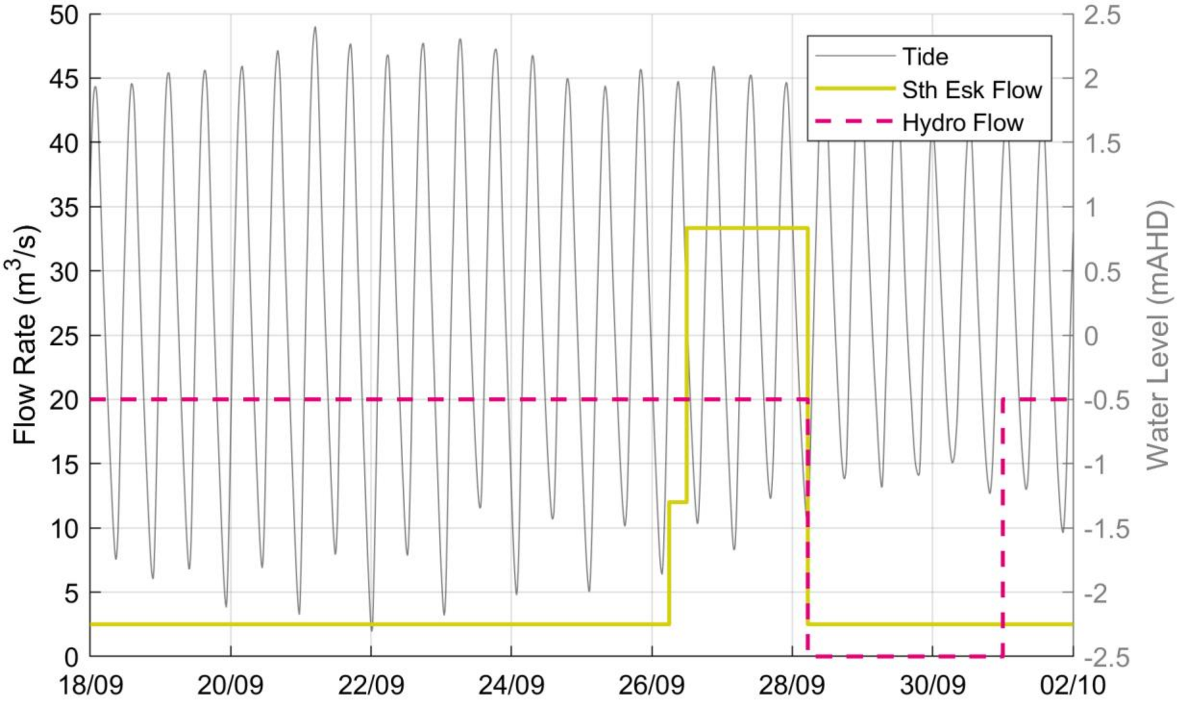


Figure 4-5 Scenario 3B (Medium flow) Flow Timeseries

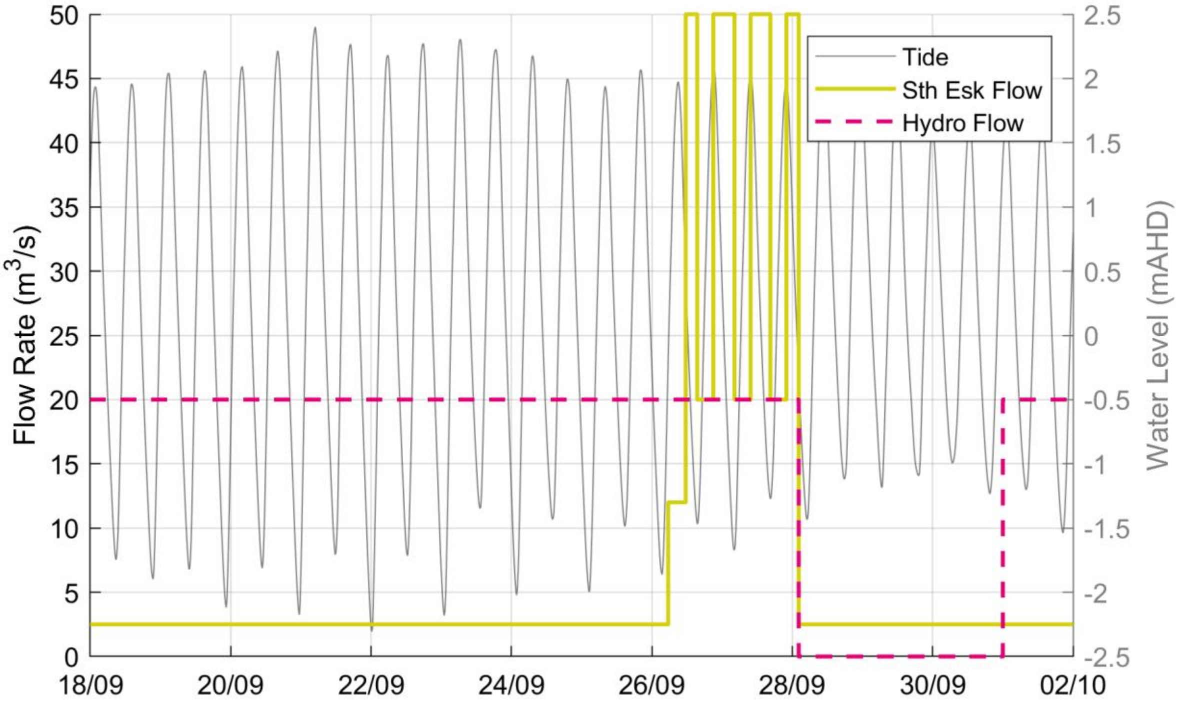


Figure 4-6 Scenario 4B (Pulsing flow) Flow Timeseries

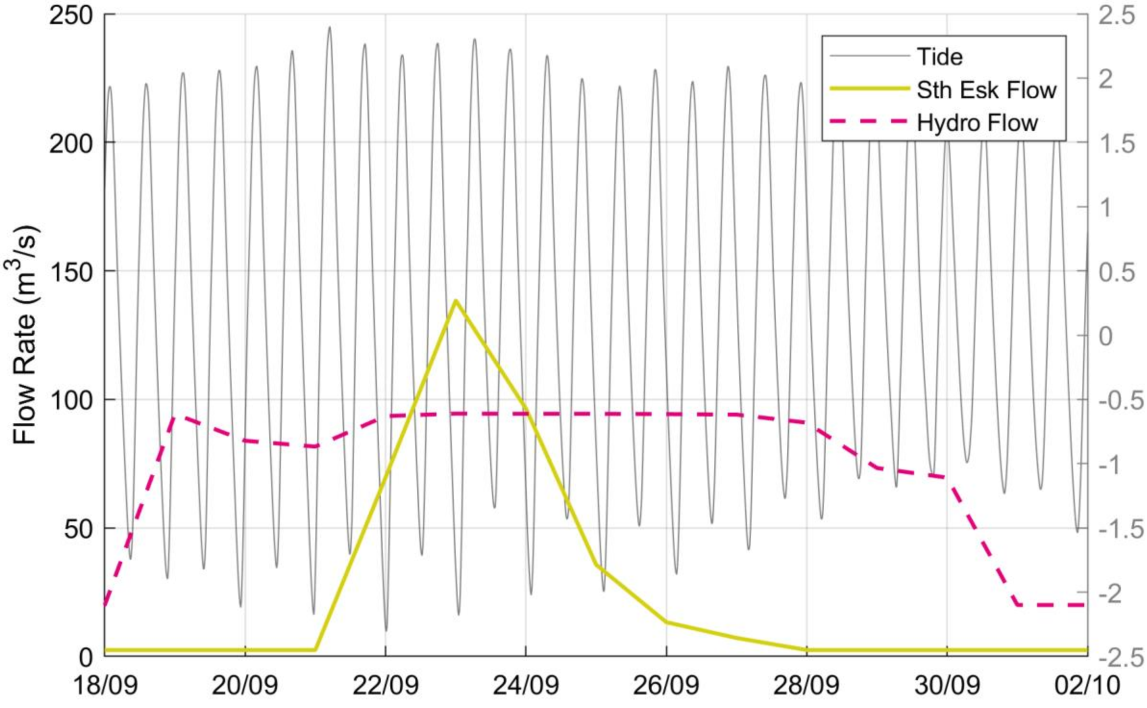


Figure 4-7 Scenario 5A and 5B (Natural Spill) Flow Timeseries (note different scale of primary y-axis in comparison to above figures)

4.2 Silt Raking

The study seeks to better understand the influence of flow releases on sediment mobilisation and the effects of silt-raking on these outcomes. As there is little information on the short-term and near-field sediment mobilisation of silt-raking, these effects have been 'averaged' by applying any effects over a region and by calibrating the silt-raking effects to match observed effects during previous silt-raking campaigns.

Analysis of past silt-raking campaigns involves examination of the bathymetric surveys of the Tamar and comparing these to the logs of the FV Karmin (the vessel used for silt-raking). The key elements of uncertainty surrounding the silt-raking impact analysis are as follows:

- Bathymetry surveys carry an inherent uncertainty that can affect the resulting analysis of a concentrated area. This is particularly notable for analysis of short periods, where an error of +/- 1 mm might equate to a significant volume relative to the actual change during that period.
- The FV Karmin logs give a daily report of the general vicinity of raking, but the exact location cannot be determined with accuracy.
- Any post-processing of the bathymetry surveys can result in smoothed data, or further differences from reality (when triangulating survey points).
- The selection of areas for analysis can also show little to no effect if silt raking moves sediment just within one target area (for example if silt raking part of an area mobilises sediment to other parts of the same area, there is no net change in volume in that target area).
- Similar to the above, silt-raking two areas within the same survey period may result in the first area being 'filled in' by the raking of the second one, showing no net benefit of the first one between those two surveys.
- The FV Karmin logs cannot provide an indication of the relative silt-raking effort between days. i.e. whether more stoppages or delays occur on a given day due to manoeuvring or maintaining equipment.
- Flows through the North Esk and South Esk often occur during silt-raking or between the successive bathymetric surveys, so any effect cannot be attributed to silt-raking only.

Despite these uncertainties, analysing the bathymetry during periods of lower-flow suggests that a two-week period of silt-raking in an area should be expected to mobilise in the order of 10,000 m³ of sediment from the target area. As an indication of scale, silt-raking between 14th August 2015 and 1st September 2015 mobilised around 16,000 m³ from the West Tamar Shoal with 9 days of operations. This period included a minor flow release trial on the 27th August and moderately high North Esk flows. However, silt-raking between 1st September and 1st October in 2015 only moved 4000 m³ with 7-days of active operations in this area. It is therefore expected that the model should predict silt-raking sediment volume mobilisation of around this range in the absence of any significant flows.

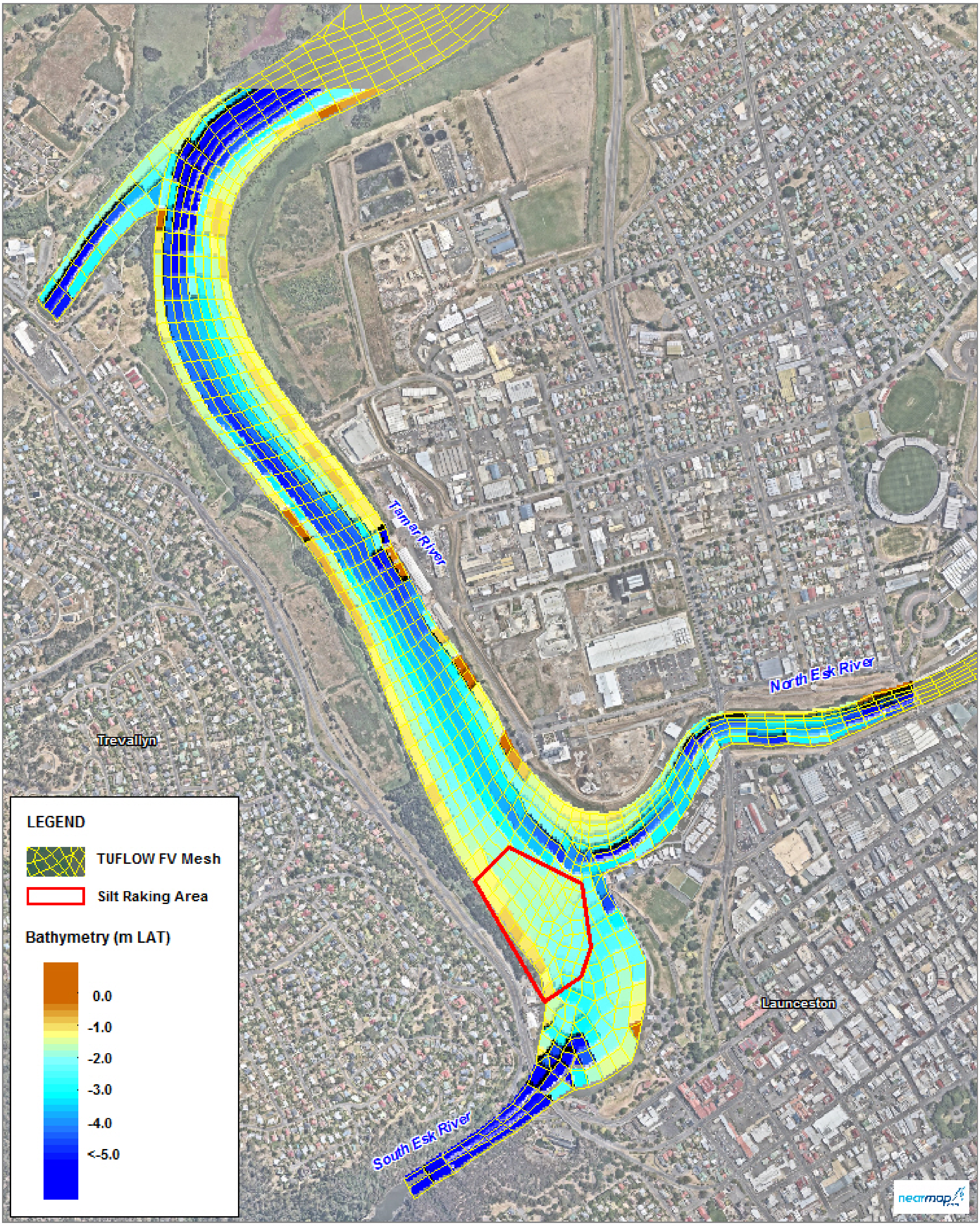
In the model, silt-raking has been schematised as a uniform mobilisation of bed-sediments across a specified area, timed to occur during ebbing tides. The silt-raking area is shown in Figure 4-8, and represents a typical region where silt-raking occurs on the western bank of the Yacht Basin. Sediment is extracted from the bed at a constant rate throughout this region and the equivalent mass is placed into the bottom 1 m of the water column. This approach is likely to suitably replicate the silt-raking where much of the sediment mobilised is suspended into the bottom of the water column where some of it will move with the currents while the rest falls back (settles) to the bed relatively quickly.

The rate of sediment mobilisation by silt-raking has been adjusted to target the range identified by the survey data. A constant rate (during ebbing tides) of 200 kg/s was shown to mobilise 8500 m^3 of sediment from the West Tamar Shoal area (for a two-week silt-raking campaign). This rate is well within the expected range given the uncertainties discussed. Additionally, as this study will be used for impact assessments, comparing multiple hypothetical scenarios with equivalent parameterisation of the silt-raking component, any errors due to this parameterisation should be common across all silt-raking campaigns and should not unduly bias comparative results.

As this uncertainty is more important when comparing the silt-raking campaigns with the non-silt-raking campaigns, sensitivity tests with rates of 100 kg/s (50%) and 300 kg/s (150%) have been examined and are presented in Appendix B. This shows that any conclusions on the impact of flows on sediment movements (relative to a base case of no flow) are likely to be +/- 5%.

This will not resolve all uncertainties and much of the near-field and short-term effects of silt-raking are still unknown and are likely to be highly variable, but any limitations around the model parameterisation of silt-raking has been attempted to be captured and minimised for their impact on conclusions.

Further studies would greatly benefit from an improved understanding and quantification of the silt-raking processes and effects. However, the adopted methodology is fit-for-purpose for providing advice on the likely outcomes of flow releases.



Title:

Silt Raking Area

Figure: **4-8**

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5 Results

5.1 Overview and Objectives

The defined objectives of this modelling investigation were to:

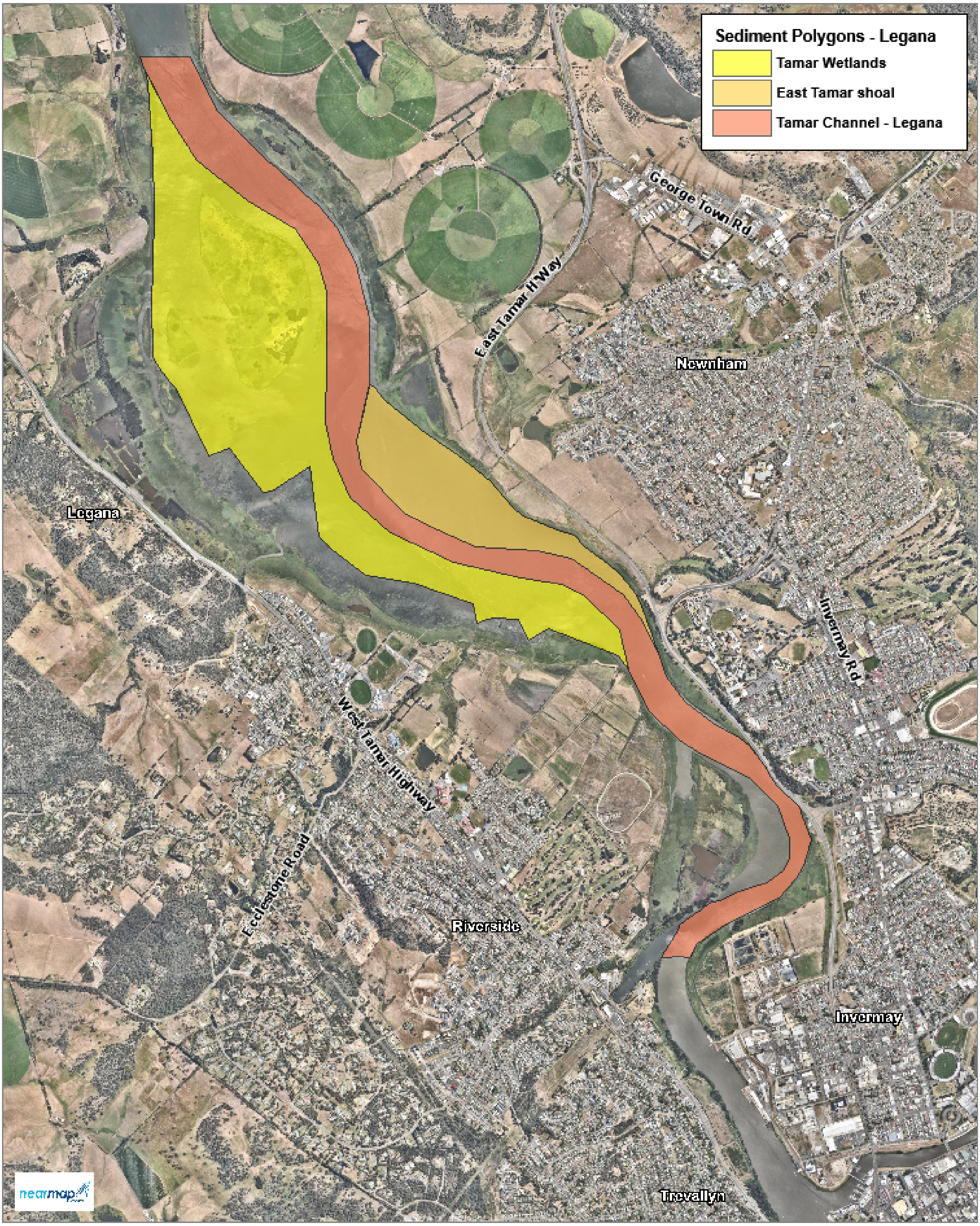
- Quantify the effect of the targeted flow releases with and without silt-raking on sediment mobilisation and siltation in the study area;
- Assess the potential relative impacts to downstream water quality of these interventions (using TSS as an indicator);
- Provide an assessment of the relative costs of alternative sediment management strategies tested; and
- Provide recommendations for the potential of further investigations of flow release strategies.

5.2 Metrics

Based on the objectives outlined above, the metrics by which the scenarios have been assessed are as follows:

- The change in silt volumes broken down into different regions identified by City of Launceston and NRM North (regions shown in Figure 5-1, Figure 5-2 and Figure 5-3). This was assessed based on differences in overall bed sediment volumes and commentary in relation to the benefits on navigation and aesthetics. Additionally, the likely duration of these effects was assessed.
- The medium-term fate of mobilised sediments. This was by assessed by deriving the additional influx of mobilised sediments to Zones 2, 3 and 4, as well as the movement within Zone 1.
- The impacts on downstream water quality. This was limited to assessing the change in TSS levels at the Ecosystem Health Assessment Program (EHAP) monitoring sites down the Tamar River Estuary.
- The potential costs associated with sediment management scenarios. Silt-raking costs were based on actual costs provided by City of Launceston. The costs of targeted flow releases were based on potential lost revenue from power generation using a representative range of electricity wholesale prices as published by the Australian Energy Regulator (https://www.aer.gov.au).

All the scenarios have been assessed on these metrics against the base scenario of no targeted flow releases and no silt-raking. Where appropriate, different scenarios have also been compared directly against one-another to inform more granular analysis of benefits/impacts.



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Sediment Polygons | Legana Region

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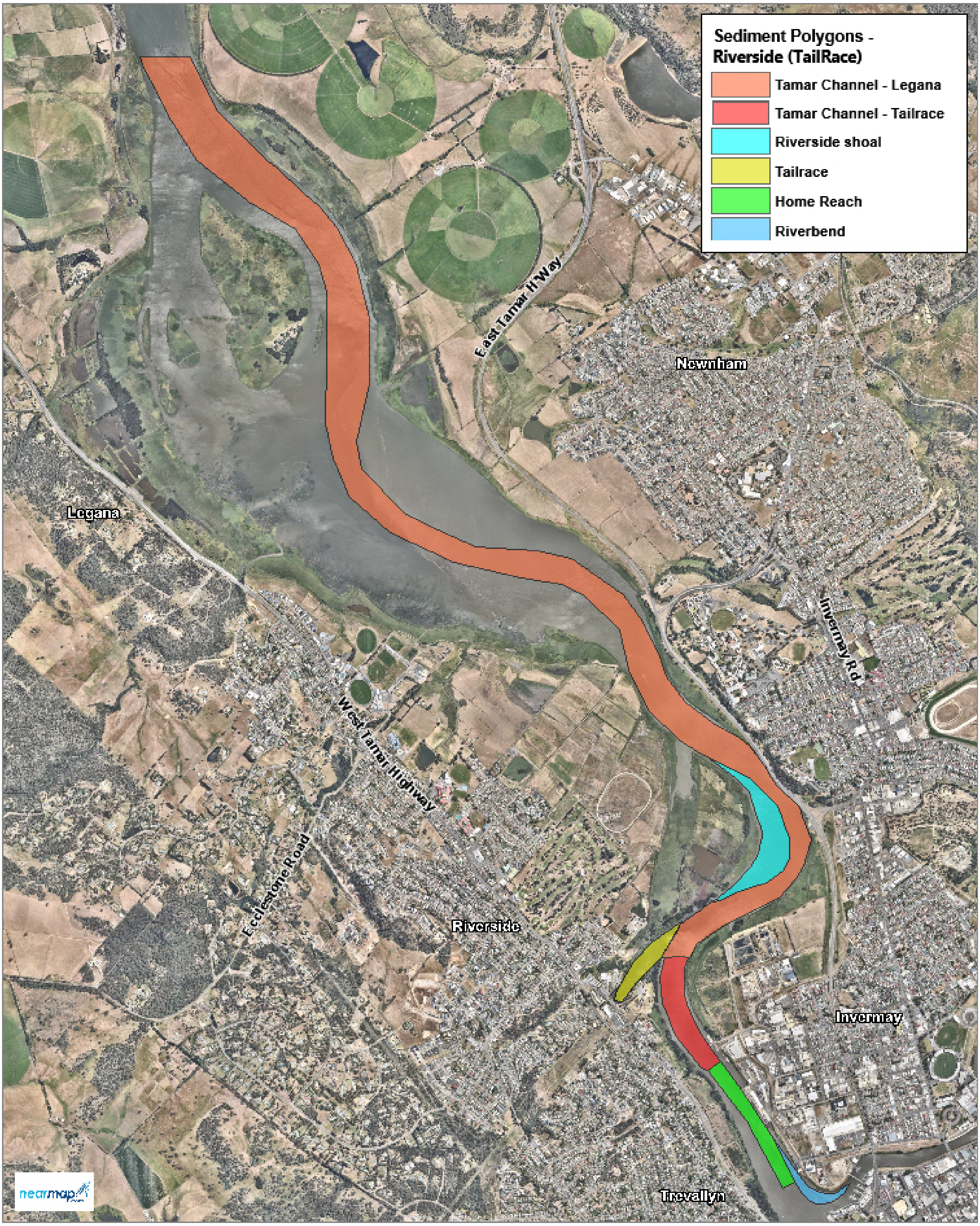

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Sediment Polygons | Riverside Region

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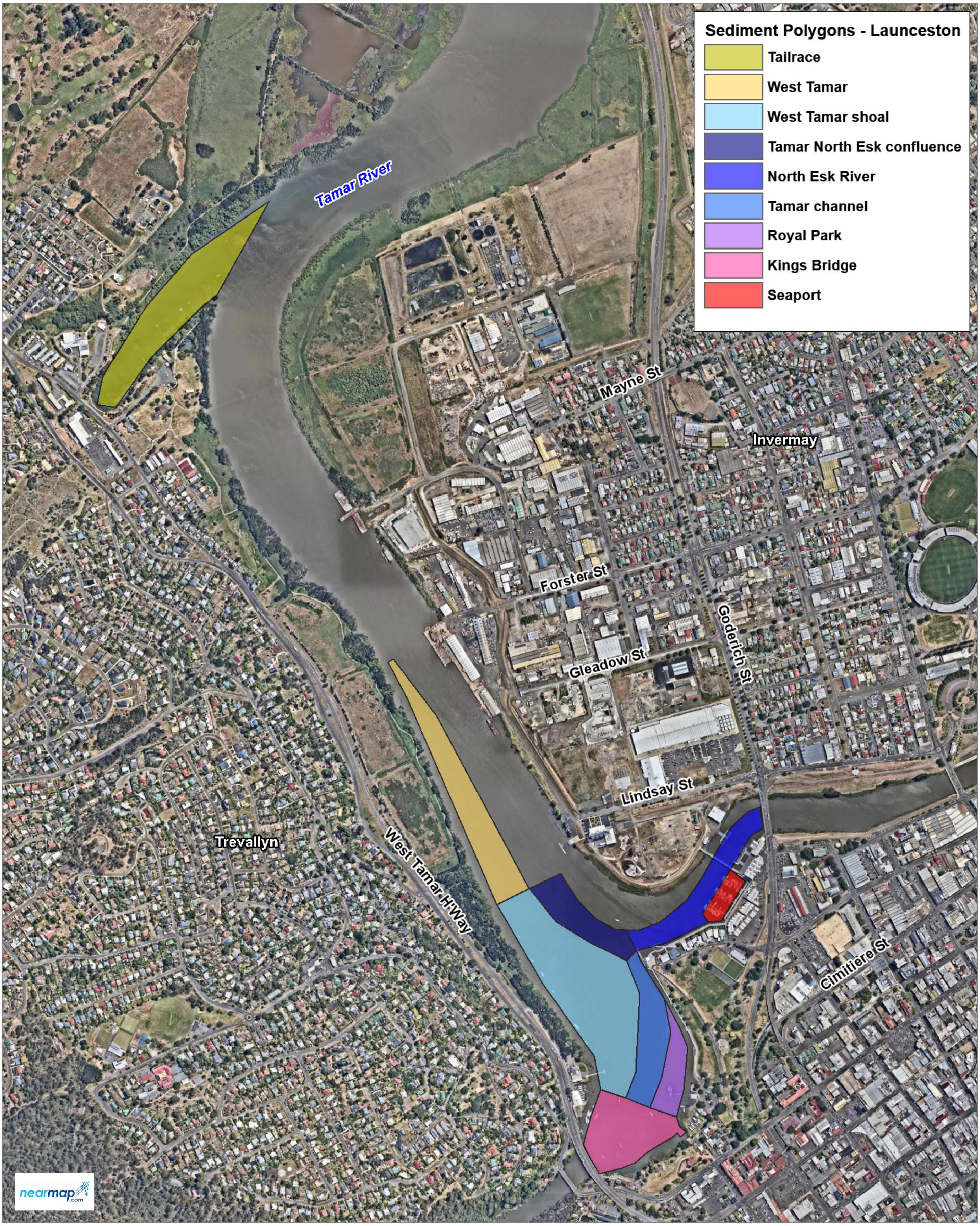

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Sediment Polygons | Launceston Region

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5.3 Outcomes

5.3.1 Siltation Change

The net sediment volume change in key areas of interest for each scenario is shown in Table 5-1 and Table 5-2. These tables present the volume change over the initial two-week period that span the flow releases and dam recharge period (and silt-raking if present). The tables contain a subset of the regions shown in Figure 5-1 to Figure 5-3. The complete set of locations can be found in Appendix C. These areas have been chosen and grouped to reflect the objectives of silt-mobilisation as follows:

(1) Banks and Shoals: These areas represent areas of siltation that cause observable silt-flats on low tides. It also includes the modelled silt-raking zone (within the West Tamar Shoal). A net-negative volume change in these areas represents the outcome of reducing silt-flat extents.

(2) Channels and Key Navigation Paths: Represents areas of navigation and mooring for many vessels (both commercial and recreational) around Launceston. A net-negative volume change can be used to infer a general improvement of the navigability within these regions.

(3) North Esk and Seaport: Spans the initial reach of the North Esk. This area is useful to analyse any ingress of mobilised sediments to these upstream areas, which may impact navigability and aesthetics around the Seaport.

(4) Downstream: Spans the area downstream of the Tail Race. While this area may have sections that represent silt-flats and/or navigable channels, it is analysed here in terms of the spread of sediments downstream.

The tables have been coloured to reflect the direction of change relative to the base case (SC0A) with blue shading a relative decrease in sediment volume compared to the base case (typically a ‘positive’ outcome) and orange representing an increase relative to the base case (typically a ‘negative’ outcome). These colour scales are only relative to the base case, so for example a blue shading may represent an area that is still accreting, but at a lower rate than base case. A bar chart of the equivalent average depth changes in these grouped regions (the sediment volume change per area of each region in millimetres) is shown in Figure 5-4.

The results show that flows from Cataract Gorge (High Flow, SC1A; and Natural Spill, SC5A) have a small scouring effect on some of the channel areas, reducing the volume of sediment. They also serve to reduce the rate of natural accretion on the remaining channel areas and on the banks relative to the base case, with the Natural Spill scenario reversing this natural accretion to a slight scouring effect. Increases in sediment in areas further downstream suggest that sediments mobilised from these areas are moving downstream before accreting. These effects are stronger in the Natural Spill scenario (SC5A) than in the High Flow (SC1A) showing that the greater flows mobilise more sediment. While these results appear to be in-line with the stated objectives, the magnitude of these effects is small and is within the range of modelling uncertainty. Such results cannot be depended on to remain the same if the model were simulated over different conditions (different tides, different North Esk flows, etc.). Furthermore, the expected differences in overall sediment depth due to such changes is less than 0.5 mm throughout these areas. Such changes in bed level are unlikely to have any real benefit to the stated objectives of silt-mobilisation.

Silt-raking cannot be directly compared to the flow-only scenarios as the modelling shows it to have a different overall action. Rather than reducing the sedimentation in the upper-estuary, the silt-raking scenarios (Base SR, SC0B) show that sediment mobilised from the targeted area (West Tamar Shoal) largely causes infilling in adjacent areas. As such, silt-raking as it has been modelled (in the West Tamar Shoal) yields a range of conflicting (both positive and negative) outcomes. While there is a reduction in the silt-flats (potentially improving the aesthetics), this comes along with slightly increased siltation of adjacent silt-flats and heavy infilling in the adjacent channels. There is also a slight increase in sediment accumulation in the North Esk and Seaport areas due to silt-raking. These are of small magnitudes and are not likely to cause an impact on their own, though do show that a small fraction of the mobilised sediments may move upstream.

When silt-raking is combined with increased flows from Cataract Gorge (SC1B – SC5B) the effects of silt-raking are enhanced (relative to silt-raking alone, SC0B). These effects occur only for the duration of the flows (shown in Figure 5-5) with no persistent effect of flows observed. The volume of sediment mobilised from within the West Tamar Shoal increases for scenarios with higher peak flow rates (High Flow greater than Low Flow, but the Natural Spill higher again). Additionally, the adjacent infilling due to silt-raking is also increased with the added flows, with greater volumes of sediment infilling into the channels and surrounding shoals than silt-raking without flows. Of interest is that while flows can increase the sediment mobilised from West Tamar Shoal by 27% (High Flow w/ SR, SC1B compared to Base Case w/ SR, SC0B), the increases in infilling of the channels is more varied. The more downstream channel areas see similar increases (25% in the Home Reach region), whereas some areas show smaller increases (6% in the Tamar/North Esk Confluence) and some actually show lower infilling than silt-raking without flows (6% decrease in Tamar Channel from SC0B to SC1B), reflecting higher flows pushing mobilised sediments slightly further downstream.

The Natural Spill scenario with silt-raking (SC5B) shows the highest mobilisation of silt from the West Tamar Shoal (-19,675 m^3). It shows a lower infilling in the immediate channel and shoal areas than the other silt-raking scenarios, but more infilling of locations further downstream (such as the Home Reach and the Tamar Channel – Tail Race areas). However, this scenario results in far higher infilling of channel areas than any scenario without silt-raking (compare for example SC5B with the base case, SC0A).

Table 5-1 Volume Change over Two-week Flow-release Period, Shoals and Channels (Coloured by change relative to Base Case, blue represents less sediment than the Base Case, orange represents more sediment)

		Banks and Shoals				Channels and Key Navigation Paths			
Scenario		Royal Park (m^3)	River Bend (m^3)	West Tamar (m^3)	West Tamar Shoal (m^3)	Tamar Channel (m^3)	Tamar NE Confluence (m^3)	Home Reach (m^3)	Tamar Channel Tail Race (m^3)
Flows Only	SC0A (Base)	50	65	22	320	133	153	- 130	- 926
	SC1A (High Flow)	42	56	15	252	115	148	- 183	- 644
	SC5A (Natural Spill)	- 35	- 5	-96	- 158	- 111	116	- 269	- 957
Silt-raking Included	SC0B (Base SR)	115	173	1819	- 8,509	1,755	3,876	1,437	- 506
	SC1B (High Flow SR)	104	166	2440	- 10,373	1,651	4,110	1,802	18
	SC1C (High Flow SR alt.)	87	155	2413	- 10,858	1,514	3,906	1,794	- 610
	SC2B (Low Flow SR)	111	171	2037	- 9,295	1,693	4,092	1,550	- 573
	SC3B (Med Flow SR)	109	172	2278	- 9,995	1,674	4,206	1,705	- 555
	SC4B (Pulsing SR)	109	168	2423	- 10,382	1,658	4,187	1,804	- 1,296
	SC5B (Natural Spill SR)	5	65	3049	- 19,675	615	3,235	2,008	1,750

Table 5-2 Volume Change over Two-week Flow-release Period, North Esk and Downstream (Coloured by change relative to Base Case, blue represents less sediment than the Base Case, orange represents more sediment)

Scenario		North Esk and Seaport		Downstream Areas				
		North Esk (m³)	Seaport (m³)	Tail Race (m³)	Tamar Channel Legana (m³)	Tamar Wetlands (m³)	East Tamar Shoal (m³)	Riverside Shoal (m³)
Flows Only	SC0A (Base)	89	34	63	533	7660	3369	922
Flows Only	SC1A (High Flow)	89	34	79	515	7749	3393	936
Flows Only	SC5A (Natural Spill)	71	27	-2620	-3472	11761	3185	199
Silt-raking Included	SC0B (Base SR)	271	51	83	1387	7713	3423	1064
Silt-raking Included	SC1B (High Flow SR)	271	51	116	1605	7832	3478	1110
Silt-raking Included	SC1C (High Flow SR alt.)	278	54	221	1806	7835	3537	1098
Silt-raking Included	SC2B (Low Flow SR)	271	51	102	1482	7772	3428	1090
Silt-raking Included	SC3B (Med Flow SR)	272	51	112	1523	7825	3456	1103
Silt-raking Included	SC4B (Pulsing SR)	278	53	105	1502	7883	3525	1124
Silt-raking Included	SC5B (Natural Spill SR)	162	35	-2586	1872	12639	3866	545

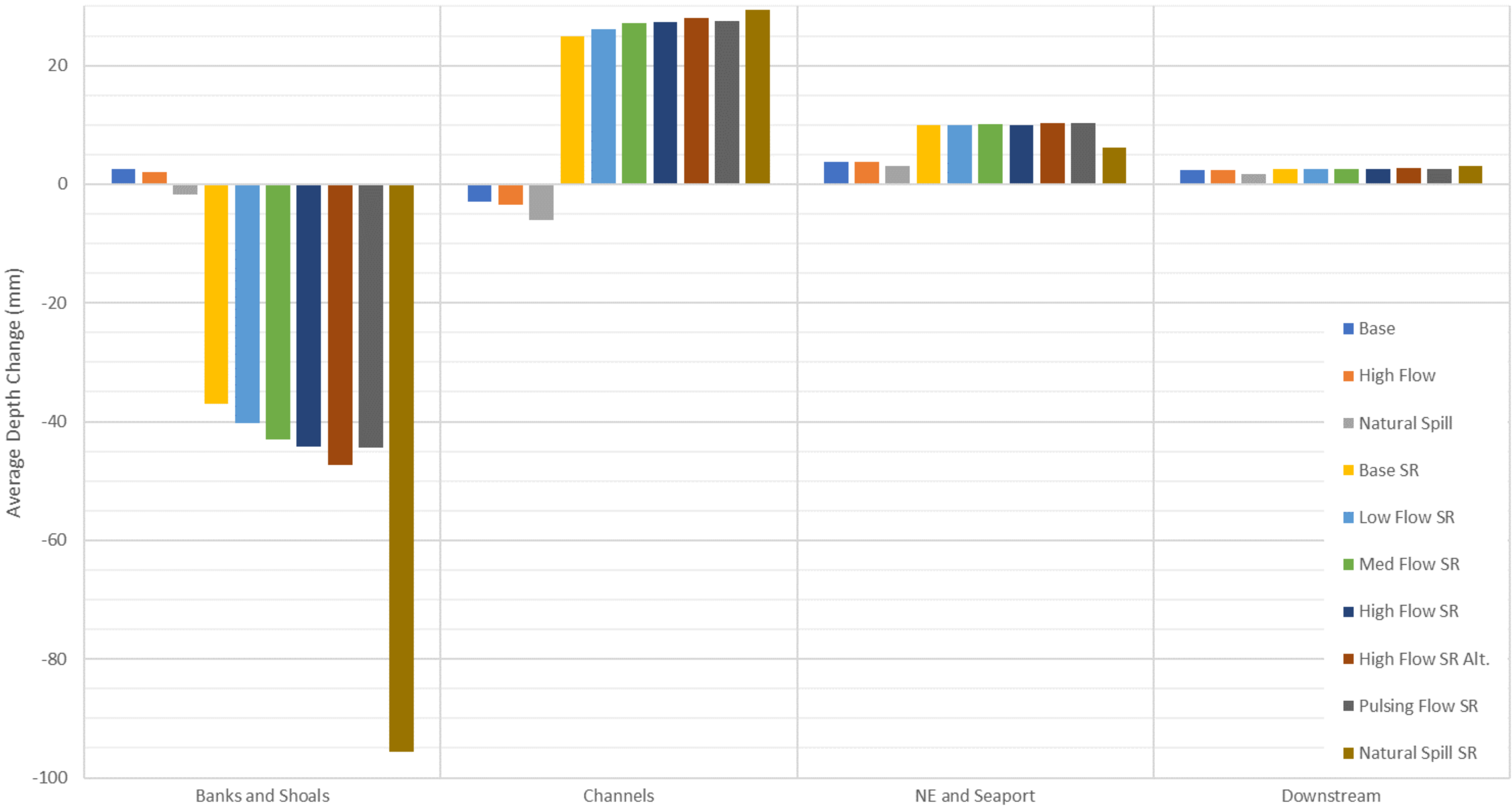


Figure 5-4 Average Depth Change for Grouped Regions

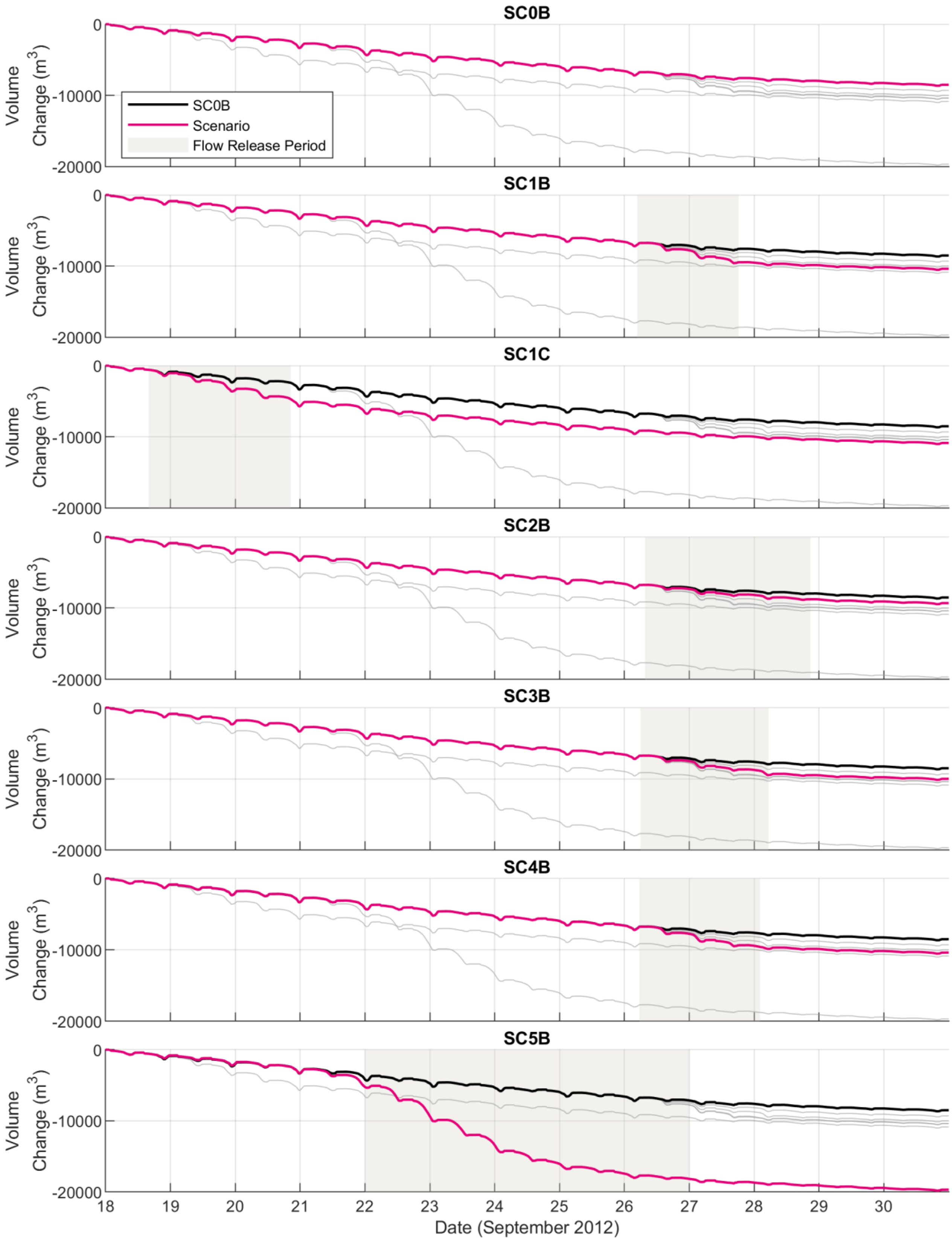


Figure 5-5 West Tamar Shoal Sediment Volume Change Timeseries

5.3.2 Sediment Fate

An understanding of the fate of any sediments mobilised is important for quantifying potential impacts on downstream sensitive receptors. Table 5-3 shows the volume of mobilised sediment in several areas at the end of the three-month period. This volume corresponds to any upper-estuarine sediment that was mobilised during the initial two-week flow release period (based on the separately tracked modelled sediments in this area). I.e. any material that is mobilised from the upper-estuary within the three-month period is not included unless it had originally been redistributed first during the two-week period. This is to limit any influence from sediment movements that would have occurred over the three-months regardless of any flow-release or silt-raking combinations in the two-weeks prior. As such, Table 5-3 include sediments in an area even if they were originally mobilised from within that area.

The areas shown are the first four functional zones used for the Tamar Estuary Report Card Reporting and the Launceston and Legana Reaches based on aggregating sediment analysis areas from above (zones shown in Figure 5-6). They cover the areas as follows:

- Launceston Banks and Channels: From the Seaport to the start of the Tail Race (part of Zone 1). Combines the same regions as the banks and shoals, the channels and the North Esk and Seaport areas in Section 5.3.1;
- Downstream Reach: From the Tail Race to Legana (part of Zone 1). The same regions as the 'downstream' grouping in Section 5.3.1;
- Zone 1: Covering the above two;
- Zone 2: From Legana down to Hillwood;
- Zone 3: From Hillwood down to Rowella; and
- Zone 4: From Rowella down to Georgetown.

The results show that as seen in Section 5.3.1, targeted flow releases down Cataract Gorge (SC1A) do not substantially alter the sediment movements relative to the base case (SC0A). Any sediments mobilisations that occur largely deposit back in the same areas. Of interest is the Natural Spill scenario (SC5A) that does show a small increase in sediment reaching Zone 2. The Natural Spill result is indicative of the lower range of flow release magnitude that is sufficient to drive broader-scale re-distributions of sediment between the estuary zones.

Silt-raking (SC0B) shows much larger overall movements of sediments than the base case. However, much of this sediment remains within the Launceston banks and channels areas. There is an increase in the sediment moving into the downstream reaches, though this increase is small relative to the overall increase in sediment movement.

The combination of targeted flow releases with silt-raking (SC1B – SC4B) shows a small increase in the downstream movement of the mobilised silt. Again though, this is a very small increase relative to the increase in silt-mobilisation with the vast majority of sediments still remaining near to the areas of silt-raking.

The combination of silt-raking with a Natural Spill (SC5B) shows a far more significant increase in the downstream movement of sediments relative to any other scenarios. The volume of sediment remaining within the banks and channels near Launceston is similar to the scenario with silt-raking alone (SC0B), though the volume moving into the downstream reaches is twice as much. There is also a larger volume of mobilised sediment predicted to reach Zone 2 than the other scenarios, though this is still only a small absolute volume.

Maps of the change in bed sediment over the two-week silt-raking period within Launceston area for the High Flow and Natural Spill cases with silt-raking (SC1B and SC5B) are shown in Figure 5-7. Maps of the accretion of mobilised sediment in the downstream area near Tamar Island (downstream extent of Zone 1) are shown in Figure 5-8 for the same cases. A set of equivalent maps for all scenarios can be found in Appendix D.

These results support the conclusion that the majority of mobilised sediment stays within the adjacent areas. Under a natural spill scenario there is a noted increase in the volume that is transported downstream relative to silt-raking alone or with targeted releases, but this downstream movement is still limited and mobilised sediments still remain largely within Zone 1.

None of the modelled scenarios show any substantial sediment being transported to Zone 3 or Zone 4 (all < 1 m^3).

The outcome of these observations is that as sediments are not transported significantly downstream, there is likely to be no longer-term impact to the rates of siltation and re-accumulation within the upper-estuary (Zone 1).

Figure 5-6 Tamar Estuary Report Card Functional Zones (sourced from NRM north)

Table 5-3 Final Mobilised Sediment Volumes after 3 months

	Scenario	Launceston Banks and Channels[1] (m³)	Downstream Reach[2] (m³)	Zone 1 (m³)	Zone 2 (m³)	Zone 3 (m³)	Zone 4 (m³)
Flows Only	Base (SC0A)	7,555	6,570	16,448	45	0.004	0.000
	High Flow (SC1A)	7,493	6,709	16,531	47	0.004	0.000
	Natural Spill (SC5A)	6,740	8,457	18,666	443	0.215	0.001
Silt-raking Included	Base SR (SC0B)	27,627	7,769	39,324	52	0.004	0.000
	High Flow SR (SC1B)	28,606	8,277	40,977	57	0.005	0.000
	High Flow SR alt. (SC1C)	28,077	8,517	40,754	67	0.007	0.000
	Low Flow SR (SC2B)	28,466	7,978	40,444	53	0.004	0.000
	Medium Flow SR (SC3B)	28,773	8,114	40,930	55	0.005	0.000
	Pulsing Flow SR (SC4B)	28,702	8,230	41,013	57	0.005	0.000
	Natural Spill SR (SC5B)	27,407	16,888	49,647	1038	0.501	0.002

[1] Launceston Banks and Channels includes: Home Reach, Riverbend, Seaport, North Esk River, West Tamar Shoal, Tamar North Esk Confluence, Tamar Channel, Tamar Channel – Tail Race, Royal Park, West Tamar and Kings Bridge.
[2] Downstream Reaches includes: Tail Race, Tamar Channel – Legana, Tamar Wetlands, East Tamar Shoal and Riverside Shoal.

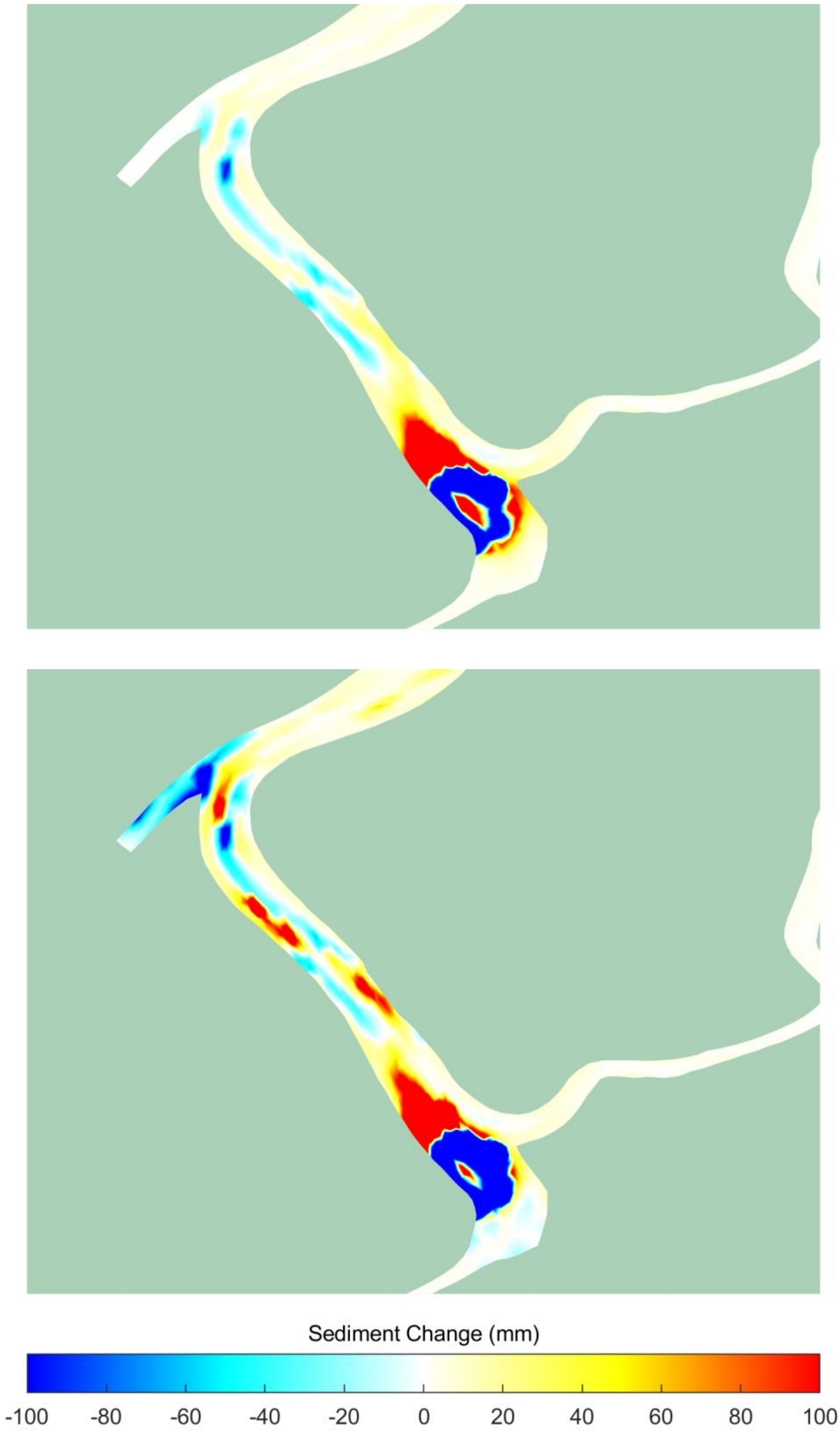


Figure 5-7 Sediment Change after Two-Week Release Period, High Flow w/ Silt-Raking (SC1B, Top); Natural Spill w/ Silt-Raking (SC5B, Bottom)

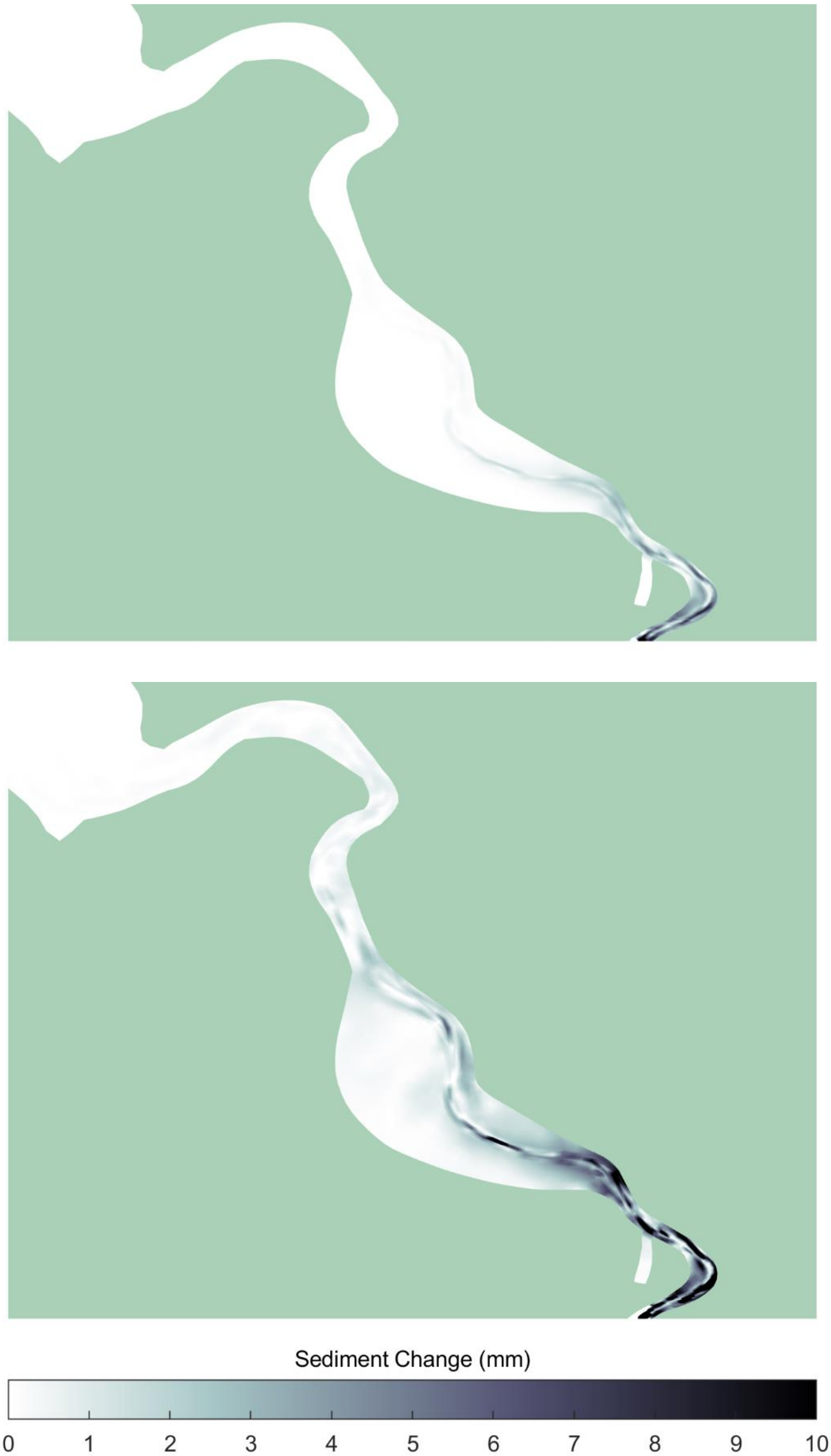


Figure 5-8 Mobilised Sediment Fate Downstream after Two-Week Release Period, High Flow w/ Silt-Raking (SC1B, Top); Natural Spill w/ Silt-Raking (SC5B, Bottom)

5.3.3 Suspended Sediment Impacts

An understanding of the potential water quality impacts due to silt-mobilisation is important to inform decision-making about siltation management options. The Total Suspended sediment (TSS) concentration within the modelled scenarios has been analysed to investigate this. It should be noted that this assesses only one aspect of potential water quality impacts, and that impacts by nutrients, pathogens, metals or other pollutants (either dissolved or bound to the sediments) has not been considered as part of this study.

Timeseries of the impact to the daily-averaged TSS concentrations (the increase/decrease relative to the base case, SC0A) are shown at several EHAP reporting locations for the High Flow (SC1A) and Natural Spill Scenarios (SC5A) in Figure 5-9 and Figure 5-10 respectively. Figure 5-11 and Figure 5-12 present similar figures for the same flow conditions but with silt-raking included (SC1B and SC5B). Such timeseries, as well as box and whisker plots of TSS concentrations are presented for every scenario in Appendix A.

In order to quantify the duration of any TSS impacts, tabulated percentiles of the impact (percentile of the increase in TSS relative to the base case) and the corresponding total duration of impact for the two-week silt-raking period are shown in Table 5-4 for EHAP site T3 and Table 5-5 for EHAP site T5.

The targeted high flow release scenario (SC1A, peak flow of 50 m^3/s) shows no significant level of long-term increase in TSS relative to the base case (SC0A). There is a short-term spike in TSS concentrations corresponding to the period of the flow release, but these levels return when the flows cease. When examining flows of the magnitude of the Natural Spill however, (SC5A, peak flow of 138 m^3/s and peak Tail Race flow of 98 m^3/s) there is a large increase in TSS during the flow peak and a smaller increase that persists for several weeks afterwards at the more upstream locations. Increases in TSS concentration by 43 mg/L or more are expected at T3 for 3.5 days of the two-week period. All locations have returned to base case levels within four weeks of the flow event.

Silt-raking during the High Flow release (SC1B) shows moderate increases in the TSS levels during the raking and a larger spike in TSS during the flow release. This spike reaches much higher levels than when silt-raking was not occurring (SC1A). All locations return to within normal ranges shortly after the two-week period of silt-raking and flow releases.

The largest TSS impacts come from the combination of silt-raking and the Natural Spill (SC5B). There is a sustained increase in TSS over the initial two-week period at all locations down to T6, with far larger increases than without silt-raking. There is a small persistent increase for several weeks thereafter in the upstream locations, though not significantly higher than for the natural spill without any silt-raking (SC5A).

All of the silt-raking scenarios (with and without flows) return to within the variability of base case conditions shortly after the silt-raking and flows cease, with only the natural spill showing any (small) continued influence for several weeks.

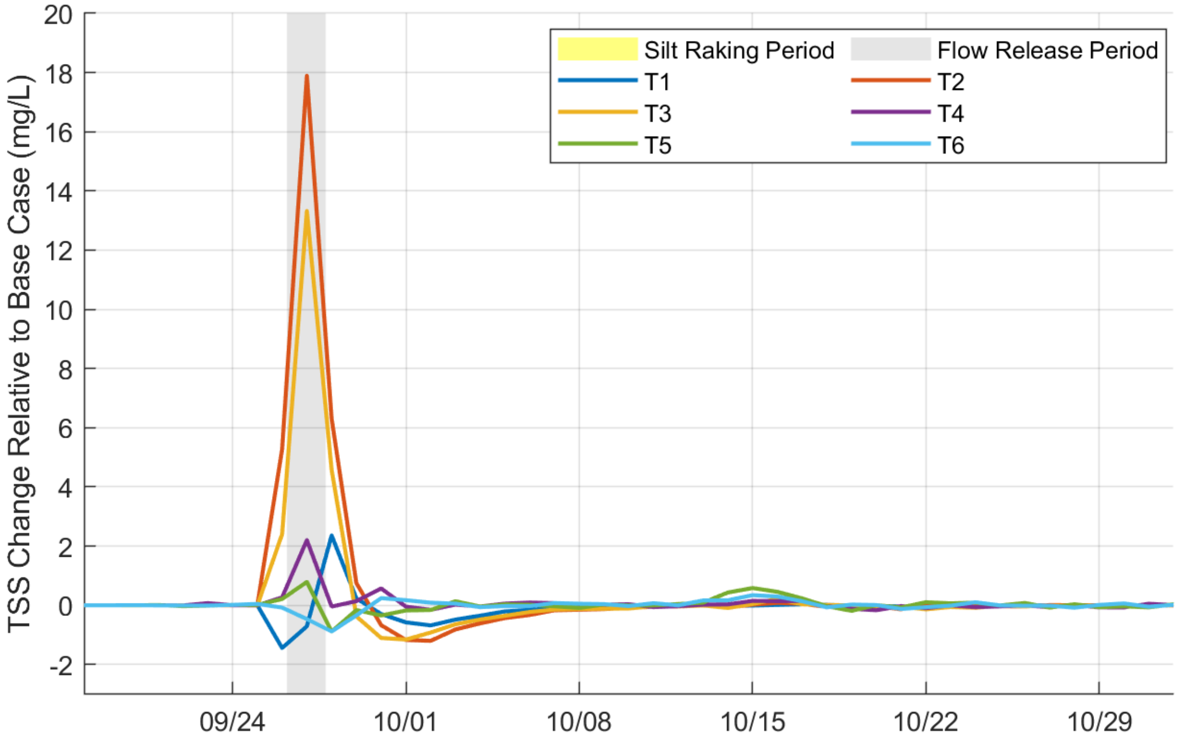


Figure 5-9 Impacts to Daily-Averaged TSS during High Flow Scenario (SC1A)

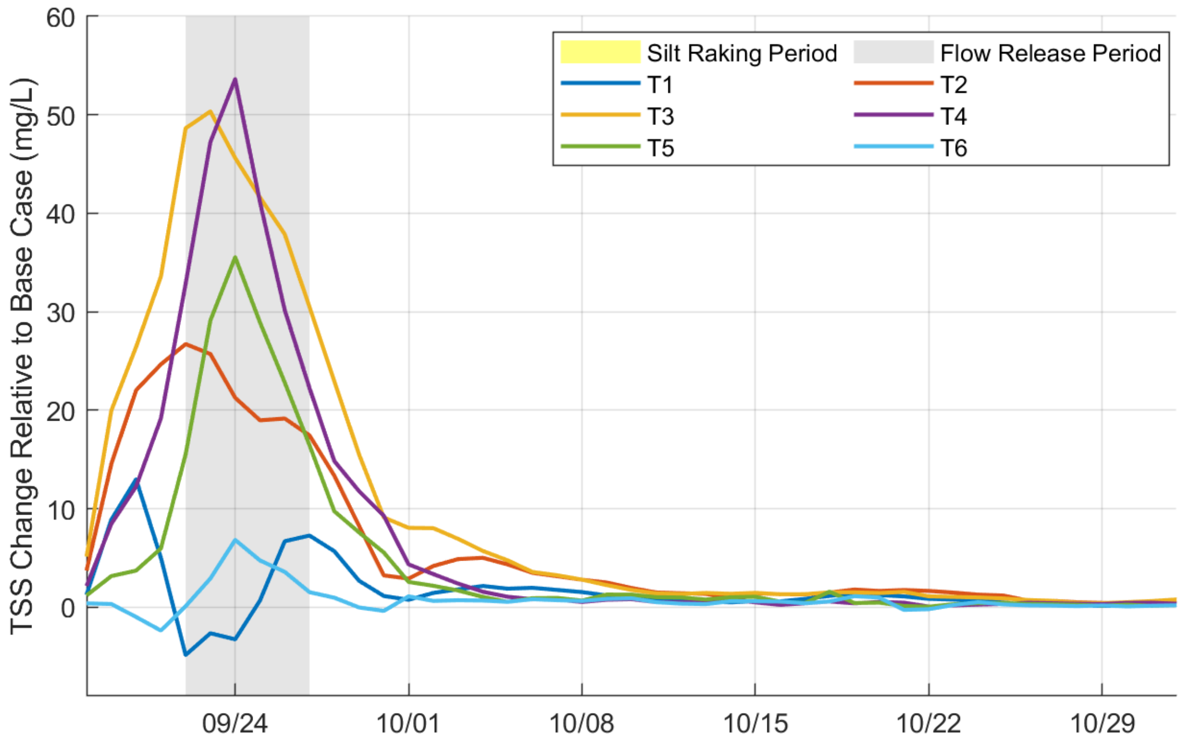


Figure 5-10 Impacts to Daily-Averaged TSS during Natural Spill Scenario (SC5A)

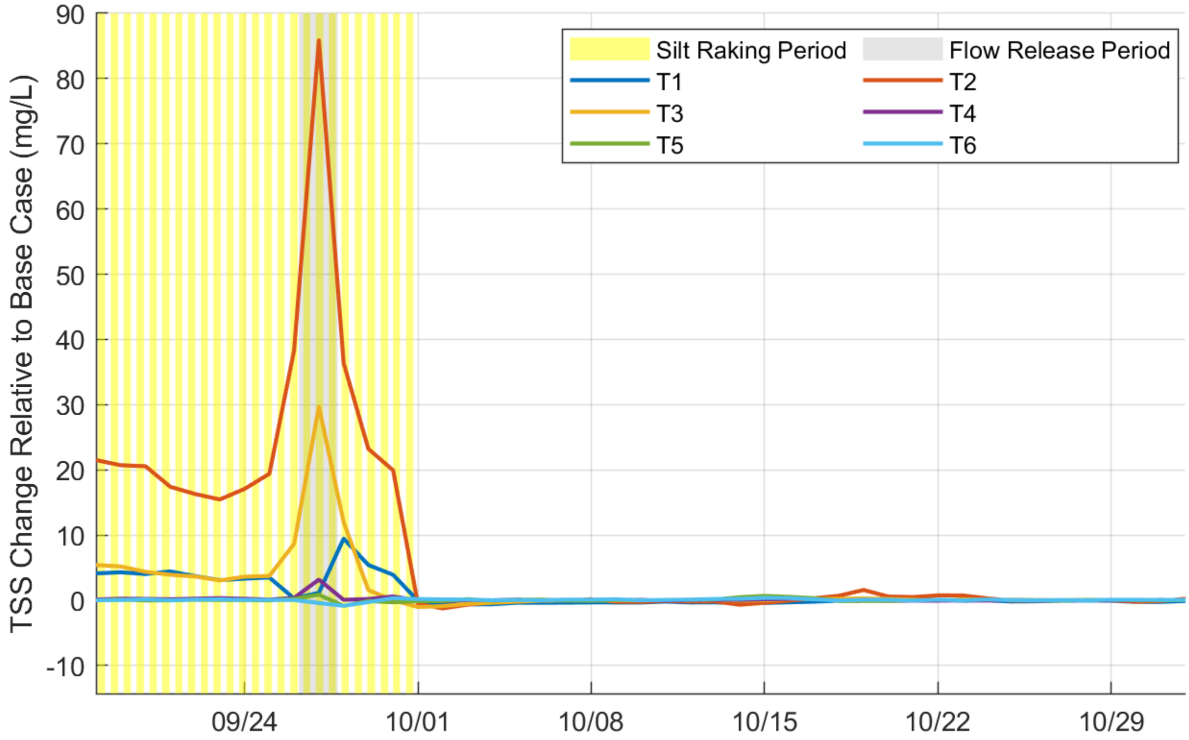


Figure 5-11 Impacts to Daily-Averaged TSS during High Flow Scenario w/ Silt Raking (SC1B)

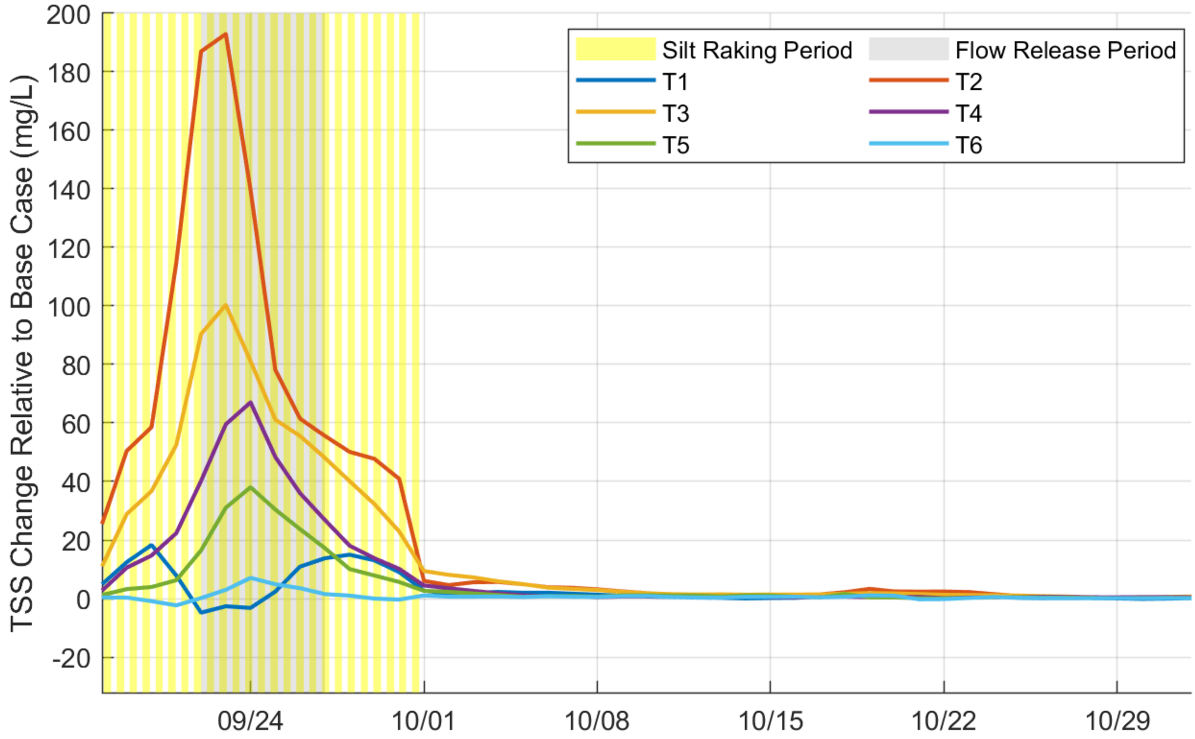


Figure 5-12 Impacts to Daily-Averaged TSS during Natural Spill Scenario w/ Silt Raking (SC5B)

Table 5-4 Percentiles, Corresponding Durations and Magnitudes of TSS impacts during initial two-week period at Site T3 (relative to Base Case, SC0A)

Percentile	Duration at/above this concentration (based on model timestep)	High Flow (SC1A)	Natural Spill (SC5A)	Base Case SR (SC0B)	Low Flow SR (SC2B)	Med Flow SR (SC3B)	High Flow SR (SC1B)	High Flow Alt. SR (SC1C)	Pulsing Flow SR (SC4B)	Natural Spill SR (SC5B)
Maximum	~30 minutes	36.5	146.1	20.1	41.5	67.5	80.7	82.2	72.4	280.9
90th	~34 hours	3.4	54.9	12.4	16.4	16.4	16.0	18.6	17.4	98.9
75th	3.5 days	0.0	43.0	7.1	8.6	8.5	8.4	6.3	8.9	63.0
50th	7 days	0.0	27.5	0.4	0.7	1.0	1.0	1.5	1.8	41.0

Table 5-5 Percentiles, Corresponding Durations and Magnitudes of TSS impacts during initial two-week period at Site T5 (relative to Base Case, SC0A)

Percentile	Duration at/above this concentration (based on model timestep)	High Flow (SC1A)	Natural Spill (SC5A)	Base Case SR (SC0B)	Low Flow SR (SC2B)	Med Flow SR (SC3B)	High Flow SR (SC1B)	High Flow Alt. SR (SC1C)	Pulsing Flow SR (SC4B)	Natural Spill SR (SC5B)
Maximum	~30 minutes	6.7	94.3	3.9	5.1	6.3	6.5	5.3	7.1	110.1
90th	~34 hours	0.4	50.2	0.2	0.5	0.9	0.5	1.4	2.0	51.8
75th	3.5 days	0.0	19.9	0.1	0.1	0.1	0.1	0.3	0.8	20.3
50th	7 days	0.0	5.2	0.0	0.0	0.0	0.0	-0.2	-0.1	5.2

5.3.4 Cost

In deriving an approximate cost of releasing water through the South Esk, any direct operational costs (in terms of costs of the dam operations in monitoring and managing the water releases) have been considered to be minor and therefore the cost of flow releases has been assessed based on the loss of potential revenue if that water were used instead for power generation.

The Trevallyn Power Station has an output of approximately 1 MW for every 1 m^3/s of water flowing through it. As the total volume of water diverted through the South Esk in all flow release scenarios is constant (100 cumec-days, or 8,640,000 m^3), the potential cost of this water (if alternatively used for power generation) is the same also. The average annual wholesale electricity price in Tasmania ranges from $30/MWh (2009-2010) to $97/MWh (2015-2016). The potential cost of a water release of 8,640,000 m^3 can therefore range widely depending on the spot price of electricity at a given time.

Figure 5-13 shows a timeseries of the potential release cost using 2-weekly averaged wholesale prices for the past decade. Key statistics from this are shown in Table 5-6. Based on this analysis a flow release of this magnitude would have an opportunity cost (in lost revenue) of at least $34,800 (for the cheapest rate in the past decade) and could range as high as $834,000. The median cost of such a release is $100,800 and would have been the approximate cost anytime between mid-2012 and mid-2015.

Silt-raking has a cost of $6,800/day ($5,000 for raking and $1800 for monitoring, based on information from City of Launceston). As all the modelled silt-raking scenarios simulating 13 days of silt-raking on ebbing tides, the total expected cost of such a campaign is a constant $88,400. There is an additional cost of $1,400 per month that corresponds to the cost of the regular bathymetric surveys, which has the potential to increase the silt-raking costs overall (an additional $16,800 per annum). However, it is likely that this cost would be incurred even in the absence of silt-raking operations in order to quantify siltation and monitor long-term trends.

Therefore, the total estimated cost of each modelled scenario is the combination of the cost of any targeted flow release and any silt-raking in that scenario. The estimated costs (assuming a median electricity price) are presented in Table 5-7.

Table 5-6 Flow Release Price Statistics

Value	Minimum	Median	Mean	Maximum
14-day average price ($/MWh)	14.50	42.00	55.48	347.50
Predicted Flow Release Cost ($)	34,800	100,800	133,156	834,000

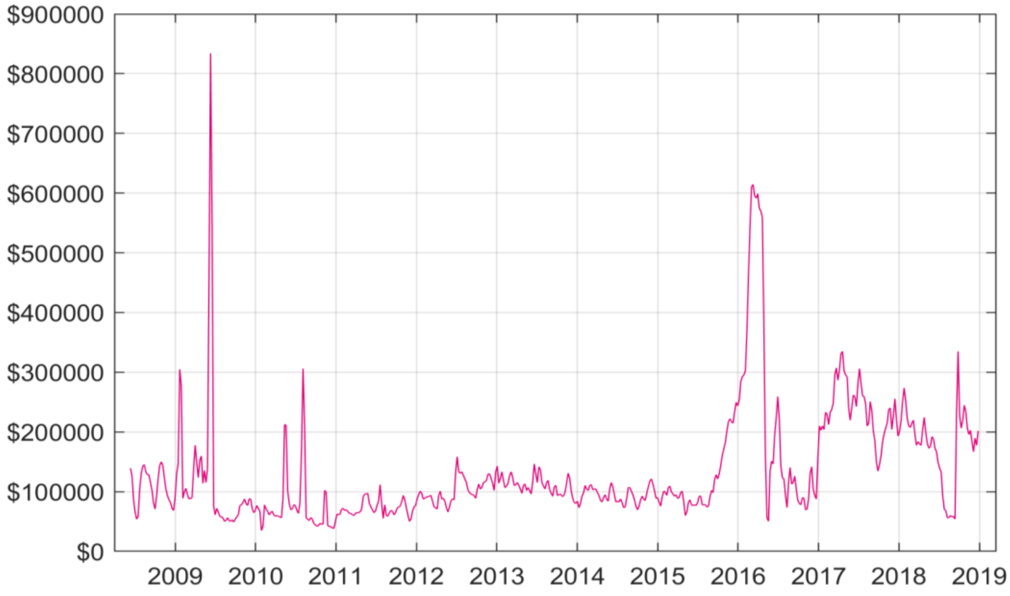


Figure 5-13 Timeseries of potential flow release lost revenue

Table 5-7 Estimated Costs by Scenario

Scenario	Flow Release Cost	Silt-raking Cost	Total Estimated Cost
Base (SC0A)	N/A	N/A	$0.00
High Flow (SC1A)	$100,800	N/A	$100,800
Natural Spill (SC5A)	N/A	N/A	$0.00
Base SR (SC0B)	N/A	$88,400	$88,400
High Flow SR (SC1B)	$100,800	$88,400	$189,200
High Flow SR alt. (SC1C)	$100,800	$88,400	$189,200
Low Flow SR (SC2B)	$100,800	$88,400	$189,200
Medium Flow SR (SC3B)	$100,800	$88,400	$189,200
Pulsing Flow SR (SC4B)	$100,800	$88,400	$189,200
Natural Spill SR (SC5B)	N/A	$88,400	$88,400

6 Conclusions and Recommendations

6.1 Conclusions

Overall, the results of this investigation indicate that targeted (planned) releases of water from Trevallyn Dam have a minimal effect on silt-mobilisation in the upper estuary and are unlikely to serve as an effective sedimentation management strategy on their own. Furthermore, such releases come at a high cost (~$100,000) given their limited effect on the objectives.

The higher flow conditions simulated in the natural spill scenario, representing a 1-in-1 year flow magnitude, was predicted to elicit a net scour response on both the silt-flats and in the channels, though not of sufficient magnitude to be of value relative to the silt management objectives. The small volume of sediments mobilised by the natural spill conditions are shown to be transported downstream, with a corresponding increase in TSS levels as far down as Legana.

In terms of silt-raking, the modelling predicts that while silt is mobilised from the immediate area targeted by the raking operations, the majority of mobilised sediments settle in immediately adjacent areas. In the modelled scenarios, silt-raking on some of the silt-flats caused a reduction in these silt-flats with a resulting increase in the silt-flats immediately downstream and infilling adjacent channels. Therefore, the effects of silt-raking for the purpose of reducing particular silt-flat areas may conflict with other silt-management objectives.

Releasing water while silt-raking amplifies the predicted effects, both in terms of removal of sediment from the silt-raked areas (by up to 27%) and transfer of these increased volumes to adjacent areas. The spatial pattern of this infilling is altered with flows present (relative to silt-raking alone), with some of the channel areas experiencing a proportionally lower rate of infilling. However, there is still a far greater infilling of the channels than under base case conditions, meaning that any silt-raking operations are likely to cause unintended impacts to the navigability and amenity of adjacent areas. Overall, the addition of the flows more than doubles the cost of silt-raking (from ~$80,000 to ~190,000) but without a substantive improvement in overall outcomes. The targeted release of water during silt-raking does not appear to be a cost-effective approach to silt-management.

Silt-raking during natural spill conditions is also shown to amplify both the positive and negative effects of silt-raking (far more than any other modelled scenario). Much like the targeted releases, this alters the spatial distribution of adjacent infilling, but ultimately causes far greater infilling of adjacent areas than would be experienced without silt-raking. If the infilling of the adjacent channels and associated accretion on adjacent banks were considered an acceptable outcome, then silt-raking during natural spills is the most effective strategy at mobilising silt away from the targeted areas.

Furthermore, silt-raking is shown to have the potential to increase TSS concentrations downstream, and even more so when combined with targeted flow releases. However, these effects are within the variability experienced in response to natural spill events in the absence of silt-raking, meaning that natural flood and high flow conditions are likely to cause greater TSS increases naturally. When the two coincide (silt-raking and natural spills) significant increases in downstream TSS concentrations can be observed. All increases in TSS return to within normal ranges shortly after silt-raking and targeted flow releases cease.

Lastly, none of the scenarios modelled show any major transfer of sediment to downstream zones within the broader estuary. A small proportion of sediment can be transported down to the areas adjacent to Tamar Island, but the vast majority remains within the upper-estuary channels and banks near Launceston. The same long-term siltation rate is therefore expected, meaning that any short-term mobilisation of sediments from an area (such as the West Tamar Shoal reduction due to silt-raking) is likely to be overcome within several months of dry conditions. The addition of targeted flow releases or even a one-off natural spill does not increase or decrease this long-term siltation rate.

6.2 Recommendations for Further Study

The silt-mobilisation effects of much larger (less frequent) natural spill events have not been examined as part of this study. Further investigation of the exact flow rate required to mobilise a useful volume of sediment (in terms of silt-management objectives) would help to support decision making with respect to expected annual siltation patterns.

Furthermore, silt-raking has been shown to demonstrate an effective mobilisation of silt from a narrow targeted area over the short-term. However, the mobilised silt is most likely to be re-distributed around the immediate vicinity, with this process depending on the occurring conditions during and after specific silt-raking events. In order to gain a better understanding of the interaction of silt-raking with the sediment transport processes in the study area, a more detailed field-based study on the specific effects and impacts of it would be recommended. This would be useful to inform model parameterisation, conduct further model calibration-validation and ultimately reduce uncertainty and confirm the efficacy of silt-raking for sedimentation management. This study would entail capturing more data about the specific movements of the silt-raking vessel and to use surveys, turbidity observations and other measurements to quantify the corresponding silt mobilisation. While no changes to the overall pattern and conclusions of this study would be expected, it would allow for testing more specific management options and using silt-raking at different rates in different areas that are beyond the precision of the current schematisation. This would allow for improved information for decision making processes on silt-mobilisation with respect to the desired outcomes, which may at times be in conflict with each other.

Similarly, this study has only investigated the effects of silt-raking in one area. The effects of silt-raking in alternative areas was not assessed and would require further study, likely based on the outcomes of the aforementioned study to refine the understanding of silt-raking processes.

The water quality impacts of silt-raking and sediment scour due to flow releases are not yet well understood. A long-term monitoring programme collecting data to assess the impacts of sediment mobilisation in Home Reach on the downstream water quality would allow for a greater understanding of any potential impacts. This could then support any modelling investigations of water quality impacts in response to proposed alternative management plans and even in response to the likely impacts of natural flood events.

6.3 Limitations and Qualifications

This study has been based on a simplified mathematical model of a complex natural system. The model is only as good as the understanding of the systems and processes involved. While all efforts have been undertaken to minimise the uncertainty the following limitations still exist:

- The detailed near-field processes of silt-raking are not modelled, and modelling is based on parameterisation of silt-raking effects derived from analysis of historical survey datasets;
- The absolute outcomes of an individual scenario contain inherent uncertainties and are also sensitive to the modelling assumptions. The best use of the modelled scenarios is to undertake relative comparisons of the predicted results; and
- Modelling has been based on known conditions and using assumed circumstances as provided by TEER partners. Any variation from these values may impact potential outcomes, though care has been taken to present conclusions that are insensitive to minor changes.

Overall, the model is considered fit-for-purpose to assess and demonstrate overall implications of flow releases and silt-raking campaigns, and to provide useful conclusions for the stakeholders.

7 References

BMT WBM 2010. Tamar Estuary and Esk Rivers Catchment WaterCAST Model: Final Report. Prepared for NRM North. Ref. no. R.B17155.001.02.

BMT WBM 2010. Tamar Estuary and Esk River Modelling - Update. Prepared for NRM North. Ref. no. R.B19268.001.01.

BMT WBM 2015. Tamar Estuary 3D Modelling, Prepared for NRM North. Ref. no. R.B20921.001.03.

BMT 2019. North and South Esk Rivers Flood Modelling and Mapping Update Volume 1: Technical Report. Prepared for City of Launceston. Ref. no. M20921.002.02.

Appendix A Total Suspended Solids (TSS) Impacts

Figure A-2 to Figure A-10 present box-and-whisker plot comparisons between the selected scenarios and the base scenario without silt-raking (SC0A). Box-and-whisker plots are shown at several EHAP sites in order from downstream to upstream.

Box-and-whisker plots show the minimum (0^{th} percentile), maximum (100^{th} percentile) as well as the lower quartile (25^{th} percentile), median (50^{th} percentile) and upper quartile (75^{th} percentile) of the TSS at each location on the same figure. A Diamond marker has also been shown to represent the mean of the TSS at each location. An example is shown in Figure A-1.

Figure A-1 Box and Whisker Interpretation

Additionally, Figure A-11 to Figure A-19 present timeseries of the impact to the daily-averaged TSS values at EHAP sites T1 to T6. These have been presented for each scenario as an absolute impact to the base case (SC0A).

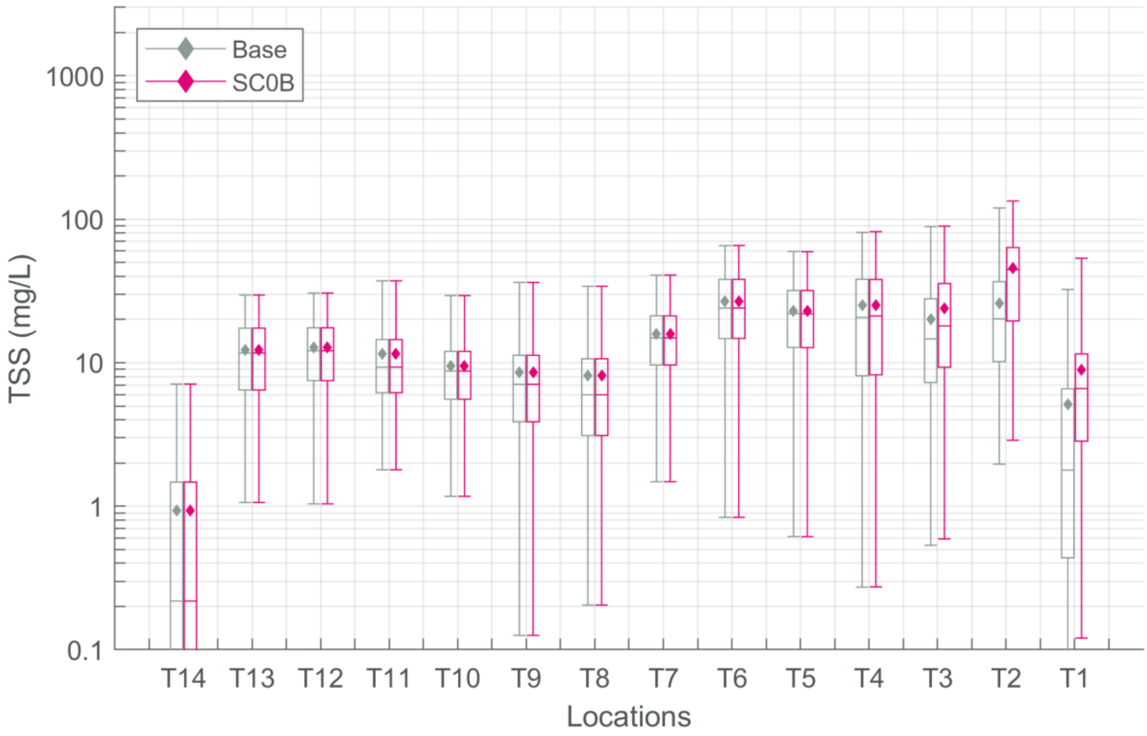


Figure A-2 SC0B (Base Scenario w/ Silt Raking) Comparison

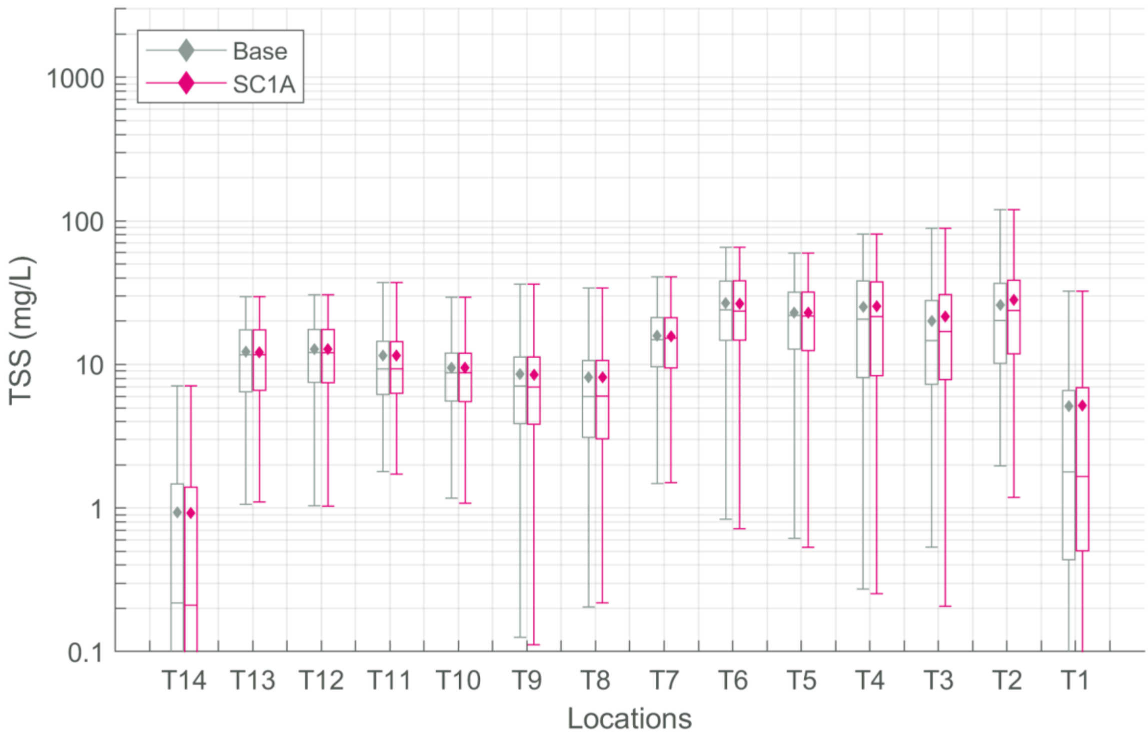


Figure A-3 SC1A (High flow) Comparison

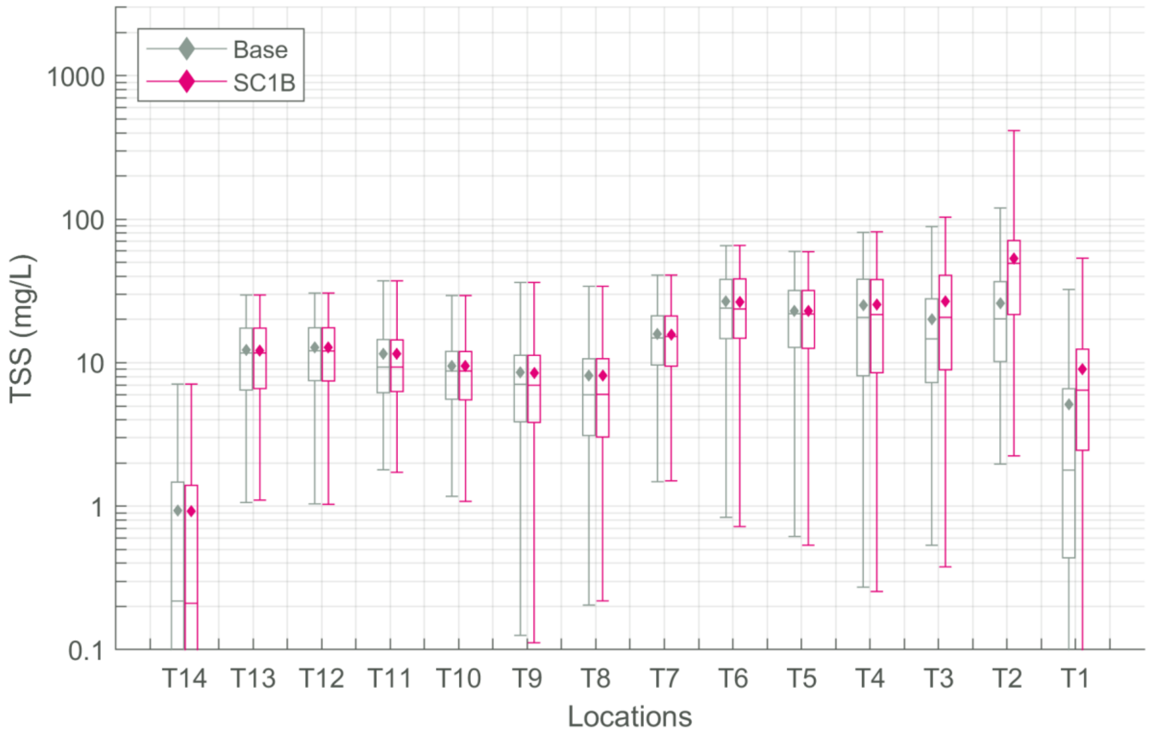


Figure A-4 SC1B (High flow w/ Silt Raking) Comparison

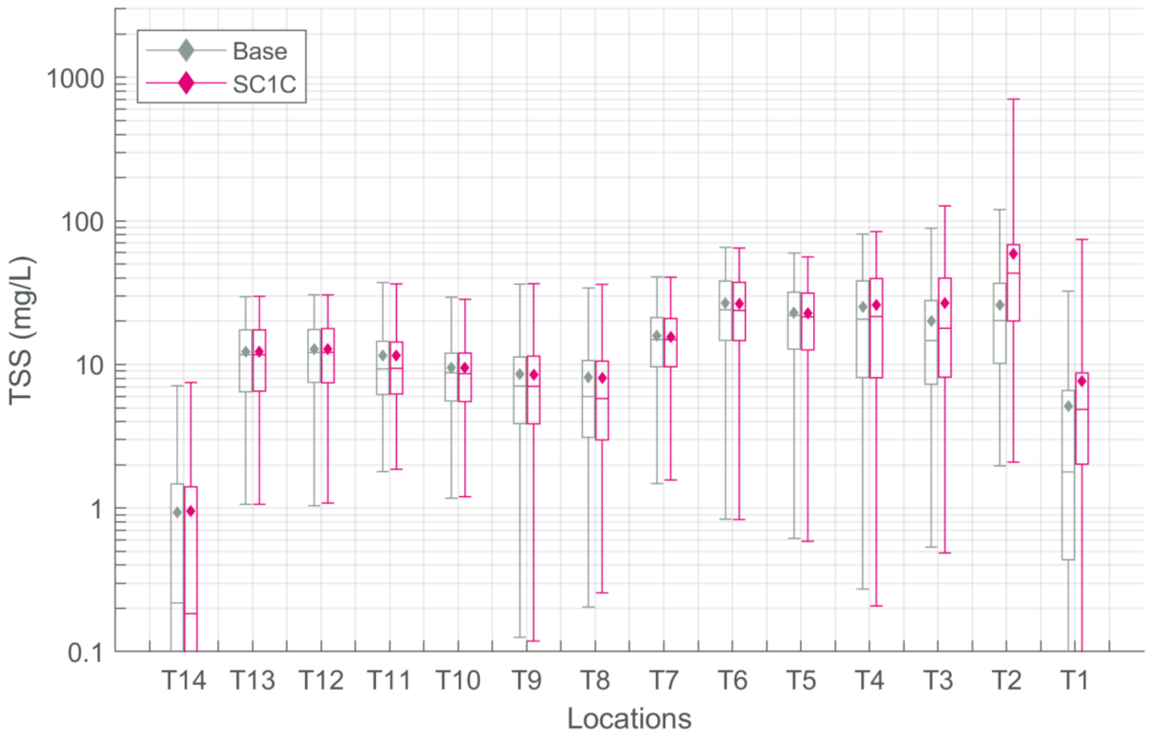


Figure A-5 SC1C (High flow with altered tail race) Comparison

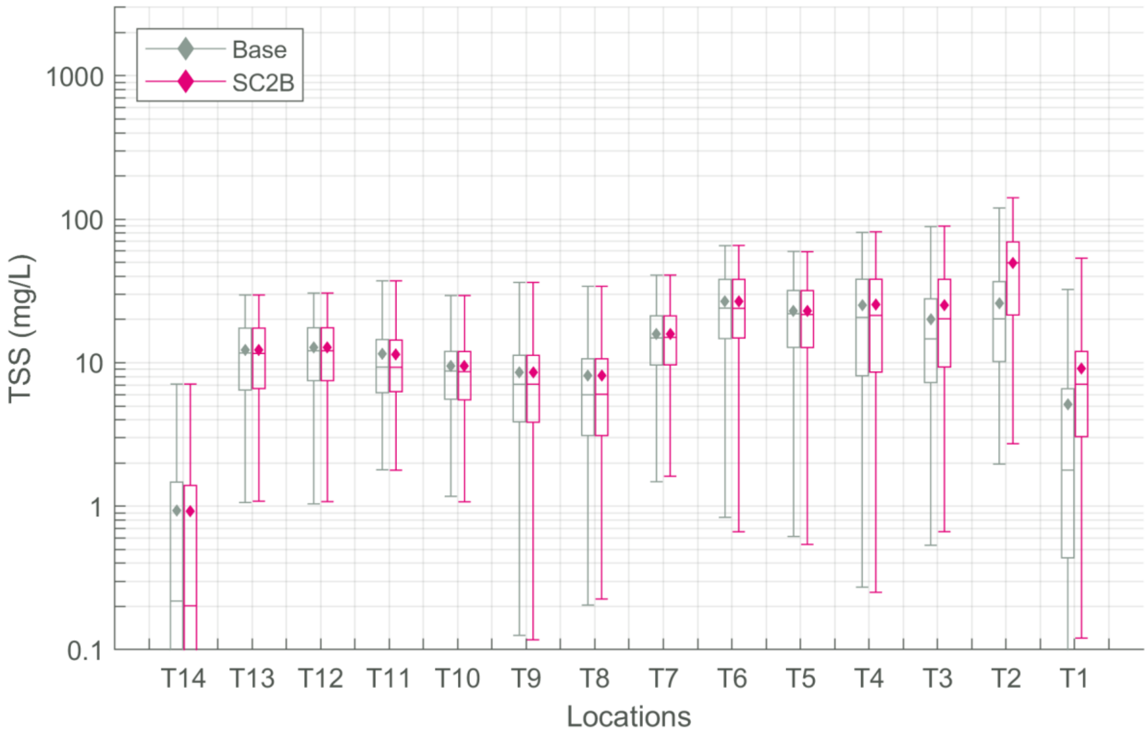


Figure A-6 SC2B (Low flow) Comparison

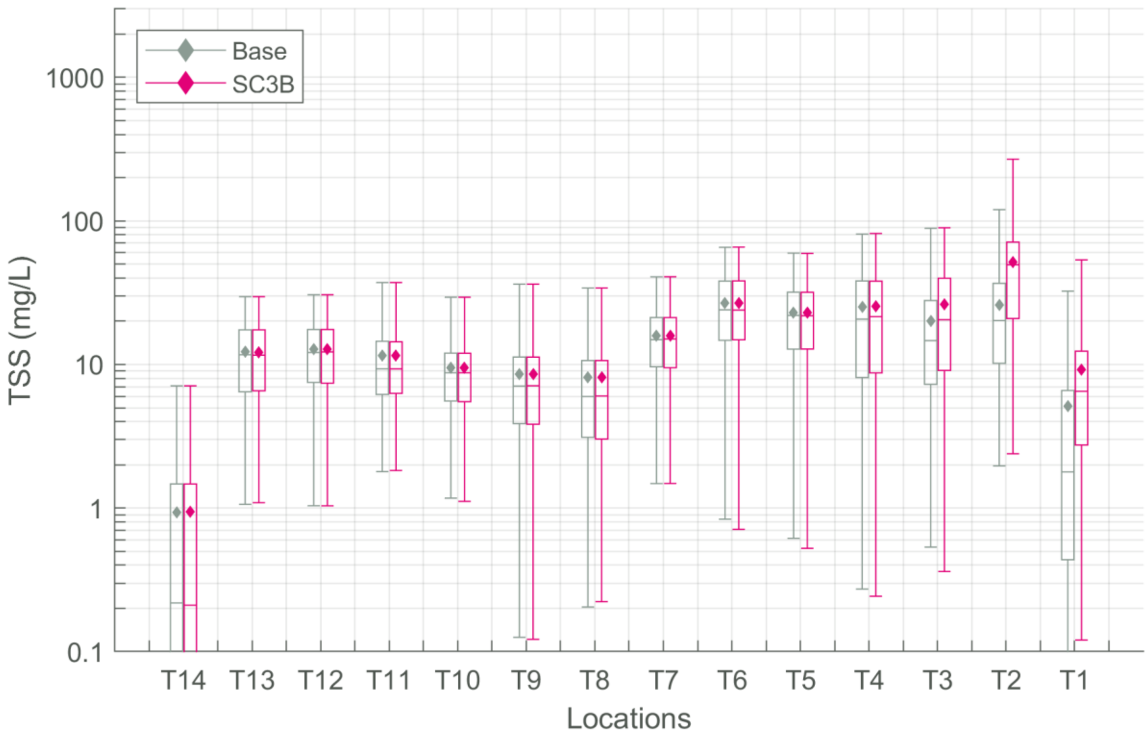


Figure A-7 SC3B (Medium flow) Comparison

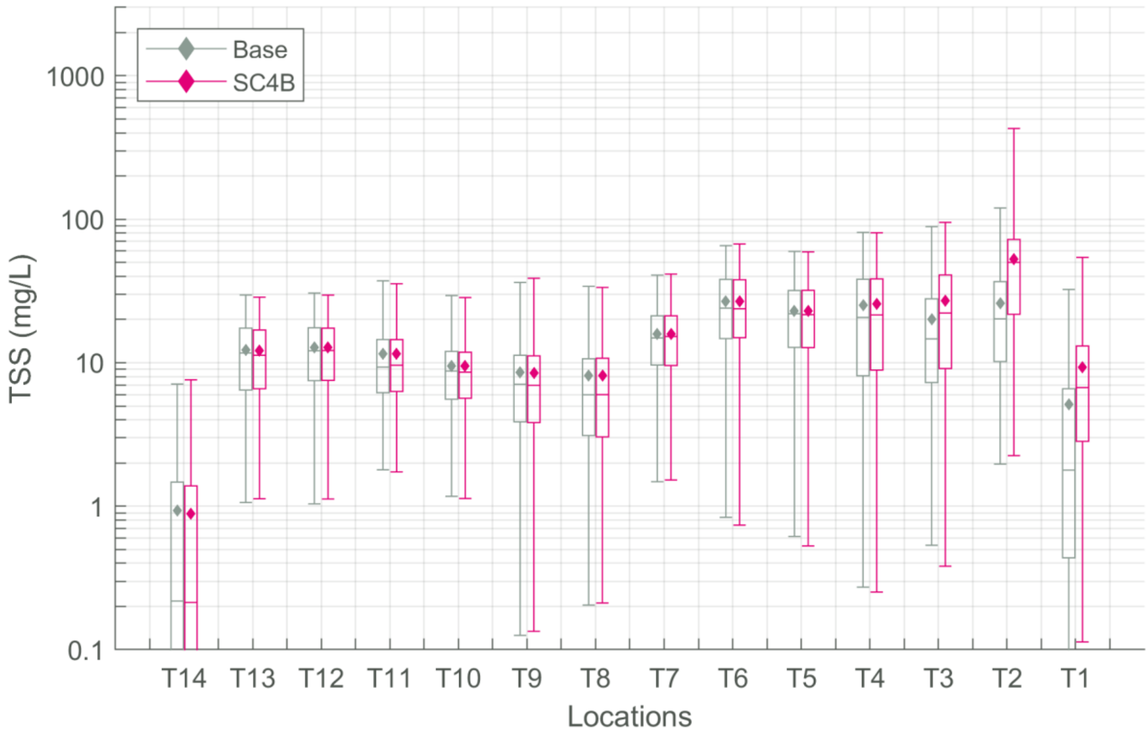


Figure A-8 SC4B (Pulsing flow) Comparison

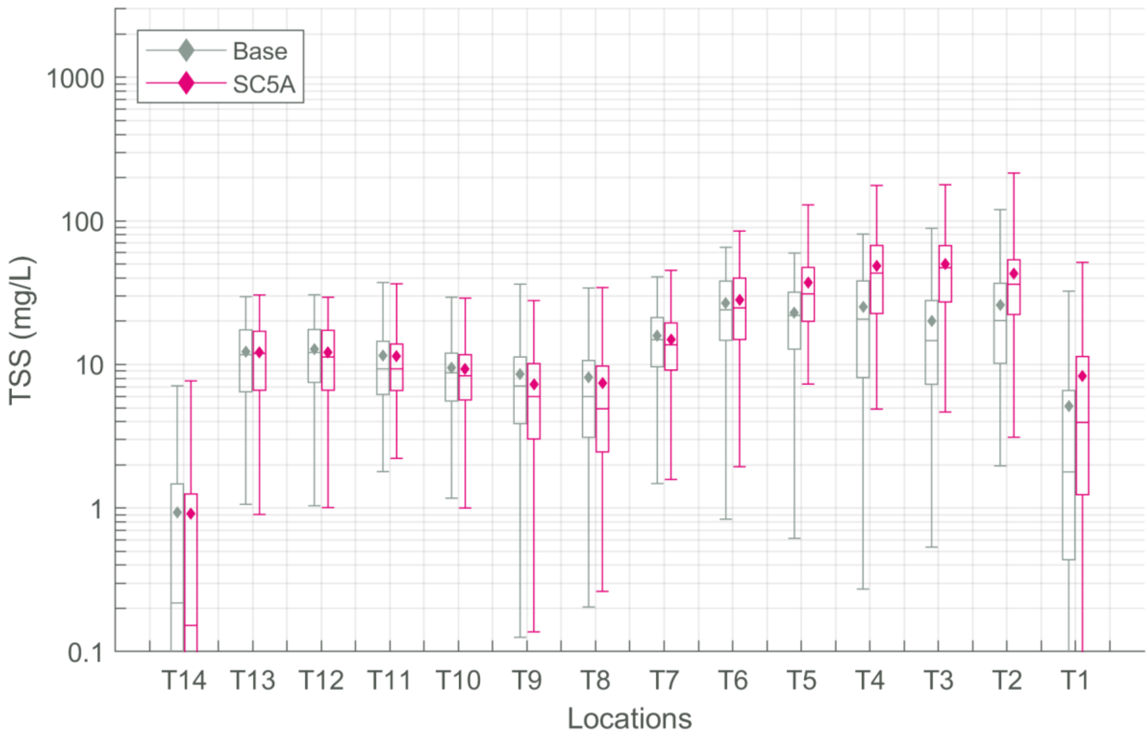


Figure A-9 SC5A (Natural Spill) Comparison

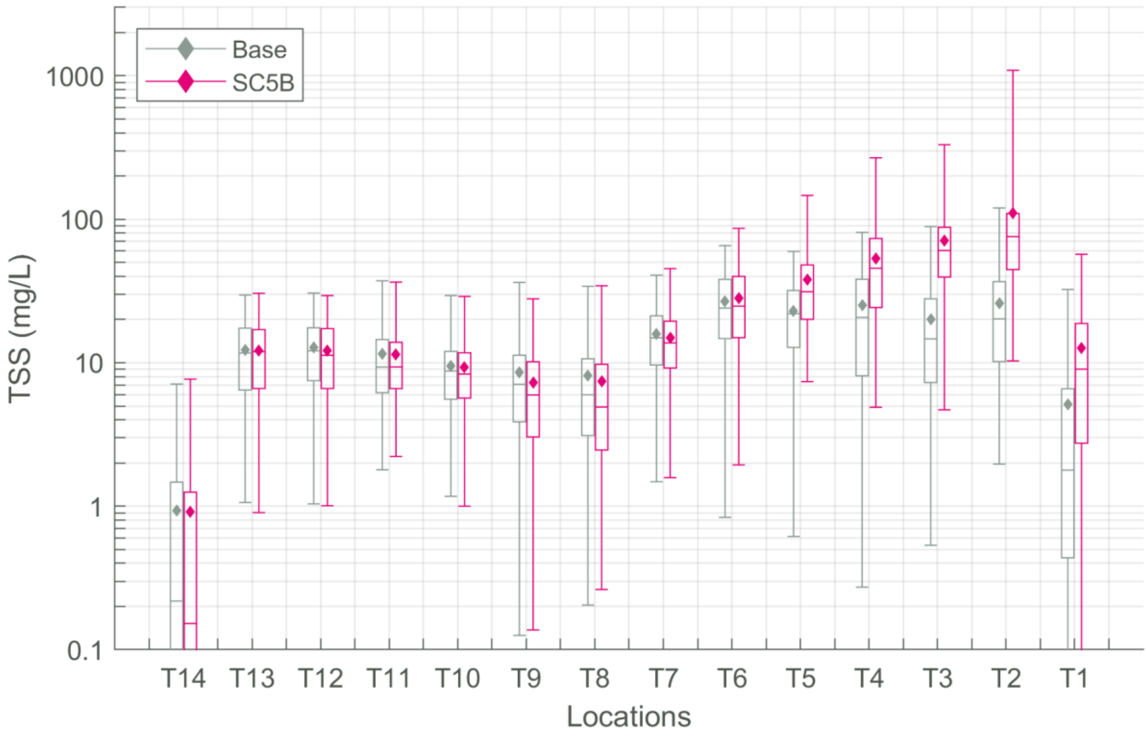


Figure A-10 SC5B (Natural Spill) Comparison

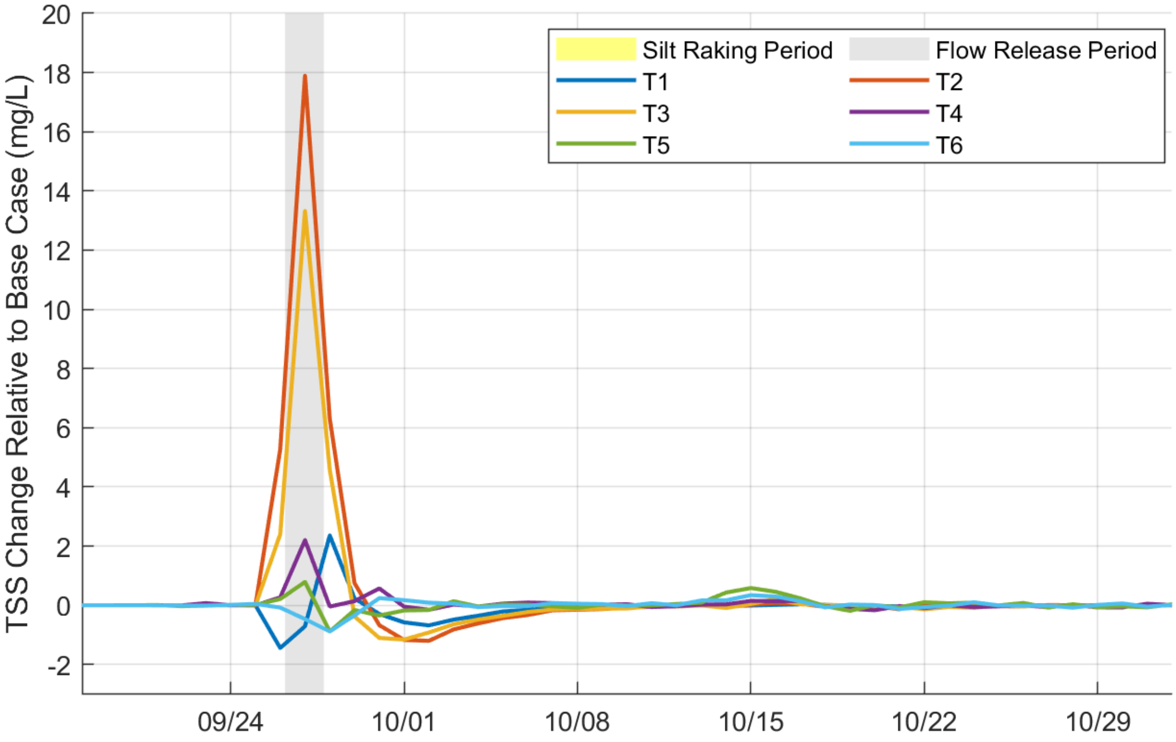


Figure A-11 Impact to Daily Averaged TSS for High Flow Scenario (SC1A) Relative to Base Case (SC0A)

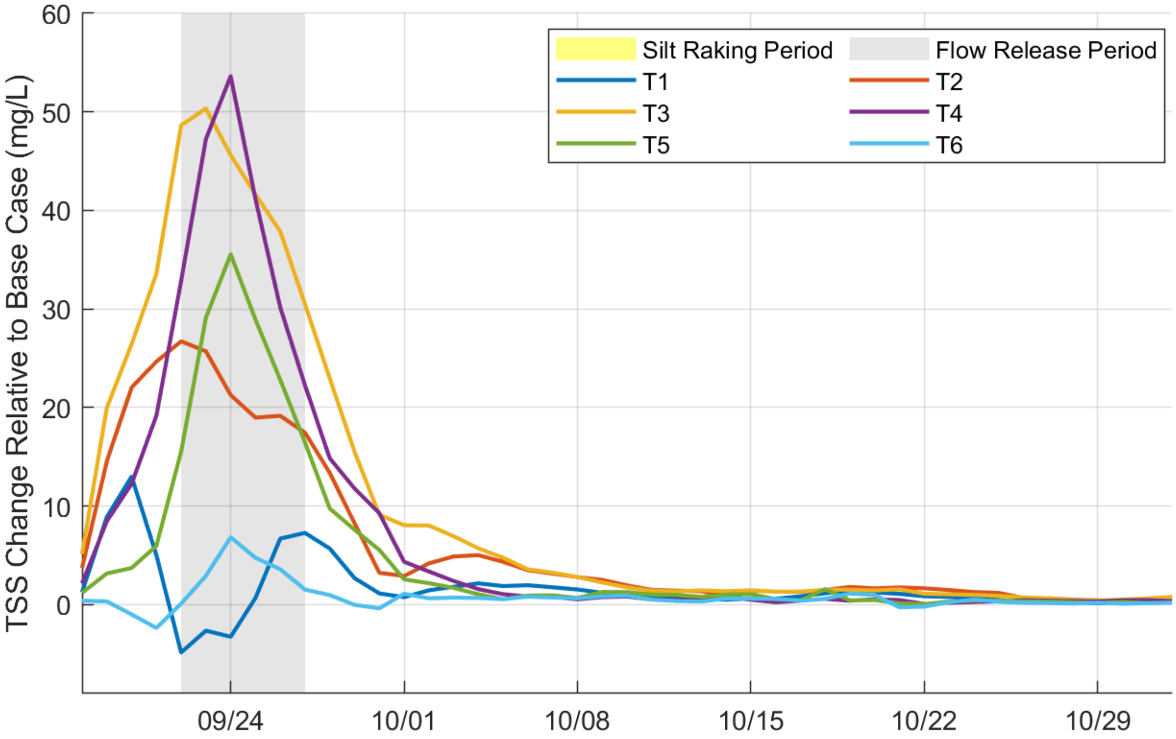


Figure A-12 Impact to Daily Averaged TSS for Natural Spill Scenario (SC5A) Relative to Base Case (SC0A)

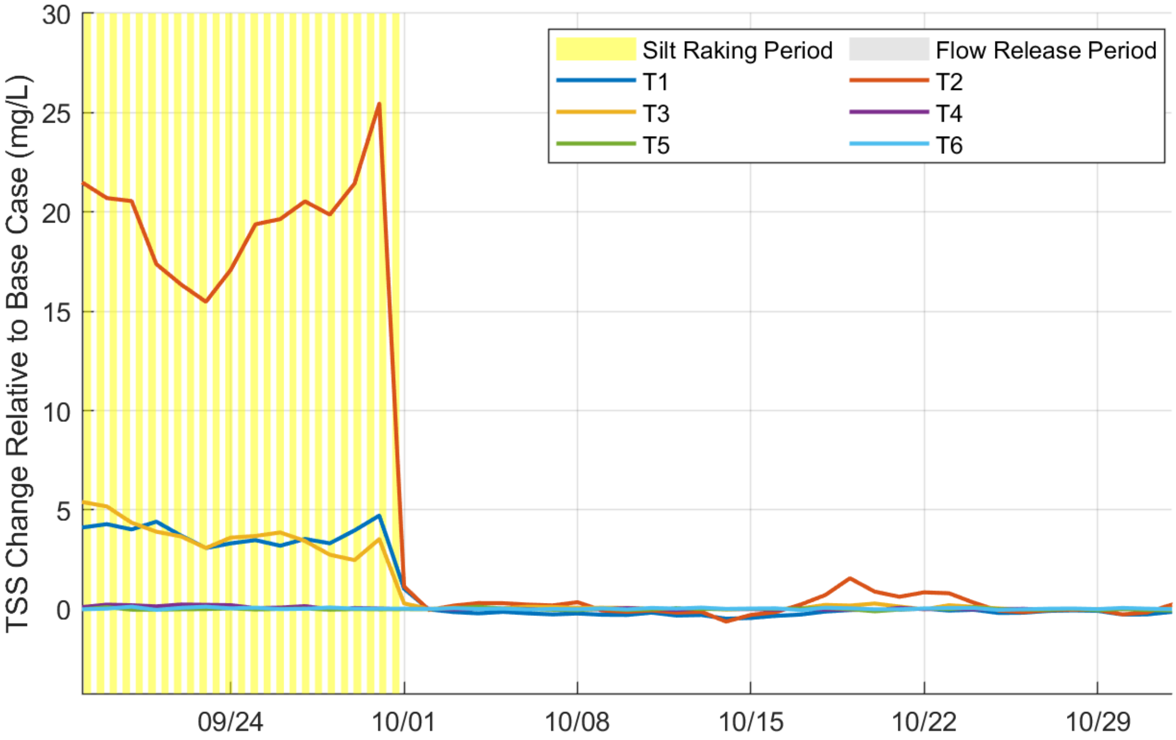


Figure A-13 Impact to Daily Averaged TSS for Base Case Scenario w/ Silt Raking (SC0B) Relative to Base Case (SC0A)

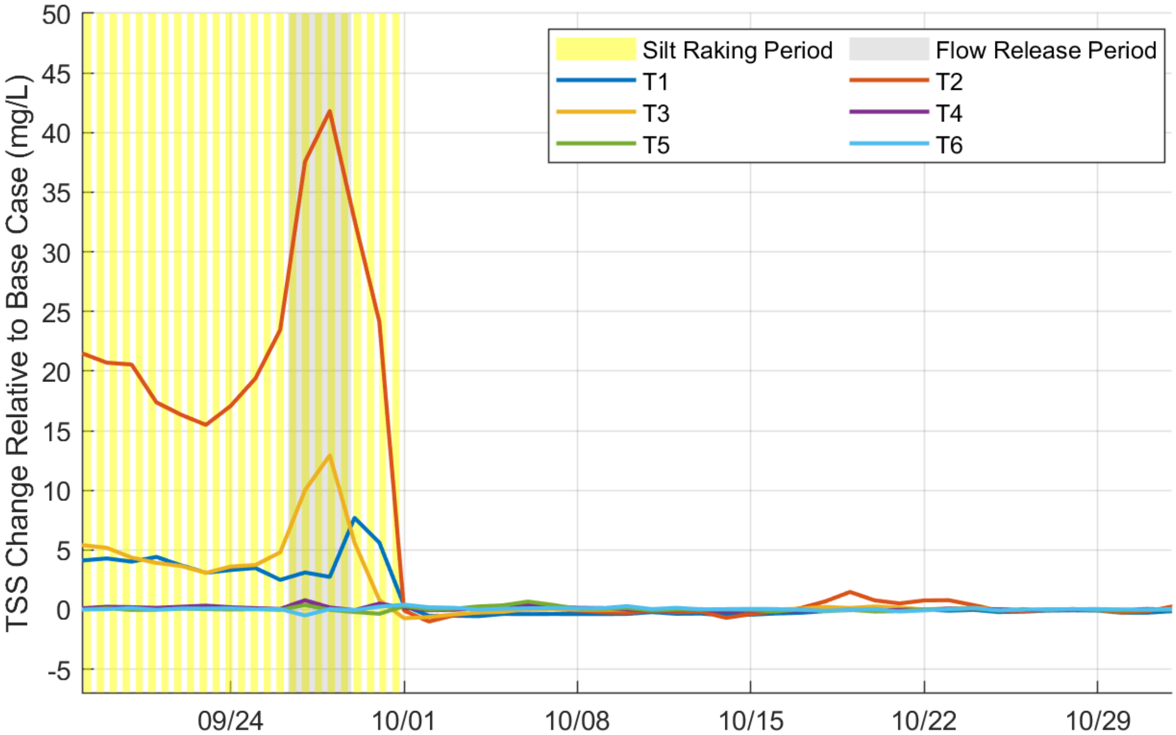


Figure A-14 Impact to Daily Averaged TSS for Low Flow Scenario w/ Silt Raking (SC2B) Relative to Base Case (SC0A)

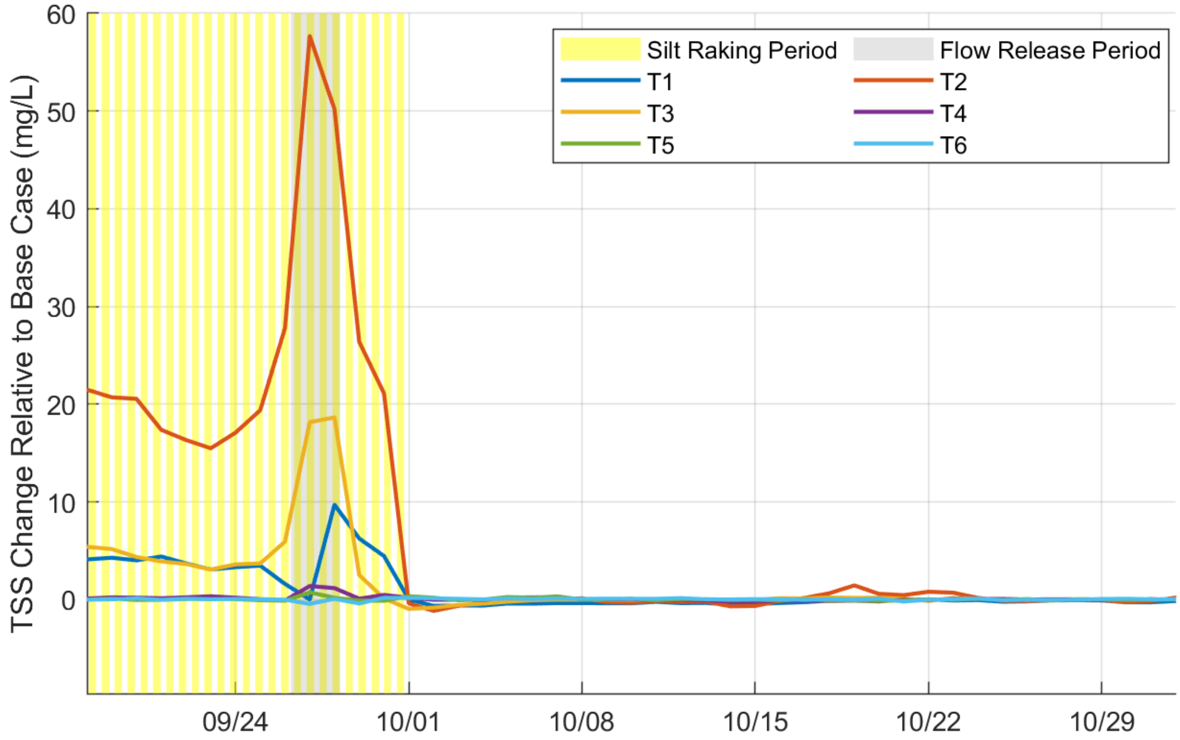


Figure A-15 Impact to Daily Averaged TSS for Medium Flow Scenario w/ Silt Raking (SC3B) Relative to Base Case (SC0A)

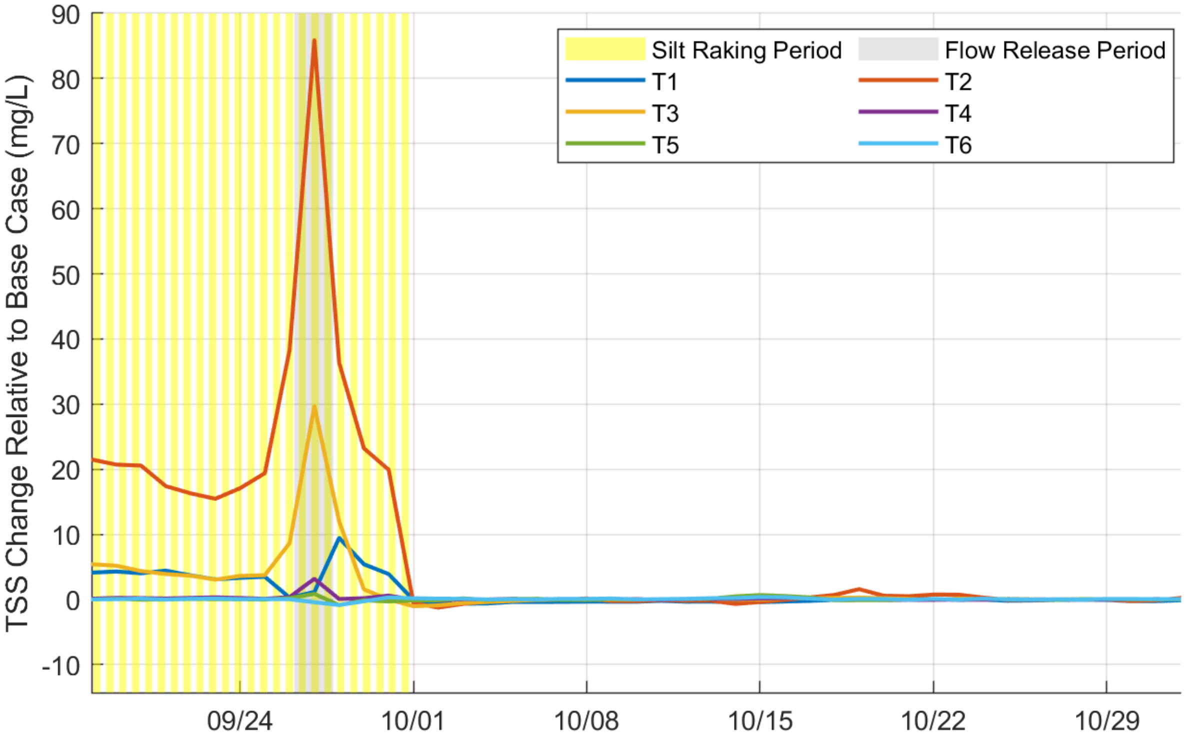


Figure A-16 Impact to Daily Averaged TSS for High Flow Scenario w/ Silt Raking (SC1B) Relative to Base Case (SC0A)

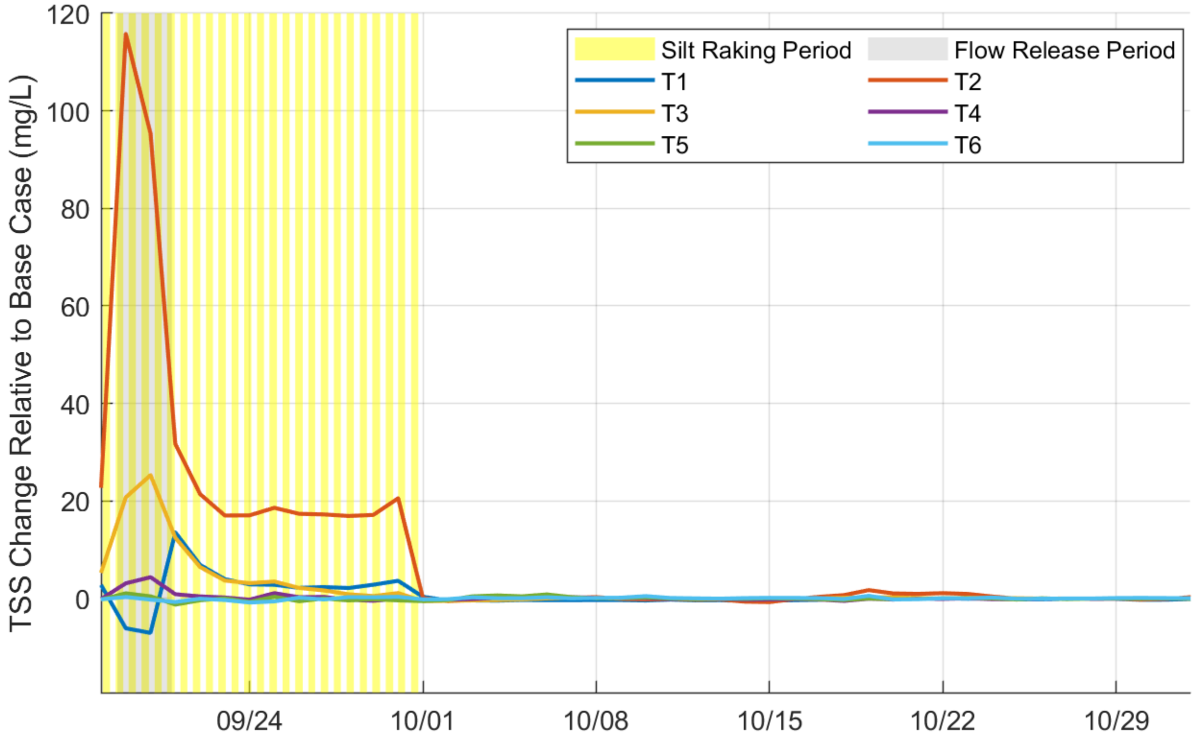


Figure A-17 Impact to Daily Averaged TSS for High Flow Alt. Scenario w/ Silt Raking (SC1C) Relative to Base Case (SC0A)

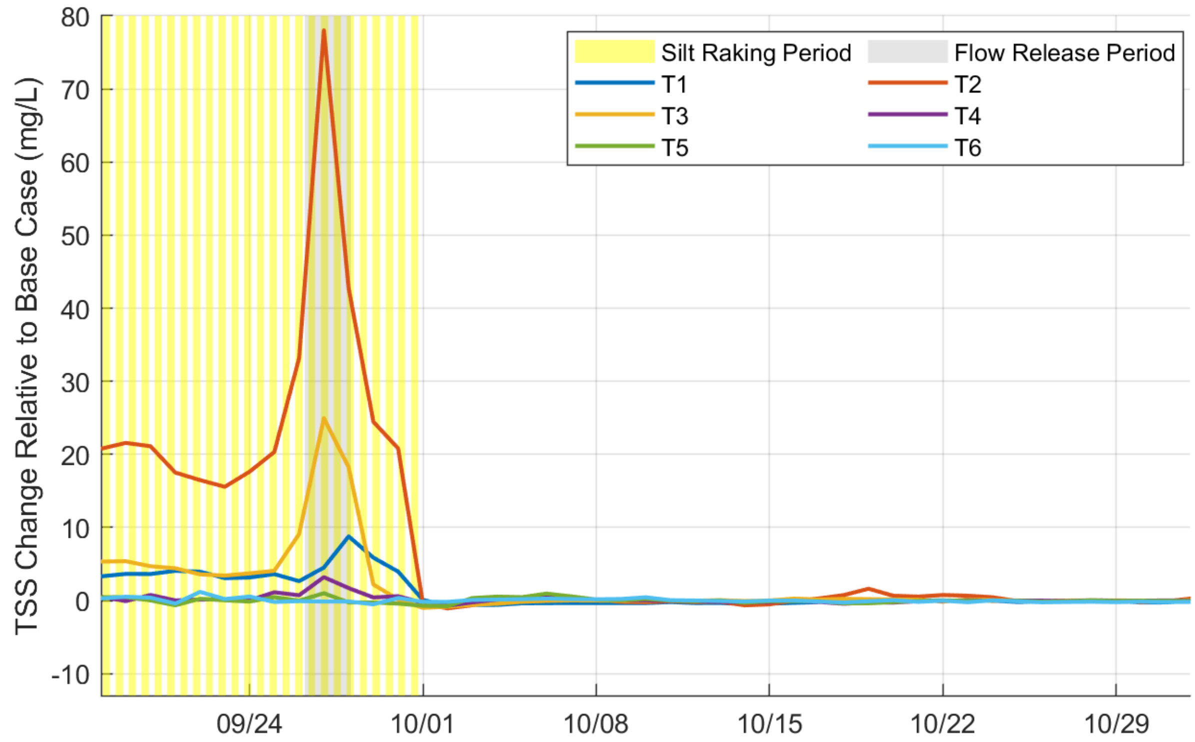


Figure A-18 Impact to Daily Averaged TSS for Pulsing Flow Scenario w/ Silt Raking (SC4B) Relative to Base Case (SC0A)

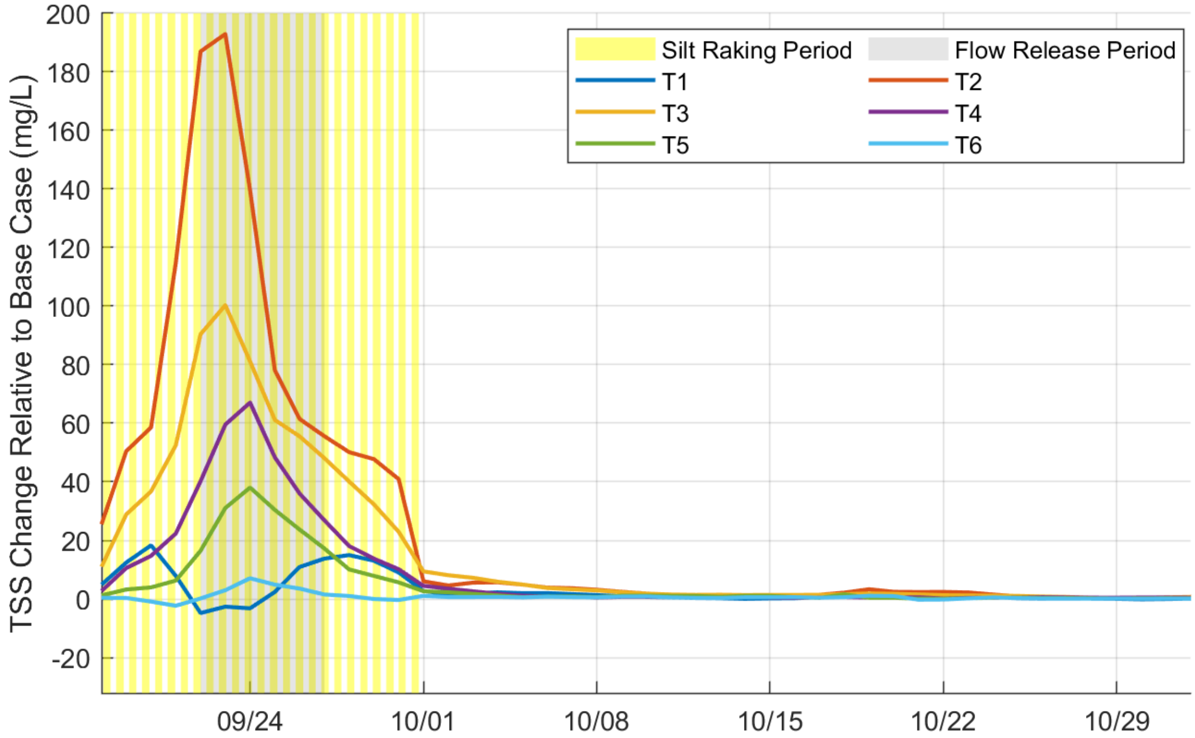


Figure A-19 **Impact to Daily Averaged TSS for Natural Spill Scenario w/ Silt Raking (SC5B) Relative to Base Case (SC0A)**

Appendix B Silt-Raking Sensitivity Tests

The exact nature of how silt-raking mobilises sediments, the rate at which this occurs and what factors influence the rates and location of material has not been studied. As such, this modelling report has schematised the silt-raking as a constant mobilisation of sediment from the bed over a large area, placing all of this sediment in the bottom one metre of the water column. This process has been calibrated to match estimations of silt-mobilisation by silt-raking that are based on bathymetric surveys. In order to ensure that the averaging over time and space that is assumed by this approach is not a key sensitivity to the outcomes and conclusions, sensitivity tests of the adopted rate has been chosen.

The adopted rate was 200 kg/s, and sensitivity tests have been conducted with rates of 100 kg/s and 300 kg/s. Figure B-1 to Figure B-3 present the timeseries of bed sediment volume change over the two-week silt-raking and flow periods for the base case with silt raking, the high flow case with silt-raking and the natural spill case with silt raking.

These results show that the key processes are still held within this range of sensitivities. The sediment is still mobilised from the area of interest (West Tamar Shoal) and deposits in other regions (Home Reach). Lower rate (100 kg/s) silt-raking sees a reduced effect, whereas higher rate (300 kg/s) shows an increased effect. Of interest is that the effect is no linear with the assumed rate, suggesting that higher rates reach a maximum effect where the plume that is generated is falling out in the same area as quickly as it is being removed.

These effects hold under the range of flow conditions assessed in this report with the higher flows still showing increased effects over a silt-raking-only scenario. This suggests that the methodology is robust, and the range of conditions assessed.

It is considered that the assumptions presented in this methodology are fit-for-purpose under the best knowledge of the silt-raking processes currently. Any further detailed investigation of short-term and near-field impacts of silt-raking would require a greater understanding of these processes. Any further broad-scale assessments of silt-raking and its impacts would also benefit from this understanding but can likely provide useful information within suitable bounds of uncertainty.

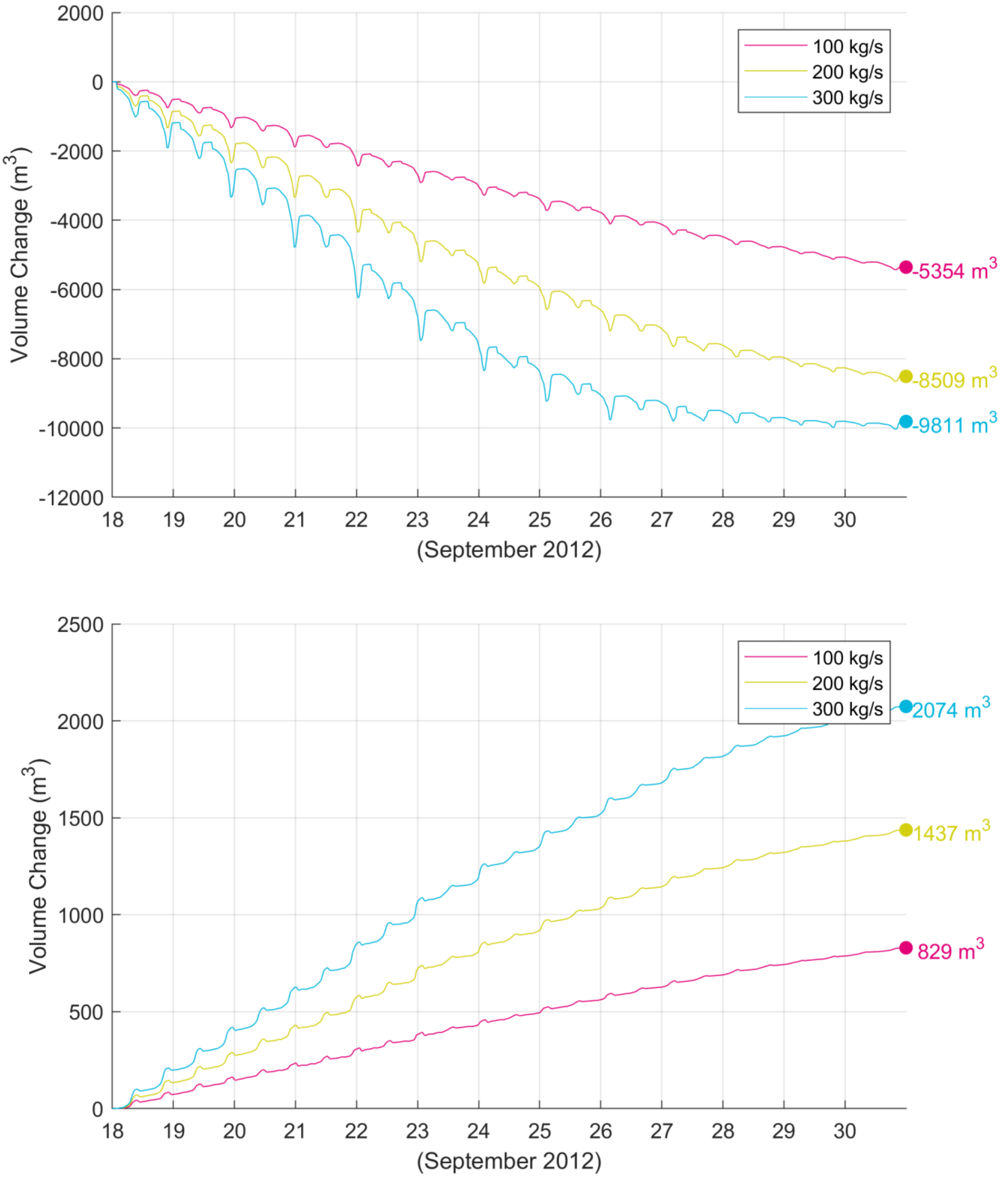


Figure B-1 Sediment Change Timeseries for the Base Case (SC0B) in West Tamar Shoal (Top); and Home Reach (Bottom)

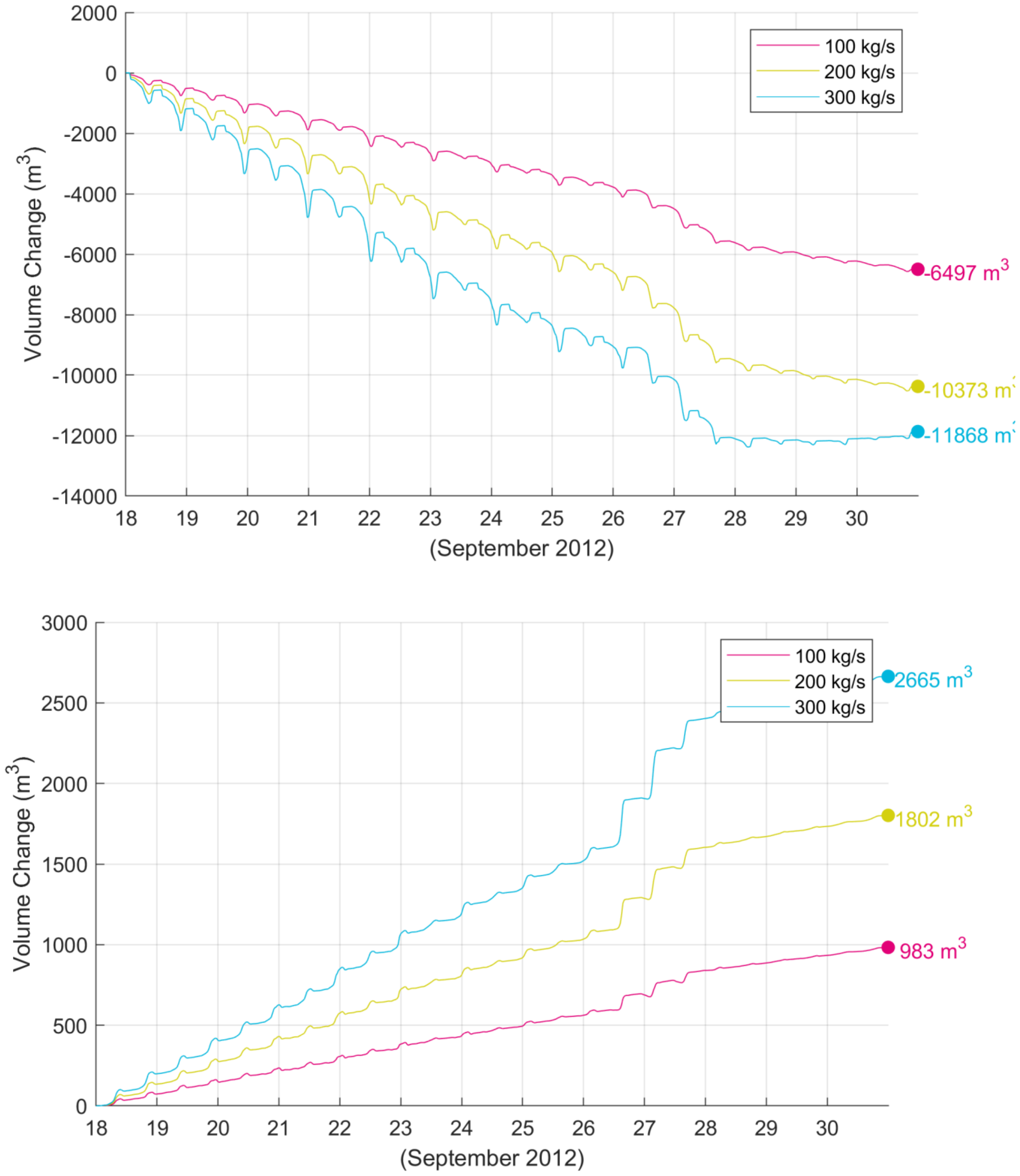
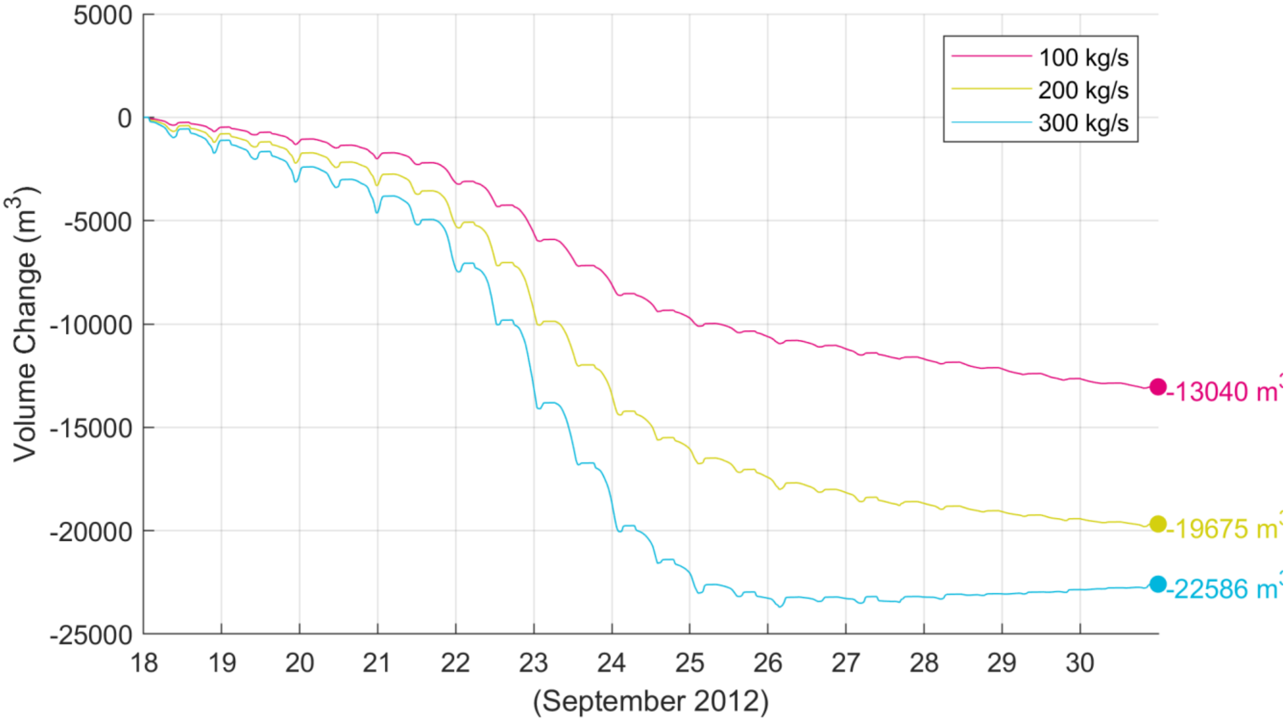


Figure B-2 Sediment Change Timeseries for the High Flow Case (SC1B) in West Tamar Shoal (Top); and Home Reach (Bottom)



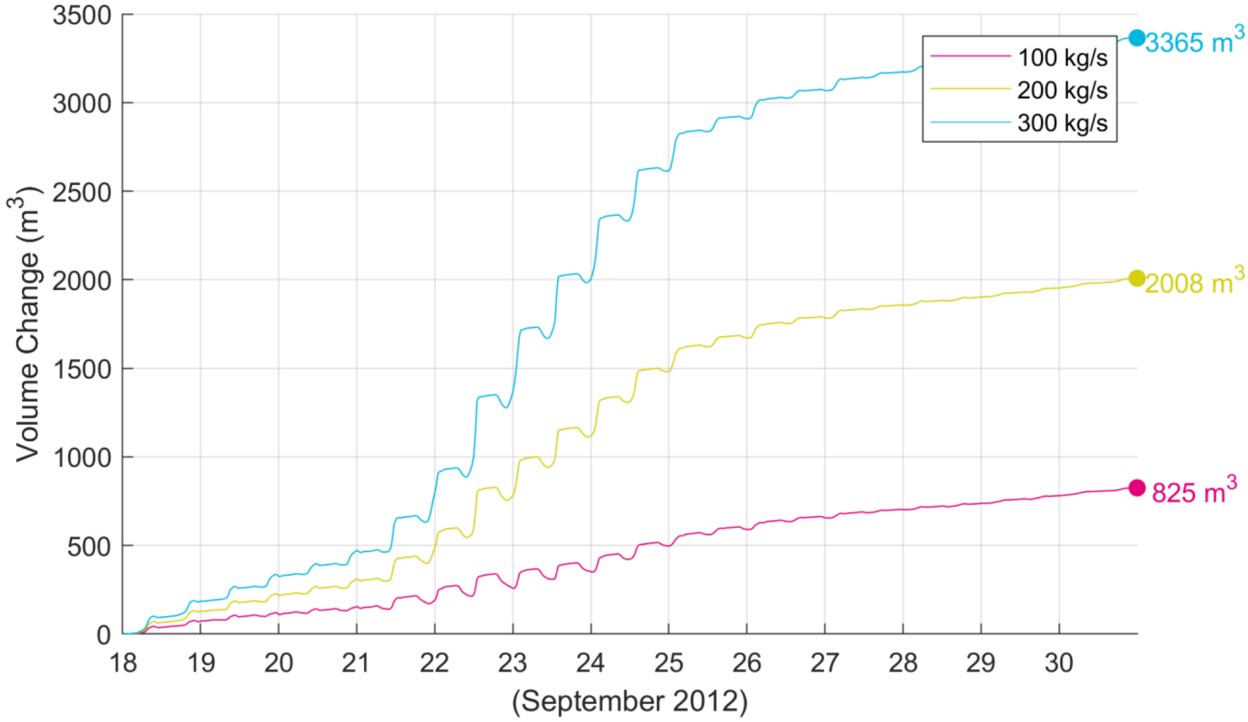


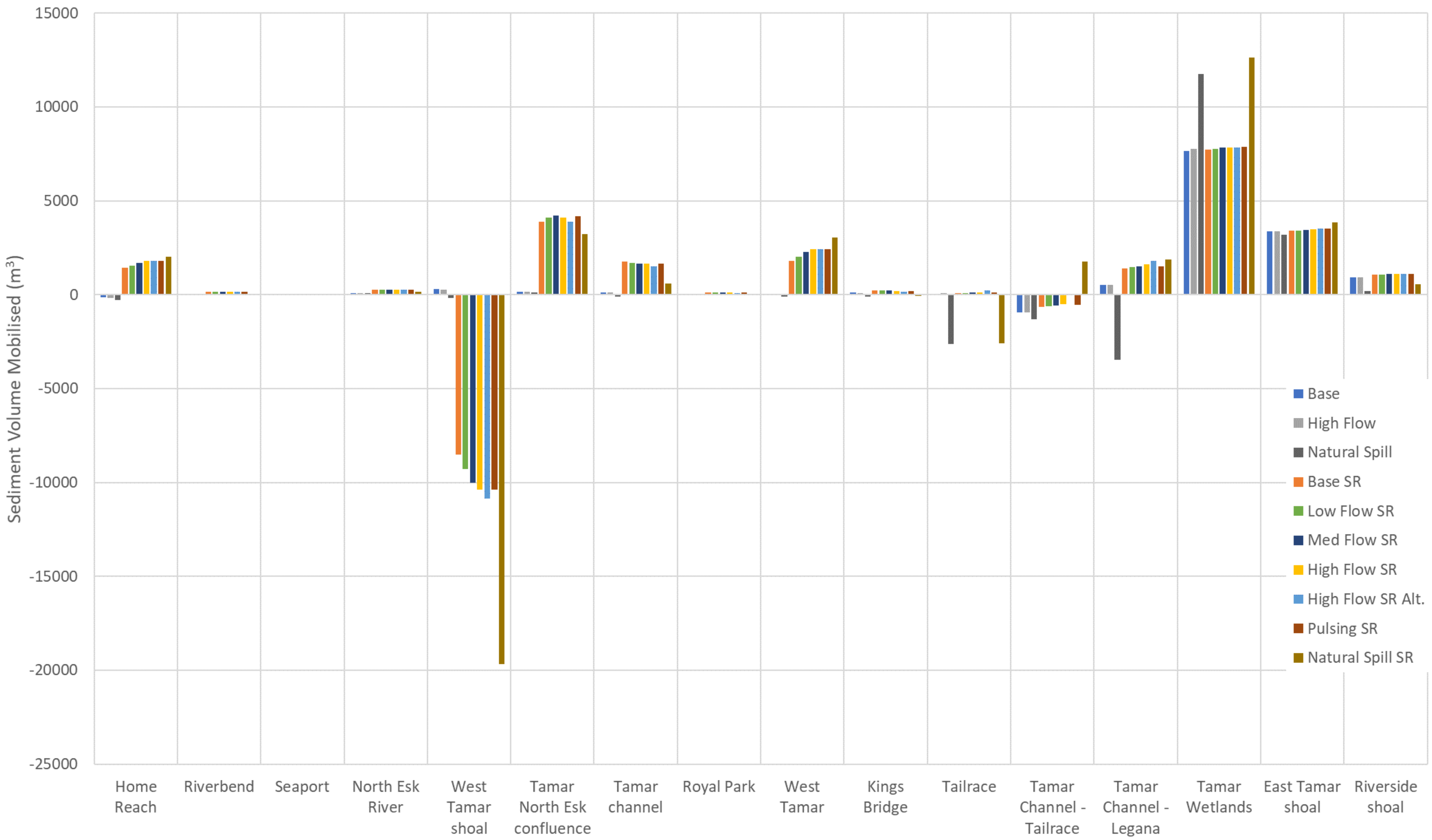
Figure B-3 Sediment Change Timeseries for the Natural Spill Case (SC5B) in West Tamar Shoal (Top); and Home Reach (Bottom)

Appendix C Sediment Mobilisation Patterns

A comparison of the sediment mobilisation volumes in different regions of interest and between the different scenarios is presented in Table C-1 with an equivalent figure in Figure C-1. As the regions have large differences in area, the average bed level change (in mm) in those areas (if the volume change were distributed over the whole region) is shown in Figure C-2.

Table C-1 Siltation Volume Changes for All Regions

Scenario	Home Reach (m³)	Riverbend (m³)	Seaport (m³)	North Esk River (m³)	West Tamar shoal (m³)	Tamar North Esk confluence (m³)	Tamar channel (m³)	Royal Park (m³)	West Tamar (m³)	Kings Bridge (m³)	Tailrace (m³)	Tamar Channel - Tailrace (m³)	Tamar Channel - Legana (m³)	Tamar Wetlands (m³)	East Tamar shoal (m³)	Riverside shoal (m³)
SC0A (Base)	- 130	65	34	89	320	153	133	50	22	104	63	- 926	533	7,660	3,369	922
SC0B (Base SR)	1,437	173	51	271	- 8,509	3,876	1,755	115	1,819	234	83	- 644	1,387	7,713	3,423	1,064
SC1A (High Flow)	- 183	56	34	89	252	148	115	42	15	82	79	- 957	515	7,749	3,393	936
SC1B (High Flow SR)	1,802	166	51	271	- 10,373	4,110	1,651	104	2,440	204	116	- 506	1,605	7,832	3,478	1,110
SC1C (High Flow SR alt.)	1,794	155	54	278	- 10,858	3,906	1,514	87	2,413	163	221	18	1,806	7,835	3,537	1,098
SC2B (Low Flow SR)	1,550	171	51	271	- 9,295	4,092	1,693	111	2,037	222	102	- 610	1,482	7,772	3,428	1,090
SC3B (Med Flow SR)	1,705	172	51	272	- 9,995	4,206	1,674	109	2,278	215	112	- 573	1,523	7,825	3,456	1,103
SC4B (Pulsing SR)	1,804	168	53	278	- 10,382	4,187	1,658	109	2,423	205	105	- 555	1,502	7,883	3,525	1,124
SC5A (Natural Spill)	- 269	- 5	27	71	- 158	116	- 111	- 35	- 96	- 109	- 2,620	- 1,296	- 3,472	11,761	3,185	199
SC5B (Natural Spill SR)	2,008	65	35	162	- 19,675	3,235	615	5	3,049	- 54	- 2,586	1,750	1,872	12,639	3,866	545



7.1.1.1.1

Figure C-1 Sediment Volume Mobilised during Two-Week Spill Period by Location

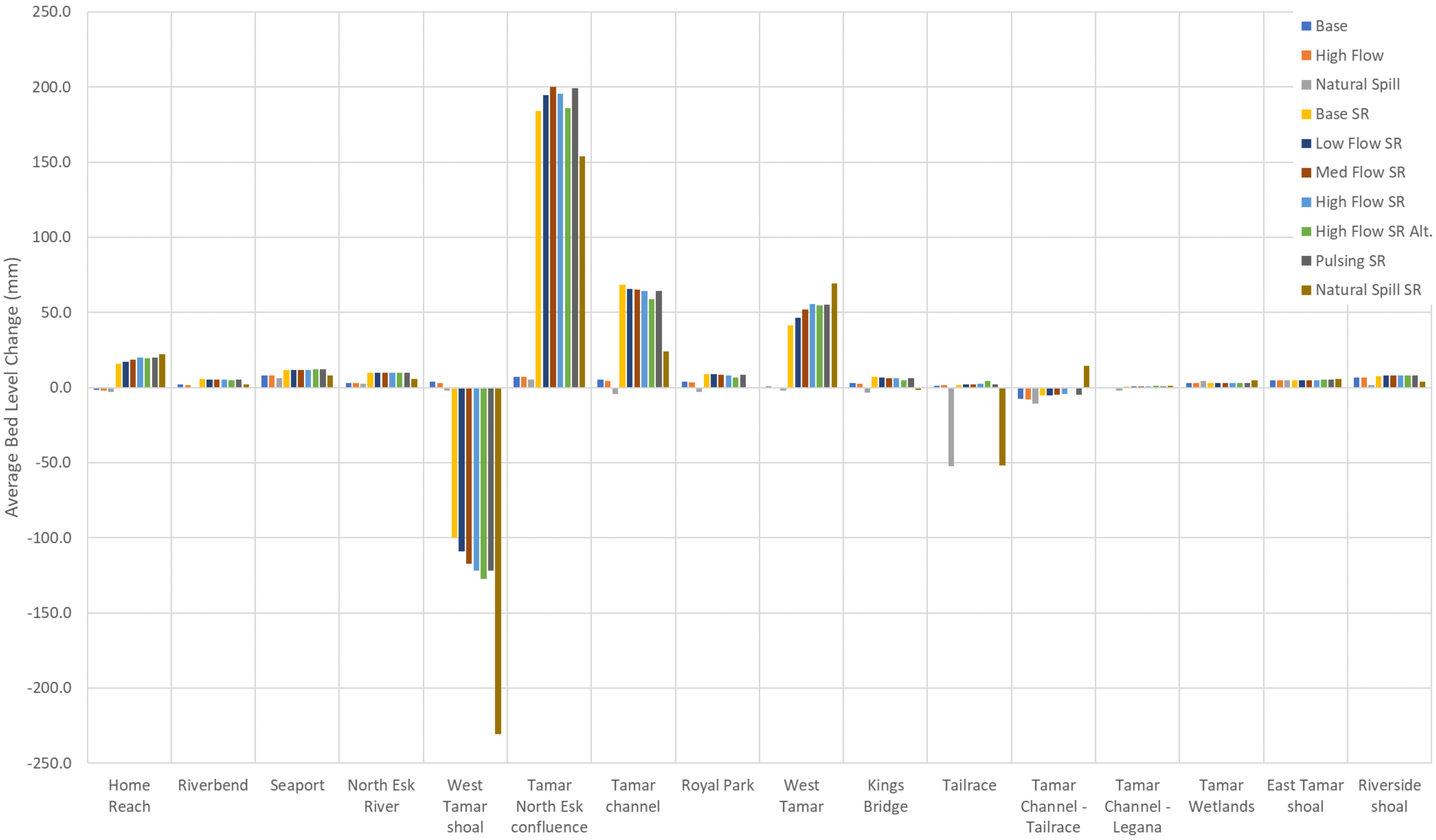


Figure C-2 Average Bed Level Change Due to Silt Mobilisation by Location (Volume/Location Area)

Appendix D Sediment Fate Maps

Maps of the immediate change to bed sediments over the two-week silt-raking and flow release period are shown for every scenario in Figure D-2 to Figure D-5, zoomed to Home Reach region. Additionally, maps of the downstream increase in sediments that were mobilised from within Home Reach over the same period are shown in Figure D-7 to Figure D-10.

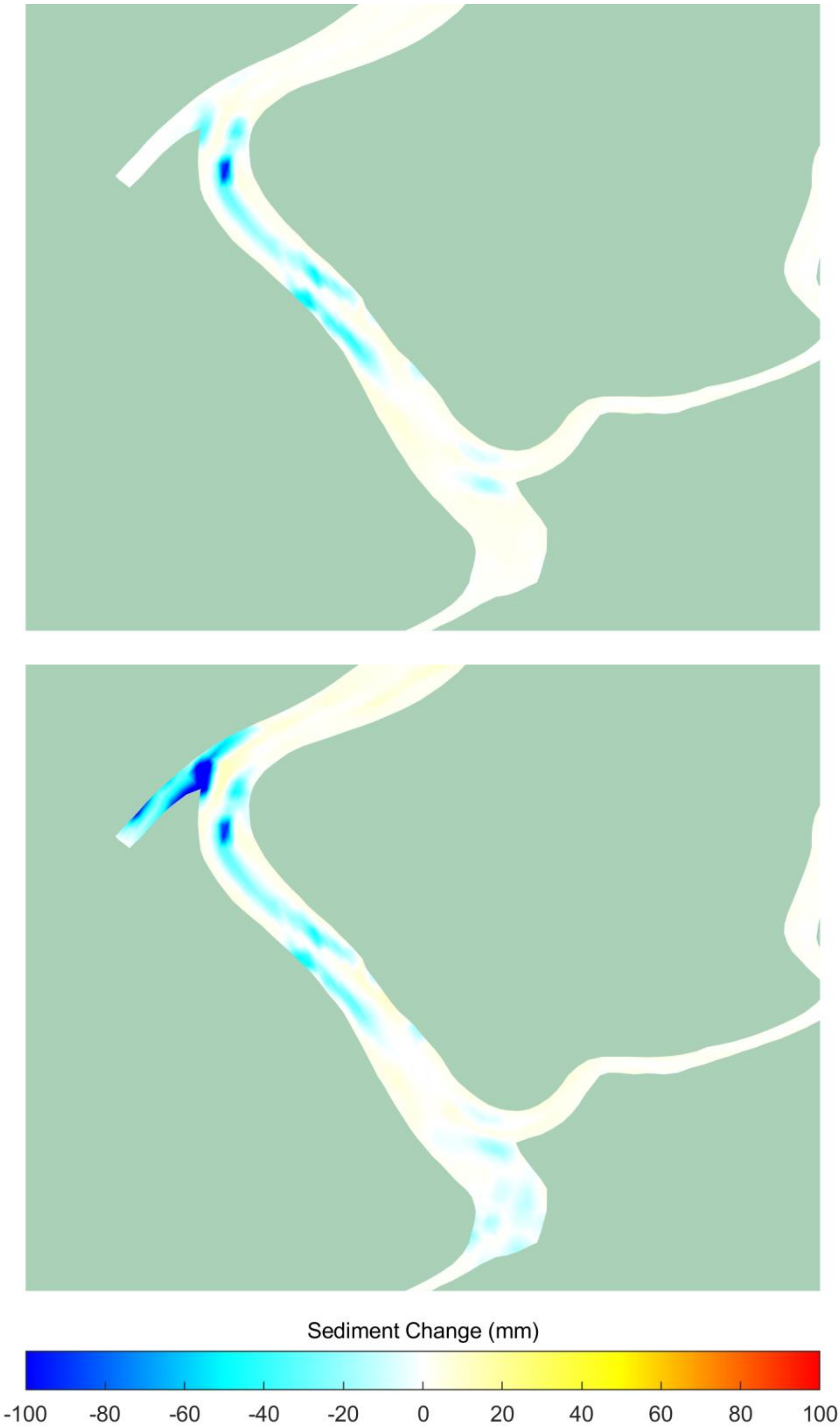


Figure D-1 Home Reach Bed Sediment Change over Two-week Silt-raking period, High Flows (SC1A, Top); and Natural Spill(SC5A, Bottom)

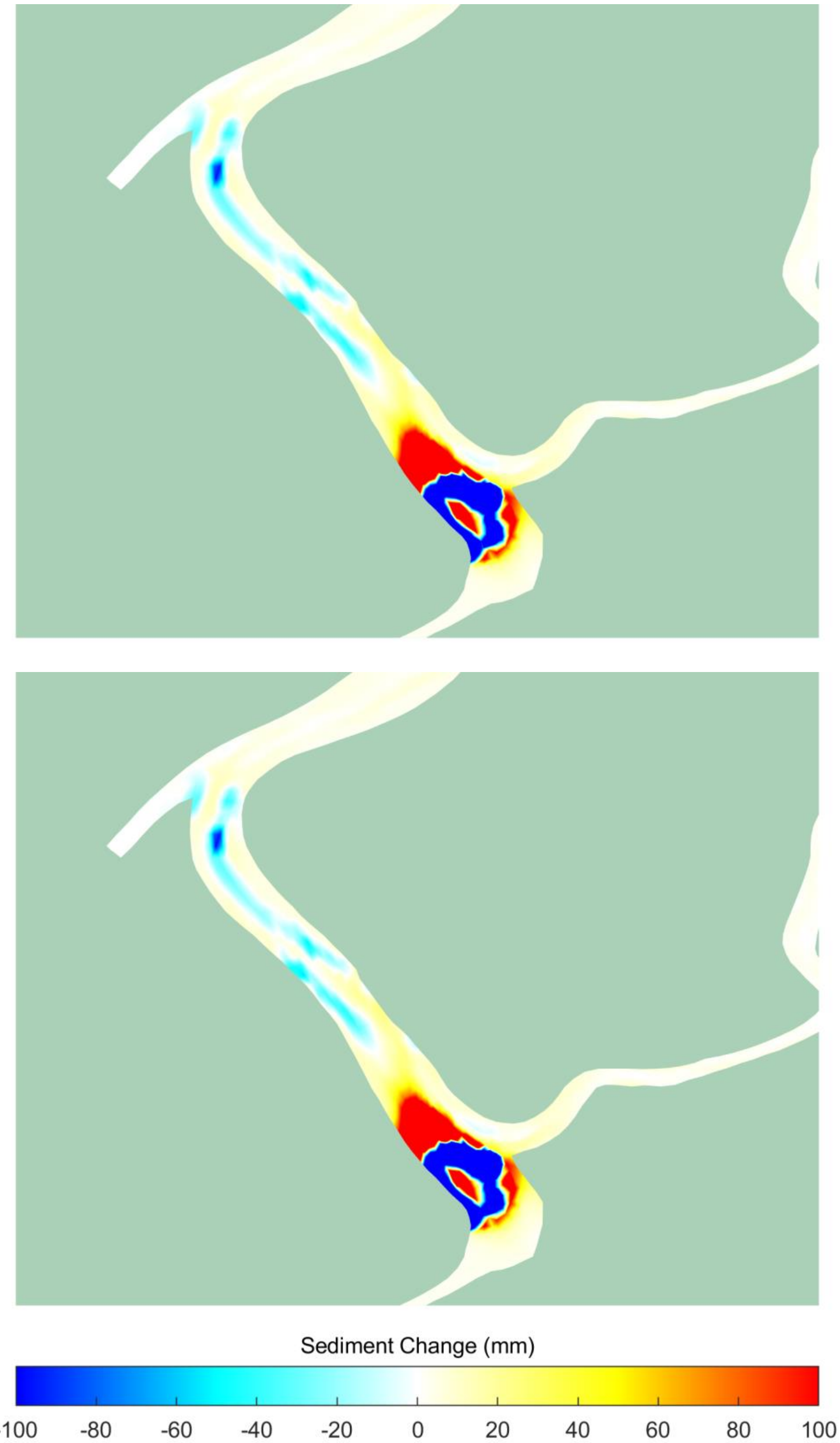


Figure D-2 Home Reach Bed Sediment Change over Two-week Silt-raking period, Base Case w/ Silt-Raking (SC0B, Top); and Low Flow w/ Silt-Raking (SC2B, Bottom)

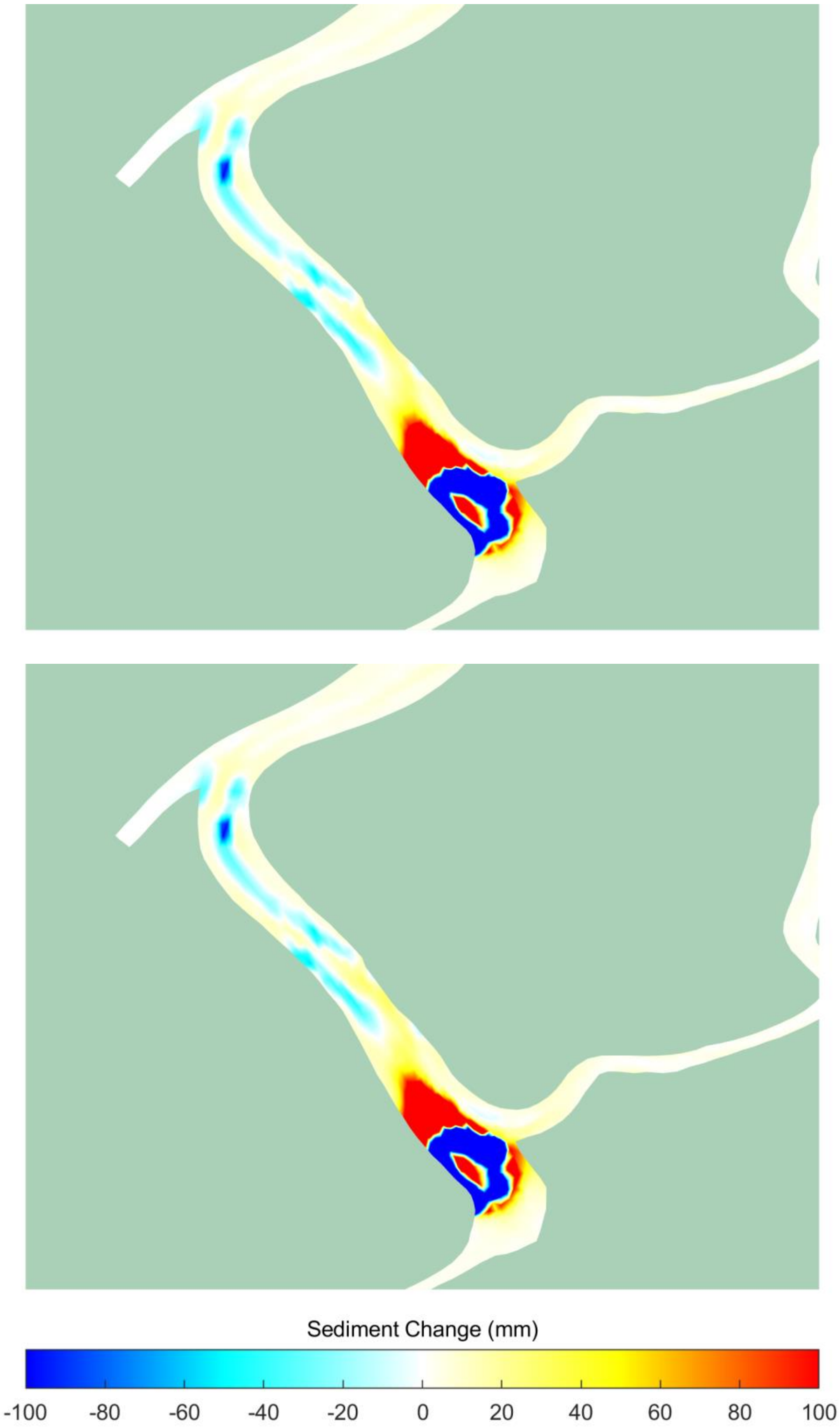


Figure D-3 Home Reach Bed Sediment Change over Two-week Silt-raking period, Medium Flow w/ Silt-Raking (SC3B, Top); and High Flow w/ Silt-Raking (SC1B, Bottom)

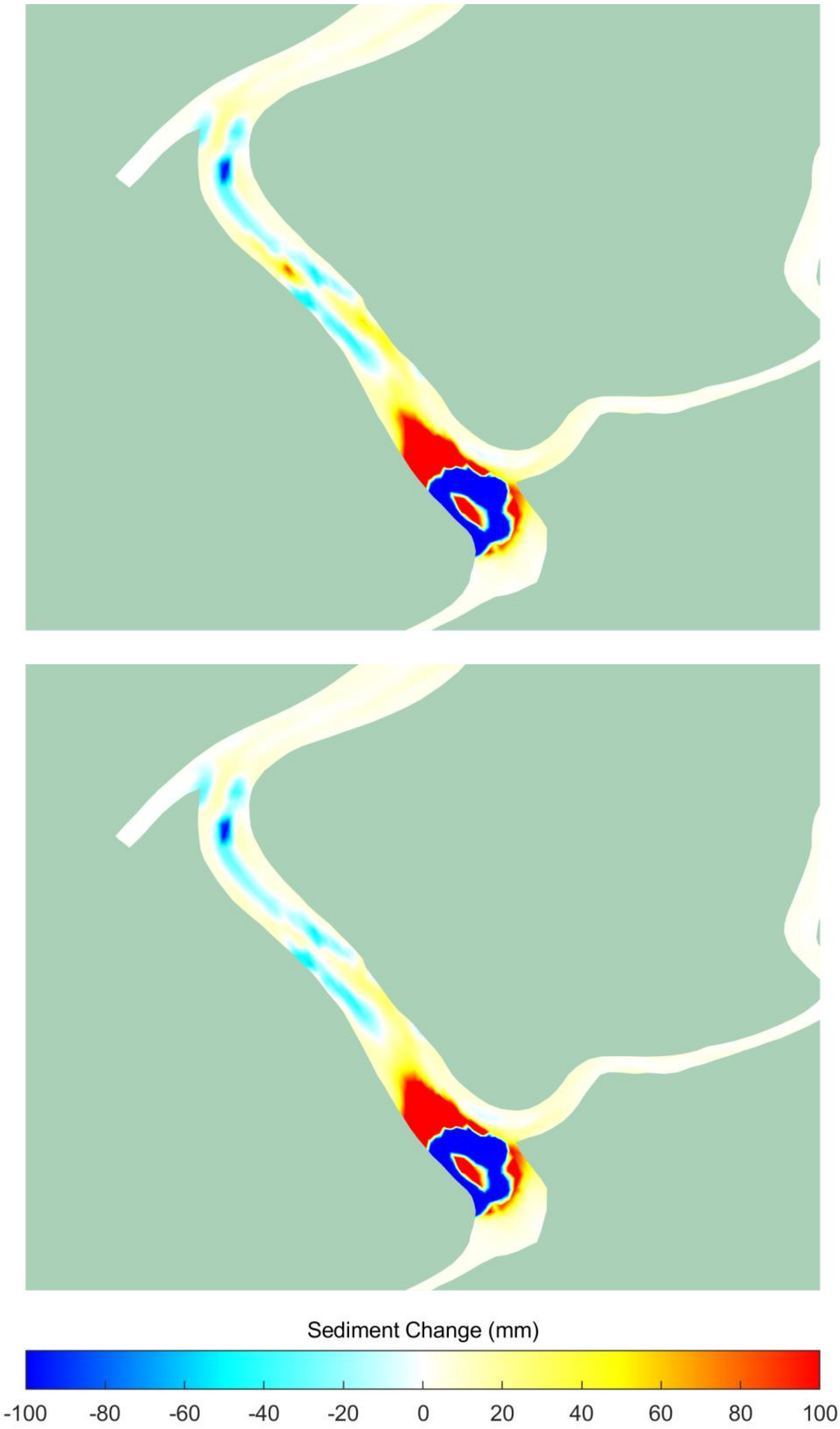


Figure D-4 Home Reach Bed Sediment Change over Two-week Silt-raking period, High Flow Alt. w/ Silt-Raking (SC1C, Top); Pulsing Flow w/ Silt-Raking (SC4B, Bottom)

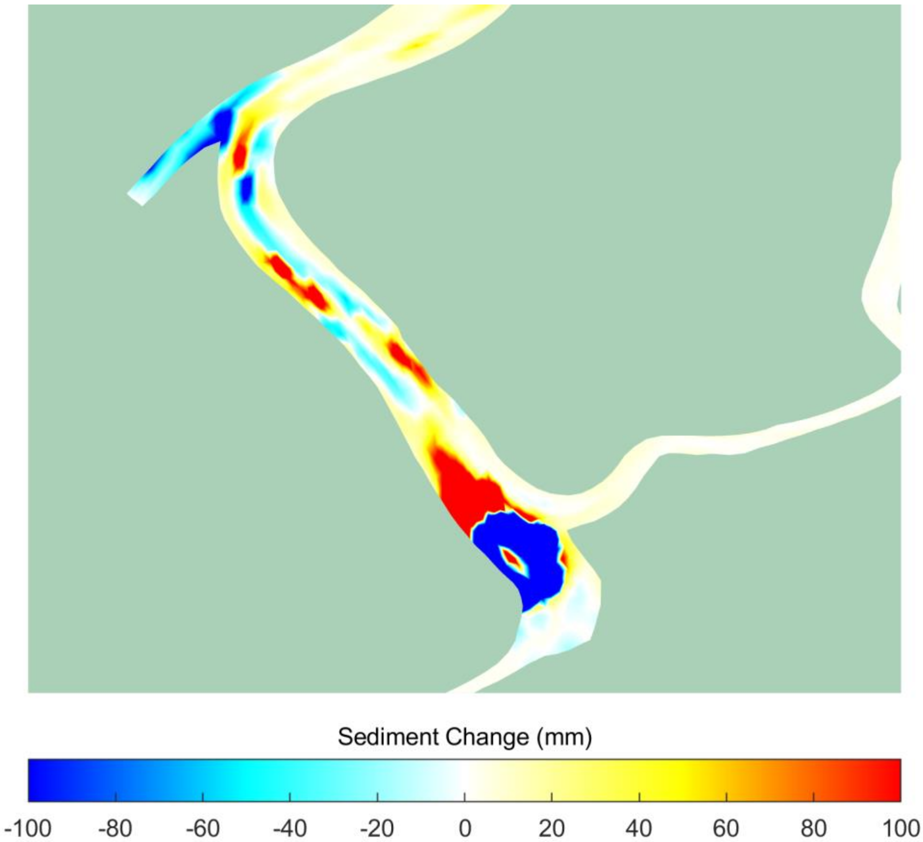


Figure D-5 Home Reach Bed Sediment Change over Two-week Silt-raking period, Natural Spill w/ Silt-Raking (SC5B)

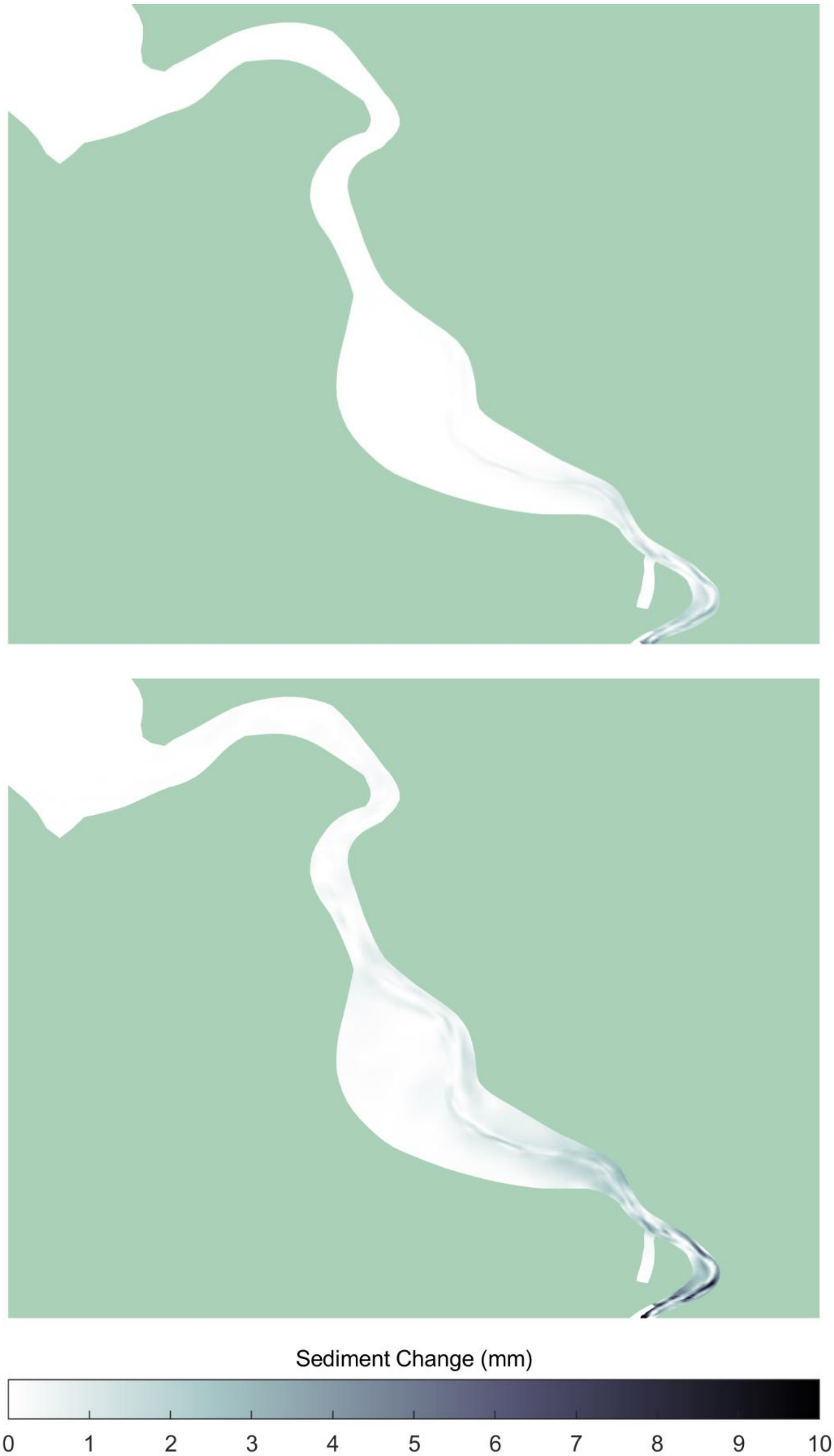


Figure D-6 Downstream Accretion of Mobilised Home Reach Sediments, High Flows (SC1A, Top); Natural Spill (SC5A, Bottom)

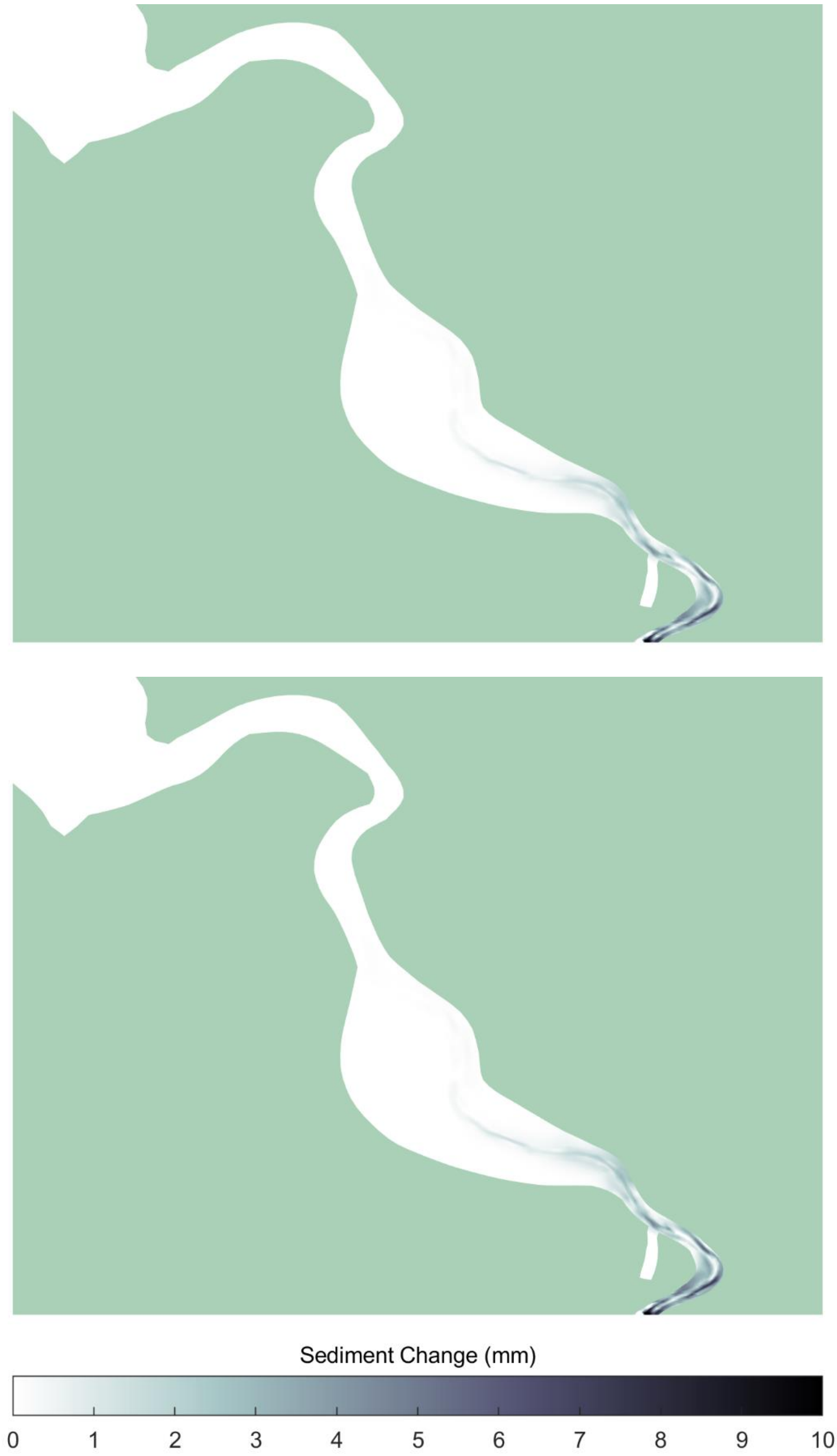


Figure D-7 Downstream Accretion of Mobilised Home Reach Sediments, Base Flows w/ Silt-Raking (SC0B, Top); Low Flow w/ Silt-Raking (SC2B, Bottom)

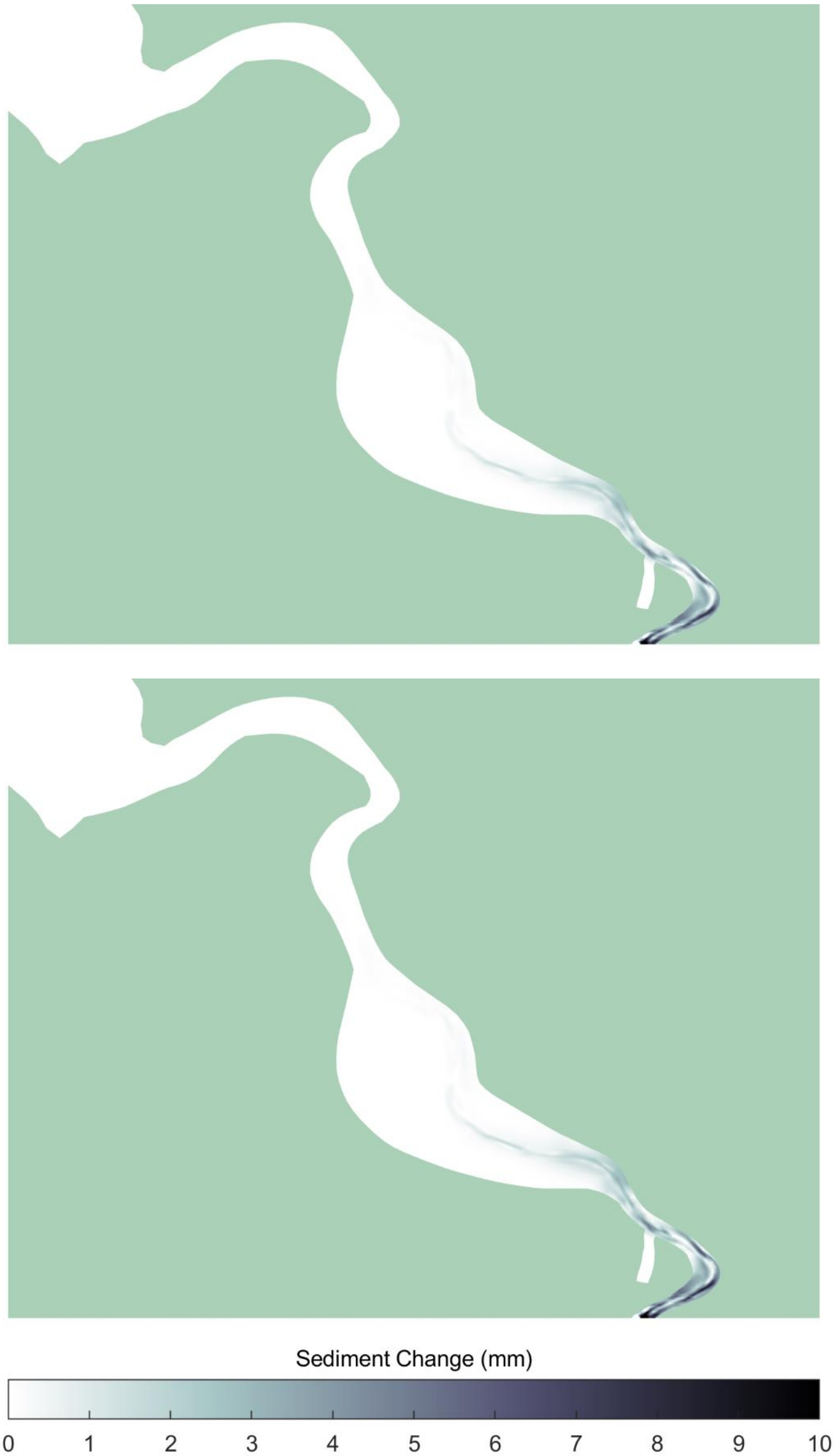


Figure D-8 Downstream Accretion of Mobilised Home Reach Sediments, Medium Flow w/ Silt-Raking (SC3B, Top); High Flow w/ Silt-Raking (SC1B, Bottom)

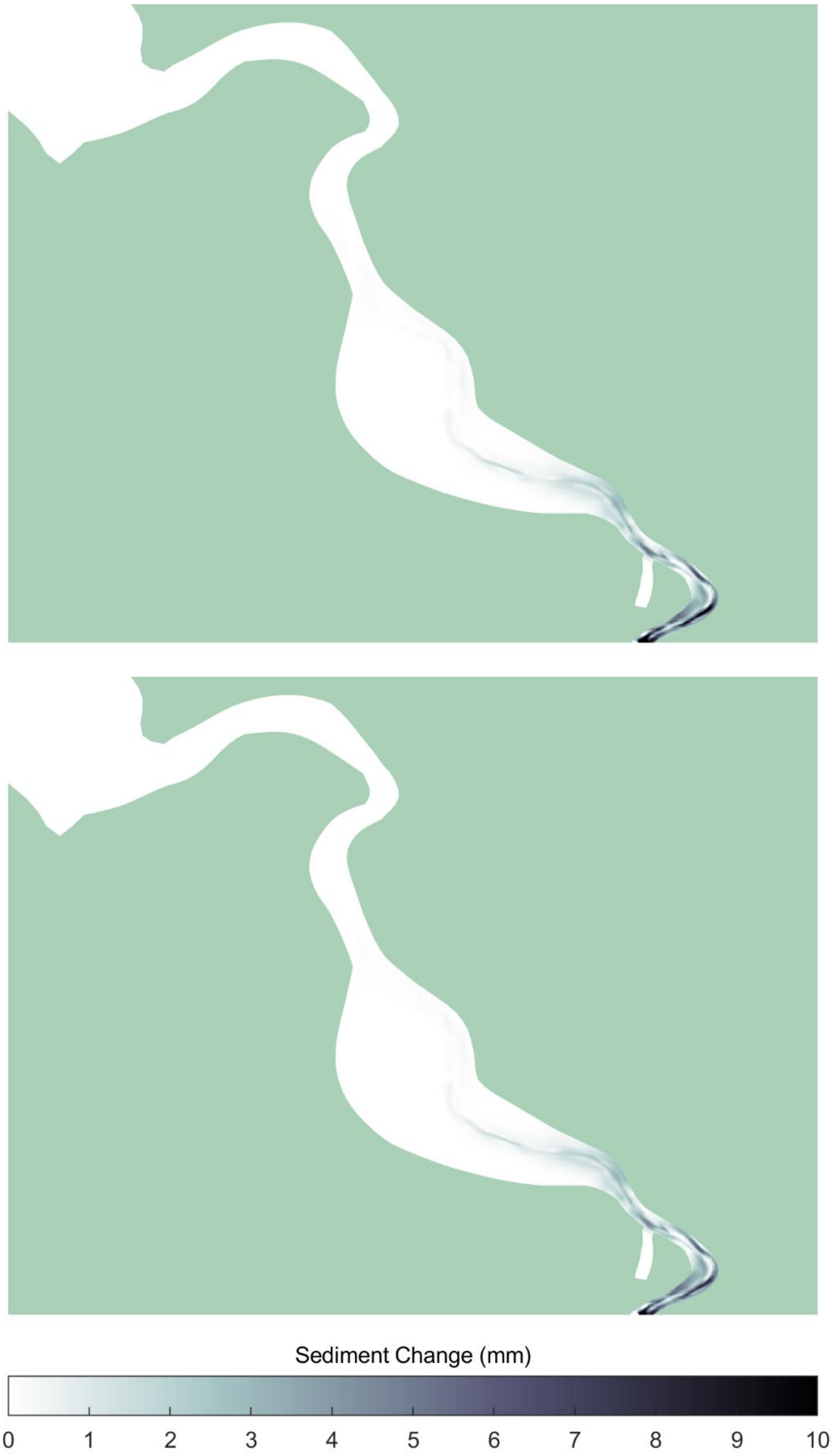


Figure D-9 Downstream Accretion of Mobilised Home Reach Sediments, High Flow Alt. w/ Silt-Raking (SC1C, Top); Pulsing Flow w/ Silt-Raking (SC4B)

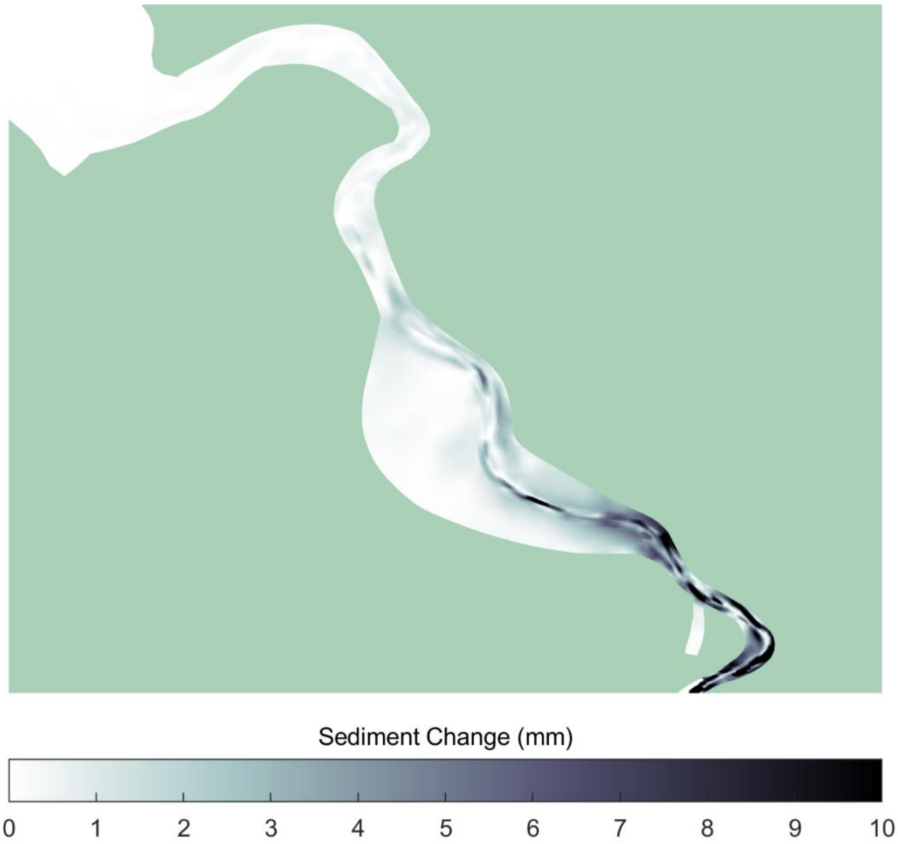


Figure D-10 Downstream Accretion of Mobilised Home Reach Sediments, Natural Spill w/ Silt-Raking (SC5B)

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