# kanamaluka/Tamar River Estuary Sediment Raking Program Review:

## Report to the Tasmanian Parks and Wildlife Service

September 2019

City of LAUNCESTON

## About this document

The purpose of this document is to present the findings of a review completed in compliance with Grant of Authority conditions. This report was prepared by City of Launceston on behalf of the Launceston Flood Authority (LFA) following the delegation of operational matters of the LFA to officers of the City of Launceston.

Detailed bathymetry and water quality data analysis was undertaken by Dr Rebecca Kelly. In order to define the scope of the project and the objectives against which sediment raking should be assessed, a working group was formed under the Tamar Estuary and Esk Rivers (TEER) Program's Scientific and Technical Committee (STC). This working group was tasked with scoping out the objectives, impacts of concern, identifying available data sets that could be used in the analysis, and reviewing the data analysis and report. Working group members included representatives from Institute for Marine and Antarctic Studies, Environment Protection Authority, Hydro Tasmania, City of Launceston, Petuna Seafoods, West Tamar Council and NRM North.

Dr Kelly's report was reviewed and endorsed by the TEER Program's Scientific and Technical Committee and the Strategic Partnerships Committee. It is referenced throughout this report, and is included in its entirety as Appendix 2.

| Revision No. | Date of Revision | Nature of Amendment | Document Author | Document Approved By |
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| Draft 1 | 31/07/2019 | | Kathryn Pugh | |
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| Final report | 23/9/2019 | Updated bathymetry information with data from final survey 13/9/19 | Kathryn Pugh | Shane Eberhardt |

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# Summary of Key Findings

In 2012 a project focusing on providing flood protection, functional waterway, amenity and aesthetic benefits through raking was commenced: The Tamar River Health and Wellbeing Improvement Pilot Project. This project led to the application for a Grant of Authority to undertake sediment raking trials.

The sediment raking zone in the upper estuary is located within the Tamar River Conservation Area, thus requiring a Reserve Activity Assessment (RAA). An RAA is an environmental impact assessment system used by the Tasmanian Parks and Wildlife Service (PWS) to assess whether activities proposed on PWS-managed land are environmentally, socially and economically acceptable.

A Grant of Authority to undertake sediment raking trials was granted by the PWS, in consultation with the EPA in September 2012. Sediment raking commenced on 19 September 2012 and continued for the duration of the spring tides that month, concluding on 2 October 2012. Subsequently, a 5-year Grant of Authority for sediment raking was issued to the Launceston Flood Authority (LFA). Upon expiry of the 5-year permit, a 12-month extension was granted to allow for sediment raking to continue while simultaneously conducting a review of the program.

Analysis of the raking logs and water quality data shows that there are a number of conditions within the Grant of Authority that were not complied with, particularly the duration of raking campaigns and the water quality monitoring requirements. Of the 41 raking campaigns, 18 exceeded the maximum 10 days' duration, and some raking campaigns were separated by less than a week. On some occasions, separate campaigns within the same month resulted in campaign durations exceeding 20 days. There is a paucity of water quality data collected during the 5-year permit period. There is no water quality monitoring associated with prop washing activities during the 5-year permit period; however, the available water quality data strongly indicates that raking activities have a substantial and long-lasting impact on water quality along the length of the estuary.

Sediment raking undertaken by the LFA in the upper reaches of the kanamaluka/Tamar River Estuary had three key performance indicators:

- Net loss of sediment measured by before and after bathymetric surveys;
- Improved visual amenity measured by net reduction of the tidal shoals at low tide; and
- Improved usability of the river, as reported by regular river users such as the rowing clubs and yacht club.

Sediment raking mobilises benthic sediments, suspending them in the water column, but it does not result in mass movement out of the upper estuary. Prior to the June 2016 flood, despite 223 days of raking, sediment volume in the Yacht Basin was only marginally lower than the maximum sediment volume prior to the commencement of raking. For all areas of the estuary, the lowest sediment volumes are observed several months after the June 2016 flood. Data from the program's final bathymetry survey (September 2019) shows that sediment volume is again approaching pre-raking levels.

Sediment raking and prop washing have resulted in short-term reduction of the extent of mudflats and shoals at low tide. For Seaport Marina in particular, this is an obvious outcome of the prop washing, with a clear and obvious change at low tide. Water depth over the West Tamar shoal, targeted during sediment raking has increased substantially at times due to the combined action of raking and significant riverine inflow, with water depths of up to 3m AHD achieved. Sediment raking and prop washing has achieved short-term improved visual amenity on the West Tamar Shoal and Seaport Marina.

Sediment raking has not achieved improved usability of the upper estuary. The raking program has resulted in substantial infilling of the navigation channels in the upper estuary and a redistribution of a large volume of sediment. The entrance to the North Esk River, Kings Wharf and the Yacht Basin are now all shallower than in February 2009 when sediment volume was at its highest. The navigation channel is now too shallow at low tide for boats to travel from the North Esk River to the Kings Bridge in the South Esk River. Redistribution of the sediment has resulted in changes to the location of the channels and shoals. There is now a large deposit of sediment on the inside bend of the North Esk-kanamaluka/Tamar confluence. Prop washing in Seaport Marina provides short-term improvements in navigational access to the marina, which requires constant maintenance, and is a trade-off with navigation access at the North Esk River confluence.

Results of the review indicate that sediment raking and prop washing have not achieved the primary goal of net loss of sediment from the upper estuary for the purposes of flood defence. The program has resulted in loss of navigational access, with flow-on impacts to commercial and recreational activities within the waterway. Raking and prop-washing has achieved short-term gains in visual amenity (loss of mudflats at low tide) at the West Tamar Shoal and Seaport Marina.

The estuary has significant natural values, including numerous threatened flora and fauna, migratory bird habitat, and a shark and ray nursery. The data demonstrate that the mobilisation of sediments in the water column has a long-lasting negative impact on water quality along the length of the estuary. While data does not exist to quantify the flow-on impact of degraded water quality on the Tamar River Conservation Area and the environmental values within it, it can be reasonably inferred that the ecosystem has been detrimentally affected by the raking and prop washing program.

The program has come at considerable social, financial and environmental cost, with long-term impacts on water quality and ecological health identified.

## Scope

In 2012 a project focusing on providing flood protection, functional waterway, amenity and aesthetic benefits through raking was commenced: The Tamar River Health and Wellbeing Improvement Pilot Project. This project led to the application for a Grant of Authority to undertake sediment raking trials, which was granted to the Launceston Flood Authority (LFA) by the Parks and Wildlife Service (PWS), in consultation with the Environment Protection Authority (EPA) in September 2012.

Sediment raking undertaken by the Launceston Flood Authority in the upper reaches of the kanamaluka/Tamar River Estuary had three key performance indicators:

- Net loss of sediment measured by before and after bathymetric surveys;
- Improved visual amenity measured by net reduction of the tidal shoals at low tide; and
- Improved usability of the river, as reported by regular river users such as the rowing clubs and yacht club.

This document presents the findings of a review completed in compliance with Condition 6 of the Grant of Authority to Undertake Works Associated with Sediment Raking Program within the Tamar Conservation Area issued by the Tasmanian Parks and Wildlife Service on 21 September 2018.

> *Condition 6:*
>
> *Ninety days prior to the expiry of this permit the Launceston Flood Authority must provide a review of data collected under the Sediment Raking Monitoring Plan that incorporates data collected under the granted permit between 20 May 2013 and 20 May 2018 and where practical data collected under this permit.*

The CoL/LFA formed a working group with members of NRM North's TEER Program to undertake the review of the data collected under the Sediment Raking Monitoring Plan: water quality monitoring and bathymetry data. The review also incorporated other relevant data sets including NRM North's Tamar Estuary and Esk Rivers (TEER) Program's Ecosystem Health Assessment Program (EHAP), City of Launceston (CoL) historic data and contemporary data collected for the Tamar Estuary Management Taskforce (TEMT) River Health Action Plan (RHAP) and available ecological data. Dr Rebecca Kelly of isNRM Pty Ltd was engaged to undertake the analysis of the water quality and bathymetry data.

Following on from submissions received during the community consultation conducted as part of development of the RHAP, the TEMT considered that there was merit in further analysis of potential releases from Trevallyn Pond to manage sedimentation in Zone 1 of the Tamar Estuary using the 3D hydrodynamic model. The results of the TEMT modelling project have also been incorporated into this review.

This report documents:

- values within the kanamaluka/Tamar River Estuary likely to be impacted by sediment raking;
- compliance with conditions in the Grant of Authority;
- the effect of flow regime on the effectiveness of sediment raking;
- the impact of sediment raking on water quality; and
- the effectiveness of sediment raking in regards to the three key performance indicators.

# Introduction

The kanamaluka/Tamar River Estuary is a drowned river valley that formed between 6,500 and 13,000 years ago when sea level rose around 60m to near its current level (Foster et al. 1986). The natural process for drowned river valleys is to infill and eventually become alluvial plains and deltas (Gunawardana and Locatelli 2008).

The main channel is quite deep in the lower estuary, reaching 45m in depth near Bryants Bay; however, upstream of Swan Point, the estuary is subject to rapid infilling by sediments and becomes very shallow near Launceston. Tidal mudflats border the main channel of the estuary throughout its length. The upper kanamaluka/Tamar River Estuary is characterised by deep, unconsolidated fine alluvial sediments. Particle size distribution analysis of dredged sediments indicates that the majority of the particles are within the clay and silt fractions (0.002 - 0.06mm).

The public generally associates the term estuary with the mouth of a river — the location where the river meets the sea. However, an estuary is more accurately defined as “a semi-enclosed or periodically closed coastal body of water in which the aquatic environment is affected by the physical and chemical characteristics of both fluvial drainage and marine systems” (Edgar et al. 1999), that is, the area where freshwater and marine waters mix. Tides carry marine waters from Bass Strait upstream into the kanamaluka/Tamar River Estuary as far upstream as St Leonards on the North Esk River and the Cataract Gorge on the South Esk River. In the summer months electrical conductivity (a measure of salinity) in the upper estuary exceeds 15,000us/cm; at this salinity the water is brackish and unsuitable for human or livestock consumption, or crop irrigation. Thus, the kanamaluka/Tamar River Estuary is formed at Launceston by the confluence of the South Esk and North Esk Rivers, some 70km upstream from the estuary mouth at Low Head. The kanamaluka/Tamar is one of the longest estuaries in Australia.

Estuaries are complex, dynamic environments with many interacting processes, and they vary both spatially and temporally (AMC Search 2015) and kanamaluka/Tamar River Estuary is no exception. There is a strong twice-daily oceanic tide from Bass Strait that is amplified up the estuary. This results in a “distortion” of the tidal curve in the upper estuary, and an asymmetric tidal curve (shorter flood tide with higher current velocities, prolonged period of high-water slack tide and an extended ebb tide with lower current velocities). This creates a net up-estuary residual current, which traps pollutants in the upper estuary. Substantial riverine inflows from the North and South Esk rivers are diverted upstream for urban and agricultural use and for the generation of hydroelectricity.

### Human-induced changes to the upper estuary

kanamaluka/Tamar River Estuary has a long history of human settlement, with many artefact scatters and cultural living places identified on the flood plains and tidal flats. The traditional owners of the country on the eastern margin of the Estuary and the area surrounding Launceston are the Letteremairrener people. The confluence of the rivers were also a meeting place, with the Panninher people from the Norfolk Plains and the Tyerrenotepanner people from the Northern Midlands known to frequent the Estuary. kanamaluka/Tamar River Estuary provided a rich food source of waterfowl, fish and shellfish (Breen and Summers 2006).

In some areas, the foreshore has changed dramatically since the early 1800s due to infilling, reclamation of tidal flats and wetlands, and altering the hydrological regime. This has altered the geomorphological processes governing the Estuary, including the alteration of sedimentation and erosion processes, and changes to the tidal prism. On the foreshore of Launceston, most of the Tamar Yacht Club, Royal Park and Seaport are constructed on reclaimed land (Figure 1).

At the time of European settlement in the early 1800s, the upper kanamaluka/Tamar River Estuary and the North Esk River featured extensive mudflats and wetlands, with channels that were difficult to navigate at low tide. One of Tasmania's largest ports was once based in the upper estuary at Launceston. Until the late 19$^{th}$ century, vessels mostly sailed with the high tides, with some dredging in the North Esk River between the Charles St and Victoria bridges. By the early 20$^{th}$ century, vessels were much larger, requiring more extensive dredging to provide adequate depth for the majority of the vessels. In the 1950s, shipping was increasingly containerised, bringing with it a change from inland ports to deep water ports at coastal transit point (Foster et al. 1986). The Port of Launceston was relocated to Bell Bay, at the mouth of the estuary, in 1967, and with the relocation dredging effectively ceased. Limited dredging between 1988-2007 removed sediment at an annual average of 42,420m$^3$ per year.

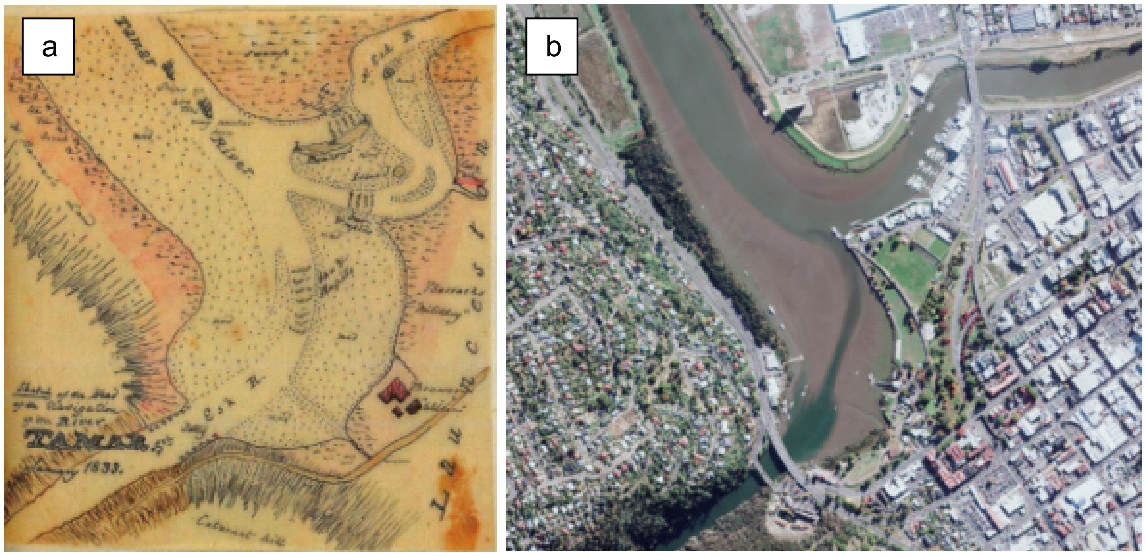

Figure 1: kanamaluka/Tamar River Estuary a) 1833 and b) 2016

After dredging ceased in the 1960s, it was still necessary to maintain adequate channel depths for the vessels using the upper estuary. Maintenance of these channels was achieved using targeted dredging and raking during times of significant tributary inflow, disturbing the silt in the navigation channels and allowing it to be transported downstream on the flood flow and assisted by the ebb tide (Edwards 1983). Tributary inflows of 850 cumecs (water velocity of 4-5 knots) was found to be the most effective in achieving significant results, however inflows of 420 cumecs (water velocity 3-4 knots) was considered sufficient to warrant raking where deepening was urgently required. Raking on the ebb tide with no tributary inflow was trialled but results were considered questionable. Despite the absence of precise bathymetry data to calculate the volume of sediment mobilised by raking, anecdotal evidence from the tug masters and other experienced operators, raking under favourable conditions increased the depth in the channels by approximately one metre (Edwards 1983).

The Launceston City Council maintained a small dredging program however, the upper estuary gradually reverted to similar conditions to those that existed prior to the turn of the 20th century; mudflats and channels in the upper reaches of the kanamaluka/Tamar River Estuary. Reports commissioned by the Launceston City Council in 2009 (BMT WBM 2009 and GHD 2009: Vol 1 and Vol 2) identified that there was no significant flood mitigation benefit derived from channel dredging (BMT WBM 2009), and that the overall economic benefits from commercial operations was minimal and provided limited justification for dredging expenditure.

The mudflats constricted the use of the river for some community events and commercial operators, and was considered visually unappealing to many in the community. The reforming of the mudflats coincided with renewed commercial and recreational development on the foreshore, such as the construction of a marina, rowing sheds and a restaurant precinct. Coupled with community concern regarding outputs from Launceston's ageing combined sewer and stormwater system, and speculation that the volume of sediment was reducing the efficacy of the flood protection scheme (levee system), there was increasing disquiet regarding the mudflats and calls for the estuary to be dredged again. Given the findings from the 2009 reports, in 2012 the Upper Tamar River Improvement Authority (UTRIA) commenced a project focusing on providing functional waterway, amenity and aesthetic benefits through raking. This project led to the application for a Grant of Authority to undertake sediment raking trials, which was granted to the Launceston Flood Authority by the Parks and Wildlife Service (PWS), in consultation with the Environment Protection Authority (EPA) in September 2012.

Investigations indicated that dredged material in sediment ponds activities had become acidic, and could not be used or disposed of without treatment. This is unsurprising given the nature of the benthic sediments and the known issues with acid sulfate soils in the upper estuary and associated swamps. Further, the material was considered contaminated waste, adding substantially to disposal fees. It was determined that dredging was no longer an economically viable option for the estuary. Sediment raking was proposed to replace dredging as a more cost-effective alternative method of sediment removal. Sediment raking is the agitation and suspension of benthic sediments using a modified scallop dredge towed behind a vessel. A second method of sediment mobilisation, prop washing, was also undertaken in areas inaccessible for the rake, although this methodology is not specifically mentioned in the permit documentation. Prop washing uses the boat propellers to agitate sediments in areas where the rake cannot get access e.g. Seaport Marina. If raking and/or prop washing are conducted on an out-going tide and during periods of high tributary inflow, resuspended sediments may be transported downstream. As sediments are not exposed to oxygen, the potential for developing acid sulfate soils (and the resultant environmental impact) is averted, and disposal fees for contaminated land avoided.

In summary, there are four distinct periods that can be identified in relation to sediment management in the upper estuary:

- 1804 -1890 - estuary in its natural state. Water depths were sufficient to meet the needs of ships then using the estuary.
- 1890 -1965 - continuous and increased dredging to meet the requirements of ever larger ships using the Port of Launceston. Tidal floodplains and wetlands infilled in the North Esk River and upper estuary; construction of flood levees.
- 1965 - 2012 major port facilities were shifted downstream to meet the requirement for larger container ships and the requirements for dredging were reduced. Minimal dredging and sediment raking was undertaken in the navigation channels.
- 2012 - 2019 - sediment raking and prop washing replaced dredging as a more cost-effective alternative method of sediment management. Intertidal mudflats also targeted during raking campaigns.

Nowadays, vessels using the upper estuary are primarily pleasure craft for recreation (sailing and rowing) and tourism, although several industrial waterfront users remain such as Southern Marine Shiplift, Seaport Marina and Tamar River Cruises.

## Natural values

The estuary supports a diverse range of ecosystems, including sponge gardens and a shark and ray nursery at the lower estuary, and important wetlands for bird habitat in the middle and upper reaches of the estuary. The diverse and productive ecosystem in the Tamar Estuary is characterised by a three to four metre tidal range and large freshwater inputs from the North Esk and South Esk rivers. The combination of a large sediment load from the catchment and strong tidal currents results in rapid sedimentation in the upper reaches of the estuary (Edgar et al. 1999).

### Topography

The topography of the Tamar catchment varies from low hills and plains characterised by agriculture in the Northern Midlands, to plateaus of the Western Tiers, Ben Lomond and Eastern Highlands. Together the Tamar and its tributaries drain a catchment area of more than 11,500 square kilometres (Edgar et al. 1999), or 15 per cent of the state of Tasmania, and span seven local government areas. At 214km, the South Esk River is the longest river in Tasmania. The South Esk basin, consisting of Macquarie, Brumbys Lake, Meander and South Esk catchments, is the main source of freshwater flows and sediments to the Tamar. At 98km, the North Esk River is considerably shorter.

### Tidal prism

The tidal prism is the amount of water that flows into and out of an estuary or bay with the flood and ebb of the tide, excluding any contribution from freshwater inflows. Freshwater flow diversions (extraction for town water supply, irrigation, industry and hydroelectricity) have substantially reduced the volume of freshwater entering the system over the past two centuries. Flows of up to 90 cumecs of water from the South Esk River pass through the Trevallyn Power Station, which discharges into the Tailrace at Riverside, bypassing the confluence of the South Esk and the kanamaluka/Tamar. Of the 90 cumecs, approximately 27 per cent consists of water diverted from the Great Lake via the Poatina Power Station. The statutory environmental flow requirement for the Trevallyn Power Station was set at 0.425 cumecs in 1955. In 2003 Hydro Tasmania voluntarily increased the daily flow to 1.5 cumecs, and to 2.5 cumecs in 2011, primarily to restore recreational and aesthetic values in the Cataract Gorge. The new valves installed in the dam in 2015 allow for easier releases of high flows (up to 20 cumecs) down the South Esk for recreational activities such as white-water kayaking events.

Over the past two centuries, many of Launceston's tidal wetlands have been drained or in-filled so that now very few contribute to the tidal prism; channel areas were also reclaimed (e.g. Royal Park and Seaport). Loss of tidal prism results in increased rates of sedimentation in the upper estuary, which causes further loss of tidal prism, setting up a positive feedback loop. Davis and Kidd (2012) estimate that the present volume of sediment above low tide is 135,000m$^3$, which equates to the loss of tidal prism due to estuary modification.

Regime equilibrium status is an important feature of stable tidal channels (GHD 2009 Vol 1). In general, the further an estuary is from equilibrium, the faster the rate of sediment return. An understanding of how altered bathymetry influences the sediment regime is therefore important for managing the upper estuary. Kidd (2016) predicts that without intervention, the intertidal flats would ultimately stabilise: accretion balanced by slumping of the banks in the channel and erosion under wind wave action.

## Sediment characteristics

The sediments of the upper estuary are highly likely to contain elevated concentrations of nutrients. Nitrogen is the primary nutrient that drives plant growth in most marine and estuarine systems, although phosphorus is also likely to be an important influence in the upper/fresher reaches (Derwent Estuary Program 2010). Large inputs of organic matter can stimulate bacterial production, resulting in low dissolved oxygen levels as the carbon is consumed. In addition to the public amenity concerns associated with eutrophic systems, such as algal blooms, fish kills and odours, low oxygen levels can have severe implications in terms of remobilizing heavy metals from sediments. Organic matter also has a strong affinity for metals, hydrocarbons and many other contaminants, and may transfer them from the water column through to the food chain or sequester them in sediments. Increased bioavailability of heavy metals in the kanamaluka/Tamar River Estuary could result in public health concerns for both recreational and commercial fisheries, as well as aquaculture.

Some habitats within the estuary are likely to be important for denitrification, particularly in areas of shallow water and wetland habitats. Habitats with high densities of macrophytes play a critical role in nutrient removal and cycling. Areas that have this capacity need to be identified and preserved, or created, to provide a critical service to the estuary.

Acid sulfate soil underlies much of the Tamar Estuary. These are natural soils that contain sulfides (mostly iron sulfides) formed by bacterial activity in underwater sediments over thousands of years. In an undisturbed and waterlogged state these soils are harmless, but when disturbed and exposed to oxygen through drainage or excavation, a process of oxidation can produce sulfuric acid in substantial quantities (DPIPWE 2009).

## Conservation reserves

There are 21 gazetted conservation areas in the kanamaluka/Tamar River estuary catchment, including the 4458ha Tamar River Conservation Area that includes the intertidal zone from St Leonards down to the Batman Bridge. In many areas the riparian strip has been cleared to the high-water mark, leaving no buffer zone between natural and modified land uses. Nevertheless, the Tamar River Conservation Area is a stronghold for coastal paperbark forest, *Melaleuca ericifolia*, a vegetation community listed as threatened under the *Nature Conservation Act 2000*. *Melaleuca ericifolia* swamp forest commonly occurs as narrow strips along the intertidal banks in the upper estuary. The conservation area also includes the Tamar Island Wetlands, which provide important habitat for many native plants and animals, and is a popular site for observing waterfowl.

The estuary has been identified by Birdlife Australia as a Key Biodiversity Area (KBA). To help conserve migratory waterbirds the Australian Government has entered a number of international bilateral migratory bird agreements with Japan (JAMBA), China (CAMBA), the Republic of Korea (ROKAMBA), the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention), the Ramsar Convention on Wetlands, the Agreement on the Conservation of Albatrosses and Petrels (ACAP) and through the East Asian - Australasian Flyway Partnership. These important agreements allow for the protected passage of migratory birds between the countries. The Tamar River Conservation Area hosts a number of birds listed on these agreements including crested tern (*Thalasseus bergii*, JAMBA), curlew sandpiper (*Calidris ferruginea*, JAMBA/CAMBA/ROKAMBA/Bonn), common greenshank (*Tringa nebularia*, JAMBA/CAMBA/ROKAMBA/Bonn) and the red-necked stint (*Calidris ruficollis* JAMBA/CAMBA/ROKAMBA/Bonn).

The sediment raking zone in the upper estuary overlaps with the Tamar River Conservation Area, the Key Biodiversity Area and the Shark Refuge Area.

## Conservation values dependent on the estuary

A total of 153 threatened species, listed under either the Tasmanian *Threatened Species Protection Act 1995* or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* are known to occur in the Tamar Valley (NVA 2019). Of these, 25 flora and seven fauna species are aquatic, semi-aquatic or riparian (Appendix 4). Five of these species have a stronghold in the upper valley around

Launceston, including creeping speedwell (*Veronica plebeia*) and swamp bindweed (*Calystegia sepium*), a plant thought to be extinct until 2001 (DPIWE 2005).

The Tamar Island Wetland Reserve is known habitat for a number of threatened fauna species, including both of Tasmania's threatened frogs: the green and gold frog (*Litoria raniformis*) and the striped marsh frog (*Limnodynastes peroni*). Drainage of wetlands for conversion for agriculture and/or housing, and habitat degradation and disturbance have been identified as a major threat to these amphibians. Some 60 species of birdlife are known to occur at the Tamar Island Wetlands, including several species of duck, black swans, egrets, cormorants and swamp harriers, as well as listed threatened species such as the white-bellied sea eagle (*Haliaeetus leucogaster*), and northern hemisphere migrants such as the common greenshank.

The Australian grayling (*Prototroctes maraena*) is known to migrate through the kanamaluka/Tamar River Estuary to reach spawning grounds in the lower reaches of the North Esk River. During the 2018/19 summer, 13 Australian grayling were identified in the North Esk River as part of a research program undertaken by the Arthur Rylah Institute (Victoria) who are assessing genetic diversity to understand the connectivity of fish populations and the links between flows in rivers and processes which help maintain genetic health. Recent research by Koster et al. (2013) indicates that downstream spawning migration of adult grayling is likely to occur with the onset of autumn rains (March - May) and upstream juvenile migration occurring from October to December, with peaks in mid-October and early November (W. Koster pers. comm. 2019). Inland Fisheries Service have confirmed grayling occur in the St Patricks River as far up the catchment as Nunamara in the 2016/17 and 2017/18 summer, and in the North Esk River at Burns Creek Road Bridge, Blessington (C. Bassano 2019, pers. comm. 26 June). The ecological requirements of threatened freshwater fishes are poorly understood, and there is a growing concern over the impact of human activities on native fish populations (Dawson and Koster 2018). Elevated turbidity in rivers can affect fish movement, predator avoidance, distribution/occurrence, feeding and growth. Australian grayling spawn in the lower fresh water reaches of rivers, and as the eggs and larvae then drift out to sea, elevated turbidity in these areas also has the potential to impact on hatching success and survival (W. Koster [Arthur Rylah Institute for Environmental Research] 2019 pers. comm. 9 January).

**Weeds**

Rice grass (*Spartina anglica*) was deliberately introduced to the Estuary in 1947 with the goal of stabilising mudflats, reclaiming intertidal lands and improving navigation. However, it spread uncontrolled throughout the estuary, and now represents Tasmania's largest infestation. Dense stands of rice grass inhibit access to the shoreline, and private boat ramp and jetties have become non-functional. In some areas, sandy beaches (e.g. Gravelly Beach) have been transformed into muddy rice grass meadows. The extensive rice grass meadows have changed the ecology of the intertidal zone, out-competing and displacing seagrass species and potentially changing fish and/or invertebrate community structure. Fish species such as flounder and flathead are unable to adapt to conditions in infested areas (Gunns Ltd 2006 in Aquenal Pty Ltd and Department of Environment, Parks, Heritage and the Arts 2008). Rice grass introduction has also affected native waterbird habitat, reducing the availability of foraging grounds, although it does provide nesting grounds and shelter for some native waterfowl (Blake and Cannell 2000) and may play a role in nutrient removal.

## Social values

It is beyond the scope of this report to provide a detailed analysis of the social values of the upper estuary and Esk rivers. As such, only a brief summary is provided below.

The confluence of the Esk rivers and kanamaluka/Tamar River Estuary is in the heart of Launceston. It is the site of many recreational activities for the residents and visitors of Launceston, and the waterfront provides a pedestrian link from the suburbs to the City and to Cataract Gorge. Recreational activities on the waterfront include walking, running and bike riding. Many parks, restaurants, memorial gardens and sporting facilities (bowls, rugby, sea scouts and Navy cadets, sailing and rowing) are part of this waterfront precinct. In 2019, the City of Launceston completed Riverbend Park at the mouth of the North Esk River. Linked to Seaport by a new pedestrian and cycling bridge, Riverbend Park is Launceston's newest, largest and best playground and recreation area. The all-abilities park includes more than 40 pieces of play equipment, barbecue facilities, a fenced toddler play area, the 'Sky Walk', a hard court, an events space and public amenities. Riverbend Park is divided into four zones: the 'River Play' area, the 'Gorge Play' area, the 'Wild Core' area, and the 'Urban Plaza' area, and draws inspiration from the natural beauty and cultural fabric of the Launceston's waterfront. Located on the waterfront, Riverbend Park is protected by Launceston's flood levees.

There is substantial community pressure from recreational water users to manage sediments in the upper estuary, particularly to maintain navigable water for rowing, sailing, boating and fishing.

The community associate mudflats with poor water quality, and perceive the removal of the mudflats as an improvement in the health of the waterway and reduce the risk of health implications when using the waterway for recreational activities such as rowing, yachting and fishing. Due to the historic dredging activities, there is now no living memory of the estuary in its natural state, and as such many in the community believe that the system is deteriorated, and that it needs to be 'fixed'. The many dozens of letters to the editor in the local newspaper for several decades are a testament to the strength of community opinion on this matter.

## Economic values

It is beyond the scope of this report to provide a detailed analysis of the economic values of the upper estuary and Esk rivers. As such, only a brief summary is provided below.

There is an inferred requirement for the LFA to undertake sediment management in the *Launceston Flood Authority Rules 2008*. The primary purpose of the LFA is to address flood risk to the 'flood risk area' within Launceston primarily though the construction and maintenance of flood levees and emergency management procedures. The LFA also manages flood risk by ensuring that the sediment does not accumulate in the upper estuary such that it impedes flow or puts unacceptable pressure on the levee system, reducing the protection level below a 1 in 200-year level of protection during a flood event by reducing the freeboard on the levees. Flood levees provide a direct economic benefit to the city by avoiding damages during floods; the levees saved the Launceston community an estimated $260 million during the June 2016 flood event.

Sedimentation in the navigations channels can directly impact economic activity, limiting the ability to navigate the upper estuary during low tide. Tourism and industrial businesses on Launceston's waterfront require navigable waters in order to operate. Sedimentation in the intertidal zone creates mudflats that are considered unsightly by some members of the community, and there is concern that this may negatively impact tourism, the waterfront restaurant precinct and marinas.

Downstream, the estuary provides significant economic value to the community through the tourism industry (e.g. the Tamar Valley Wine Route), aquaculture (salmon, abalone and seahorses), commercial fishing and industry at the Bell Bay Industrial Precinct.

## Grant of Authority Compliance

The sediment raking zone in the upper estuary is located within the Tamar River Conservation Area, thus requiring a Reserve Activity Assessment (RAA). An RAA is an environmental impact assessment system used by the Tasmanian Parks and Wildlife Service (PWS) to assess whether activities proposed on PWS-managed land are environmentally, socially and economically acceptable.

The 2008 Reserve Activity Assessment (RAA) identified that *"the activity of silt raking will have a detrimental impact on water quality for the period of the operation. It will increase turbidity, relocated sediment and could also introduce contaminants into the water. For these reasons, it is recommended that this activity be limited to 'one off' trial for a specified period and a monitoring program be established that establishes any impacts and recommended remediation actions required to mitigate these impacts."*

A Grant of Authority (hereafter the "permit") to undertake sediment raking trials was granted by the PWS, in consultation with the EPA in September 2012. Sediment raking commenced on 19 September 2012 and continued for the duration of the spring tides that month, concluding on 2 October 2012. Subsequently, a 5-year Grant of Authority for sediment raking was issued to the LFA. Upon expiry of the 5-year permit, a 12-month extension was granted to allow for sediment raking to continue while simultaneously conducting a review of the program.

Six Grants of Authority have been issued to the LFA:

- Level 1 RAA: Raking trial 21 September 2009 – 21 December 2009
- Raking trial: 19 September 2012 – 20 October 2012
- Raking: 20 May 2013 – 19 May 2018
  *This authority is subject to review of the Sediment Raking Monitoring Plan and Sediment Raking Scoping Document, operations and conditions following the first two years of operation and may be subject to further conditions and amendments at the discretion of the Director Parks and Wildlife Service and or Director EPA.*
- Raking: 8 – 22 August 2018
- Raking and preparation of review report: 22 September 2018 – 21 September 2019
- Submission of raking review report: 22 August 2019 - 27 September 2019

### Grant of Authority Conditions

Conditions 1, 2 and 3 of the 2013 permit, and condition 2 of the current permit, form the basis of this review.

2013 permit

*1. Prior to undertaking any sediment raking activities, a Sediment Raking Monitoring Plan (the Plan) must be submitted to the Director, EPA, for approval. The Plan must include, but not be limited to:*

*a. details of monitoring to assess the success of the sediment raking; and*

*b. details of a monitoring strategy to assess the potential impact on the receiving environment*

*2. Unless otherwise approved in writing by the Director EPA, the sediment raking must be implemented in accordance with the approved Sediment Raking Monitoring Plan.*

*3. All sediment raking works must be undertaken consistent with the Sediment Raking Scoping Document and Sediment Raking Monitoring Plan unless otherwise approved by the Parks and Wildlife Service*

Current permit

*2. The Launceston Flood Authority must provide a review of data collected under the Sediment Raking Monitoring Plan that incorporates data collected under the granted permit between 20 May 2013 and 20 May 2018 and where practical data collected under this permit. This review must be provided prior to the expiry of this permit*

The Sediment Raking Monitoring Plan is presented in Table 1 below; the Scoping Document is presented as Table 2. The Grants of Authority are attached in Appendix 1.

Table 1: 2013 Sediment Raking Trial Monitoring Plan

| | |
|---|---|
| **TIMING AND EXTENT:** | |
| | Refer Scoping Document |
| **MONITORING TO ASSESS THE SUCCESS OF SEDIMENT RAKING:** | |
| **Key Indicators:** | |
| **a.** | ***Volume of sediment removed.*** |
| | Bathymetric surveys will be conducted by LCC and volumetric assessment of sediment will be determined. Surveys will consist of historical cross sections from the Yacht Basin to north of Stephenson's Bend with full survey taken from the Yacht Basin to Kings Wharf. Bathymetric surveys will be undertaken at the following times: |
| | □ Prior to first raking campaign to establish baseline condition |
| | □ Following first raking campaign to assess volume of sediment removed |
| | □ Prior to second raking campaign to assess accumulation between campaigns |
| | □ Thereafter following each monthly campaign |
| **b.** | ***Location of Re-deposition.*** |
| | Passive Sampling shall be undertaken at four (4) locations as agreed with the EPA downstream of the raking. Each sampler shall have a collecting surface of 17,675mm$^2$ and shall be assessed for the following properties after a seven (7) day collection period during raking campaigns and during non-raking periods. Properties to be assessed are: |
| | □ Particle size of sediments deposited |
| | □ Total mass and settling rate |
| | Data collected will be compared with and used for calibration of the BMT WBM Hydraulic Model of the Tamar River estuary when the 3D version is available. |
| **WATER QUALITY MONITORING:** | |
| Water quality will be monitored for: | |
| Field: | Dissolved Oxygen, pH, conductivity |
| Analysis: | Total Nitrogen, Total Phosphorous, Ammonia, Metals, Dissolved Nitrate ($NO_3$) and Nitrite ($NO_2$) |
| Grab samples must be collected: | |
| | □ Upstream of the sediment raking, during each day, during the ebb tide |
| | □ Downstream during the raking where four (4) samples collected at 15 minute intervals shall be composited to form one sample. |
| The location and time of all samples taken must be recorded. | |

Table 2: Sediment raking scoping document

**2013 SILT RAKING TRIAL**
**SCOPING DOCUMENT**

| | |
|---|---|
| **SCOPE OF TRIAL:** | |
| Location: | In the North Esk River to the Charles Street Bridge, and extending north to 100 metres beyond the Tailrace junction in the Tamar River estuary, maintaining minimum 20 metre buffer to all riverbank edges. |
| Duration: | Monthly campaigns centred around the full moon tide or during flood events. Each campaign will rake for 10 days and or nights on each ebb tide. |
| Process: | Raking to occur at beginning of ebb tide utilising velocity from ebb tide flows of approximately 200 cumecs or greater. |
| Sampling & Monitoring: | Detailed in Monitoring Plan as approved by EPA. |
| **VESSEL DETAILS:** | |
| Owner/Captain: | Karl Krause<br>0428 573 076 |
| Vessel Name: | FV Karmin (2002) |
| Size: | 16m steel hull |
| Powered by: | 330 hp |
| Propeller dimensions: | 4.5/1 propeller reduction<br>52" diameter propeller<br>42.5" pitch |
| **RAKE DETAILS:** | |
| Weight: | 1.5 tonne |
| Dimensions: | 4.0m long x 2.0m wide |
| Raking Tines: | 1.0m tines (400 mm- effective rake depth) at 55mm centres |

## Grant of Authority Compliance

Analysis of the raking logs and water quality data shows that there are a number of conditions within the Grant of Authority that were not complied with (Table 3), particularly the duration of the raking campaigns and the water quality monitoring.

Condition 3 of the permit requires raking to be conducted in accordance with the Scoping Document (Table 2), with 10-day monthly campaigns specified in the Scoping Document. Of the 41 "campaigns" (defined as having consecutive days of raking with no breaks in between), 18 of them exceeded 10 days' duration (44%; Table 4). Some raking campaigns were separated by less than a week; on some occasions, separate campaigns within the same month resulted in campaign durations exceeding 20 days. The maximum number of raking on consecutive days was undertaken in July 2014 (25 days). Water quality data was collected on 7 of these 25 days. Two separate campaigns in 2017 (6 -20 Aug 2017 and 23 Aug - 3 Sept 2019) resulted in raking and prop-washing occurring on 27 days out of the 29 days. There was no water quality monitoring undertaken during either of these two campaigns.

There is a paucity of water quality data collected during the 5-year permit period, with monitoring completed on 10.4% of raking days. There is no water quality monitoring associated with prop washing activities during the 5-year permit period. The LFA wrote to the EPA on 7 May 2015 requesting consent to reduce, then cease, water quality monitoring. Condition 2 of the permit requires approval in writing to alter the monitoring plan. There is no reply on record from the EPA, nonetheless the LFA took the decision to cease monitoring. If the 107 days' raking in 2016-17 are taken in to account, water quality monitoring was still conducted on <15% of raking days.

All raking campaigns completed under the 12-month permit issued in 2018 were of <10 days' duration, and there was a maximum of 10 days' raking/prop-washing in any given calendar month (Table 4). Water quality data was collected on 36 of the 37 days when raking/prop-washing occurred.

Bathymetry surveys were completed regularly, and there is a large, robust dataset available for analysis of the sediment movement within the upper estuary. Early results indicated that undertaking bathymetry surveys too soon after raking confounded the results, as the sonar was unable to detect the difference between unconsolidated flocculated sediments in suspension and the sea bed (L. Cornwall, [City of Launceston Engineering Surveyor] pers. comm. 2019).

Table 3: Compliance summary

| Compliance condition | Criteria | Compliant? Y/N | Comment |
|---|---|---|---|
| Location | North Esk River to the Charles St Bridge and extending north to 100m beyond the Tailrace junction in the kanamaluka/Tamar River Estuary maintaining 20m buffer to all riverbank edges | No data | Accurate GPS track data unavailable. Excluding Seaport Marina, raking likely complied with this permit condition. |
| Duration | Monthly campaigns centred around the new moon tide or flood event | No | Prop washing generally not timed to coincide with new moon or flood. Raking often, but not always, coincided with elevated inflow (not necessarily flood events) or strong tides. |
| | Each campaign will rake for 10 days and or nights on each ebb tide. | No | 44% (18/41) of raking campaigns to June 2018 exceeded 10 days' duration. A number of campaigns separated by <10 days.<br><br>Refer to Table 4. |
| Process | Raking to occur at beginning of ebb tide | Yes | |
| Sampling & monitoring | | | |
| Bathymetric surveys | Bathymetric surveys to be undertaken:<br>• Prior to first raking campaign to establish baseline condition<br>• Following first raking campaign to assess volume of sediment removed<br>• Prior to second raking campaign to assess accumulation between campaigns<br>• Thereafter following each monthly campaign | No | Difficult to collect sensible sounding data if taken too close to the end of a raking campaign due to unconsolidated nature of the benthic sediments.<br><br>Bathymetric surveys conducted at least bi-monthly during raking period. Substantial data set for analysis. |
| Location of re-deposition | Passive sampling to be undertaken at 4 locations agreed with the EPA.<br><br>Samples to be assessed after a 7 day collection period during raking and non-raking periods for particle size, total mass and settling rate. | No | Some passive sampling undertaken in May 2013.<br><br>Total mass data available for raking and non-raking days, but no documentation on sample location or duration. |

| | | | |
|---|---|---|---|
| | A bulk sample collected from the area to be raked to be assessed for particle size, total mass and settling rate. | | |
| Water quality | Water quality will be monitored for:<br><br>Field data – dissolved oxygen, pH, conductivity<br><br>Analysis – total nitrogen, total phosphorus, ammonia, nitrate, nitrite and metals. | Yes | When water quality monitoring was conducted, all required parameters were measured. |
| | Grab samples must be collected:<br>• Upstream of the sediment raking, during each day, during the ebb tide<br>• Downstream during the raking where four (4) samples collected at 15 minute intervals shall be composited to form one sample. | No | Water quality monitoring completed on 42 days out of 402 days' (10.4%) raking/prop washing to June 2018. More than 80% of raking campaigns to June 2018 had zero days' water quality monitoring. There was no monitoring conducted in 2016 or 2017.<br><br>The LFA wrote to the EPA on 7 May 2015 requesting consent to reduce, then cease, water quality monitoring. Condition 2 of the permit requires approval in writing to alter the monitoring plan. There is no reply on record from the EPA, nonetheless the LFA took the decision to cease monitoring.<br><br>Refer to table 4. |
| | The location and time of all samples taken must be recorded. | No | Date and time data recorded, often sample location noted as "upstream" or "plume" with no other identifying data. No spatial data recorded. |

Table 4: Compliance summary - raking campaign duration and water quality monitoring

| | No. days raking/prop washing | No. campaigns | No. campaigns > 10 days duration | Campaigns >10 days duration | Mean campaign duration (days)* | Max campaign duration (days)* | No. days WQ monitoring | No. campaigns with 0 days WQ monitoring | Campaigns with 0 days WQ monitoring |
|---|---|---|---|---|---|---|---|---|---|
| Total | 439 | 49 | 18 | 37% | 8 ±6 | 25 | 78 | 34 | 69% |
| 5-years to June 2018 | 402 | 41 | 18 | 44% | 9 ±6 | 25 | 42 | 34 | 83% |
| 12-months to Sept 2019 | 37 | 8 | 0 | 0% | 5 ±3 | 9 | 36 | 0 | 0% |

# Results

## Bathymetry

Bathymetry data show that sediment raking mobilises benthic sediments but it does not result in mass movement out of the upper estuary.

Bathymetry surveys have been conducted in the upper estuary at regular intervals since 2008, with more than 70 bathymetry surveys completed during this time. Surveys were completed before and after raking campaigns, with the frequency of surveys dependent on river conditions and length of raking campaigns. For example, a bathymetry survey was conducted on 2 June 2016, immediately prior to the large flood event, and again on 18 June 2016 immediately after the flood had abated.

The bathymetry data has been used to calculate sediment volumes in defined zones in the upper estuary (Figure 2 and Figure 5) to monitor water depth (Figure 8) and create estuary cross sections (Figure 9 and Figure 10). The bathymetry data were supplied to Dr Kelly to undertake detailed analysis for the working group established under NRM North's TEER Program. Dr Kelly's full report is attached as Appendix 2.

Sediment volume in the Yacht Basin has varied substantially in the past decade, see-sawing between 263,950m$^3$ and 58,467m$^3$ (Figure 2). Sediment volume in 2008/09, during the Australian Millennium Drought, reached a peak of 263,950m$^3$, and had been following a slow upward trend, despite active dredging campaigns in 2008/09. Numerous flood events from September 2009 - September 2011 removed more than 115,000m$^3$ of sediment from the area. A number of drier years then followed, with few flow events >500cumecs and sediment volume rose sharply, back almost to where it was at the end of the Millennium Drought. Sediment raking then commenced after a short trial, and combined with elevated river inflows in 2013 sediment volumes dropped by more than 140,000m$^3$. However, despite on-going raking campaigns, sediment volume again rose sharply until it reached a peak of 260,000m$^3$ immediately prior to the June 2016 flood event despite 28 raking campaigns. The June 2016 flood, combined with elevated flows through to November 2016, saw sediment volume in the whole Yacht Basin fall to just under 60,000m$^3$ (Figure 2). In the intervening years, with no significant flood events, sediment volume has risen steadily; as of 13 September 2019 the volume in the Yacht Basin was back up to 182,766m$^3$. A similar pattern is observed in the Kings Wharf section of the estuary (Figure 3), however reduction in sediment volume in the Seaport Marina seems strongly dependent on prop-washing, with sediment volume only lower after prop-washing and trending upwards between prop-washing campaigns (Figure 4).

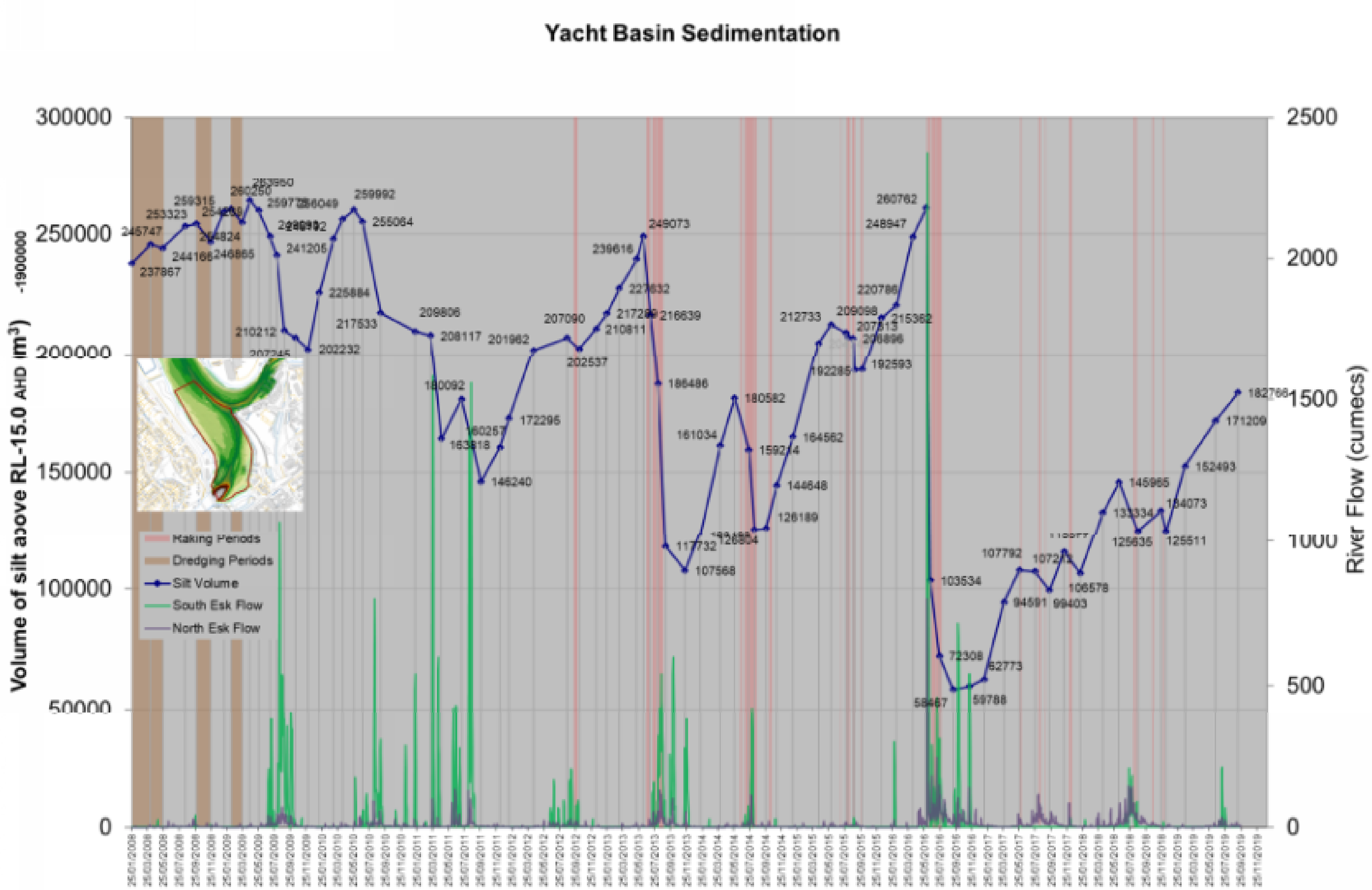


Figure 2: Sediment volume in the upper estuary: Yacht Basin

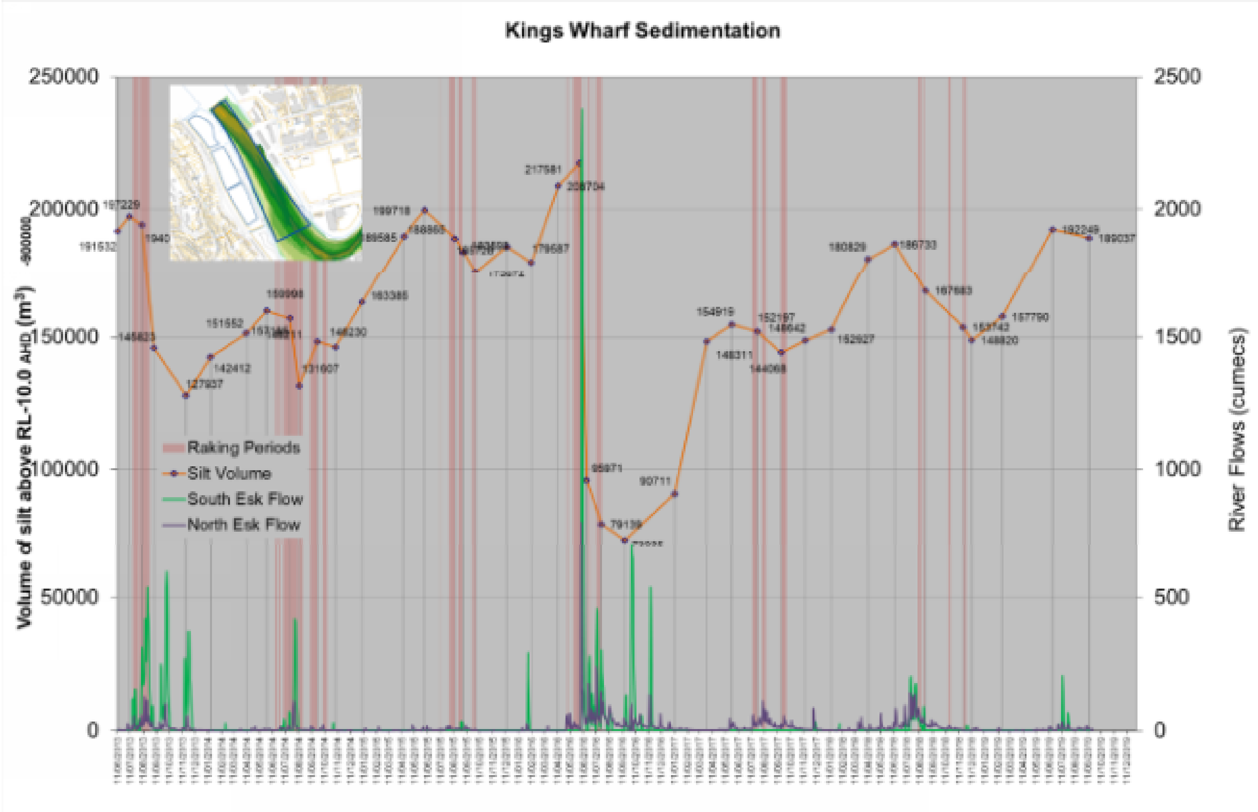


Figure 3: Sediment volume in the upper estuary: Kings Wharf

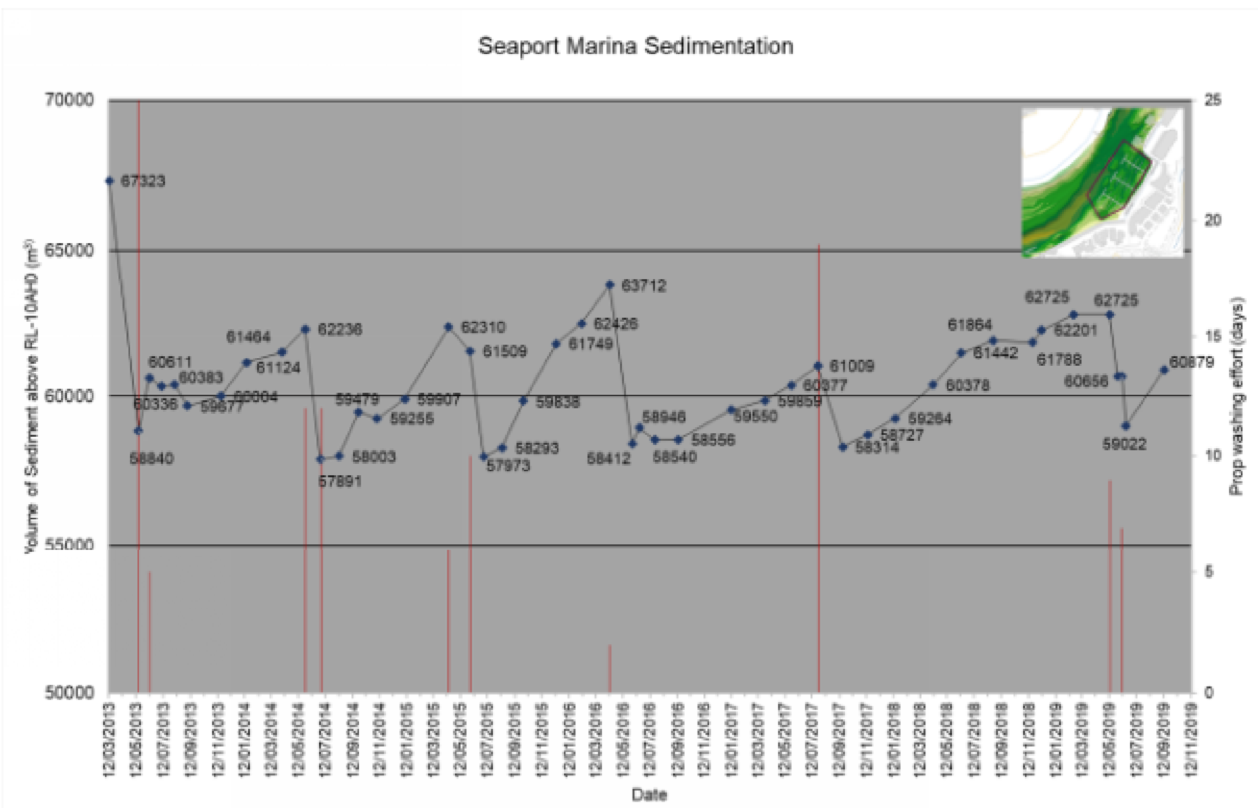


Figure 4: Sediment volume in the North Esk River: Seaport Marina

These volume calculations are based on large areas of the upper estuary, and contain areas of both deposition and scout (shoals and channels), and so can be somewhat misleading when attempting to understand the fate of mobilised sediments. For the purposes of this review, those broad areas were broken down into sections of channel and shoals, to better interrogate the data to determine the effectiveness of the raking program (Figure 5).


Figure 5: Estuary zones used to analyse raking effectiveness

The sediment volume calculations based on the zones presented in Figure 5 show that sediment raking results in a redistribution of the sediment - from the shoals into the channels. Data from the shoals are presented in Figure 6 and data from the channels are presented in Figure 7.

The data show that while sediment raking is successful in removing sediment from the shoals, with less sediment volume in these areas after raking, the opposite is true for the channels. Silt raking appears to have led to significant decreases in sediment levels in the West Tamar Shoal (Zone 3), key to achieving aesthetic objectives relating to the visibility of sediment banks around Launceston (Kelly 2019). North Bank also appears to have reduced sediment levels with the advent of silt raking though these are not sustained, with sediment levels increasing through the period before and then again after the 2016 flood to levels similar to before raking commenced (noting that sparse data pre-raking makes this result less certain than was the case for the West Bank) (Kelly 2019). The large West Tamar shoal was particularly targeted during raking campaigns, due to the large volume of sediment in this area, and the sediment volume in this area is substantially lower than before raking. During periods without a combination of significant flow and silt raking, sediment returns rapidly to the West Bank. Silt raking alone (with low flows) does not appear to lead to a sustained lower sediment level in the West Bank (in Zones 3 or 6; Kelly 2019). The major flood event in 2016 coupled with silt raking led to a large and rapid decrease in silt levels in the Upper West Bank section (3) however sediment has been steadily returning to this section of the estuary despite continued silt raking efforts. Sediment levels also increased in the Lower West Bank (6) but appear to have stabilised at a level well below the period before silt raking. By contrast sediment levels in the North Bank (7) have increased to greater than any of the values from silt raking before the flood, indicating that any aesthetic benefits of silt raking in this section of the estuary have not been sustained (Kelly 2019).

Sediment levels in the Royal Park mudflat (Zone 1) initially decreased with the commencement of silt raking but increased to levels higher than pre-silt raking during the period before the 2016 flood in spite of continued silt raking efforts (Kelly 2019). Silt raking without flows appears to lead to little immediate effect on sediment levels in the Royal Park section, with levels rapidly returning to levels similar or higher than before the silt raking took place. The 2016 flood and associated silt raking led to large decreases in sediment levels around Royal Park, however sediment has been steadily returning to this section of the estuary despite subsequent silt raking campaigns in the period since (Kelly 2019).

The data show that the early raking campaigns conducted during periods of high flow resulted in a reduction in sediment volume in the channels; when raking is conducted without the high flow events, there is an increase in sediment volume in these areas (Figure 7). Zone 4, at the confluence of the kanamaluka/Tamar River estuary and the North Esk River is the worst affected, with substantially more sediment in this section since the commencement of raking (Figure 7). The major flood event in June 2016 was insufficient to restore this section of channel to pre-raking volumes. The data also indicate that prior to the commencement of raking, high flow events were efficient at removing sediment from the channels. This increased sediment volume translates to a loss of channel depth (Figure 9 and Figure 10), resulting in difficulty navigating the upper estuary at mid-low tide.

In February 2009, when sediment volume in the upper estuary was at its highest, the main channel at the confluence of the North Esk River had a depth of 6.4m (datum); prior to the June 2016 flood the channel was only 4.7m deep, a loss of 1.7m. The June 2016 flood increased the depth by 0.3m (refer to cross-section 12 in Figure 10). In the Yacht Basin, the channel was approximately 4.2 m deep and 40m wide in 2009 while the mudflats were approximately 1.5m deep (refer to cross-section 27 in Figure 10. Prior to the June 2016 flood, the channel had lost around 0.5m of depth and 10m width; the mudflats were 0.5m deeper. Immediately following the June 2016 floods and an active raking campaign, the channel had been deepened to between 3.5-4.2m and was now some 70m wide. By May 2019, significant infilling had occurred and the channel in this section was 3.8m deep and approximately 30m wide.

Data for the Lower Channel (Zone 5) is sparser pre-raking than for the other channel sections but suggest that even immediately after the 2016 flood, sediment levels were higher than after much smaller high flow periods before the commencement of silt raking, indicative of infilling of the channel (Kelly 2019). Changes in the channel are likely to mean that access to the Southern Marine Shiplift and Home Point pontoon is more difficult now than it was before silt raking commenced, and that navigation in the channel itself may be compromised. It is not clear whether this process of infilling has finished or the time scale over which this process might cease even if silt raking were to cease today (Kelly 2019). It is possible that unconsolidated sediments may continue to be pushed upstream for some time and settle in the channel rather than in shoals adjacent to the bank (Kelly 2019).

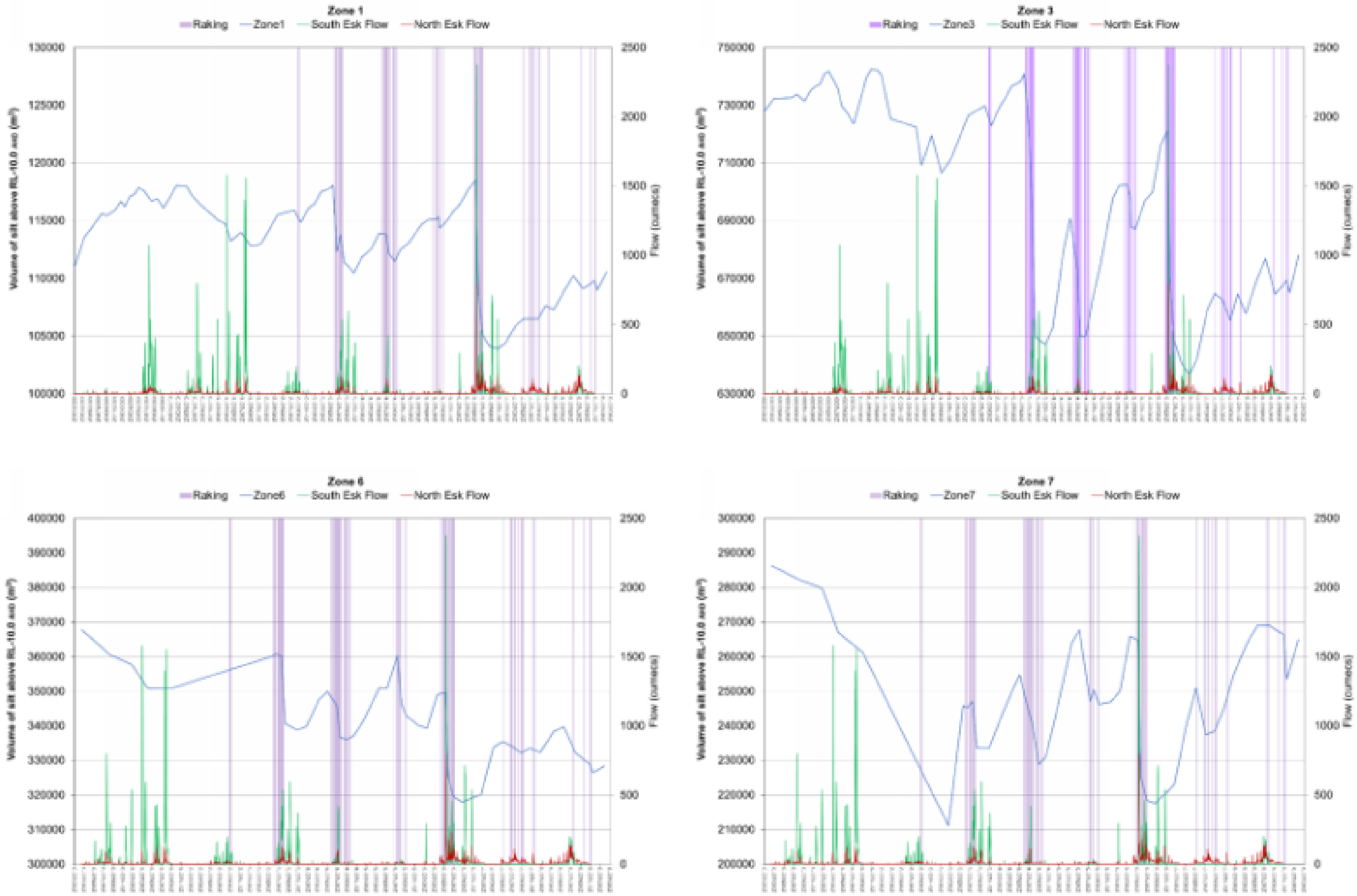


Figure 6: Sediment volume in the upper estuary shoals

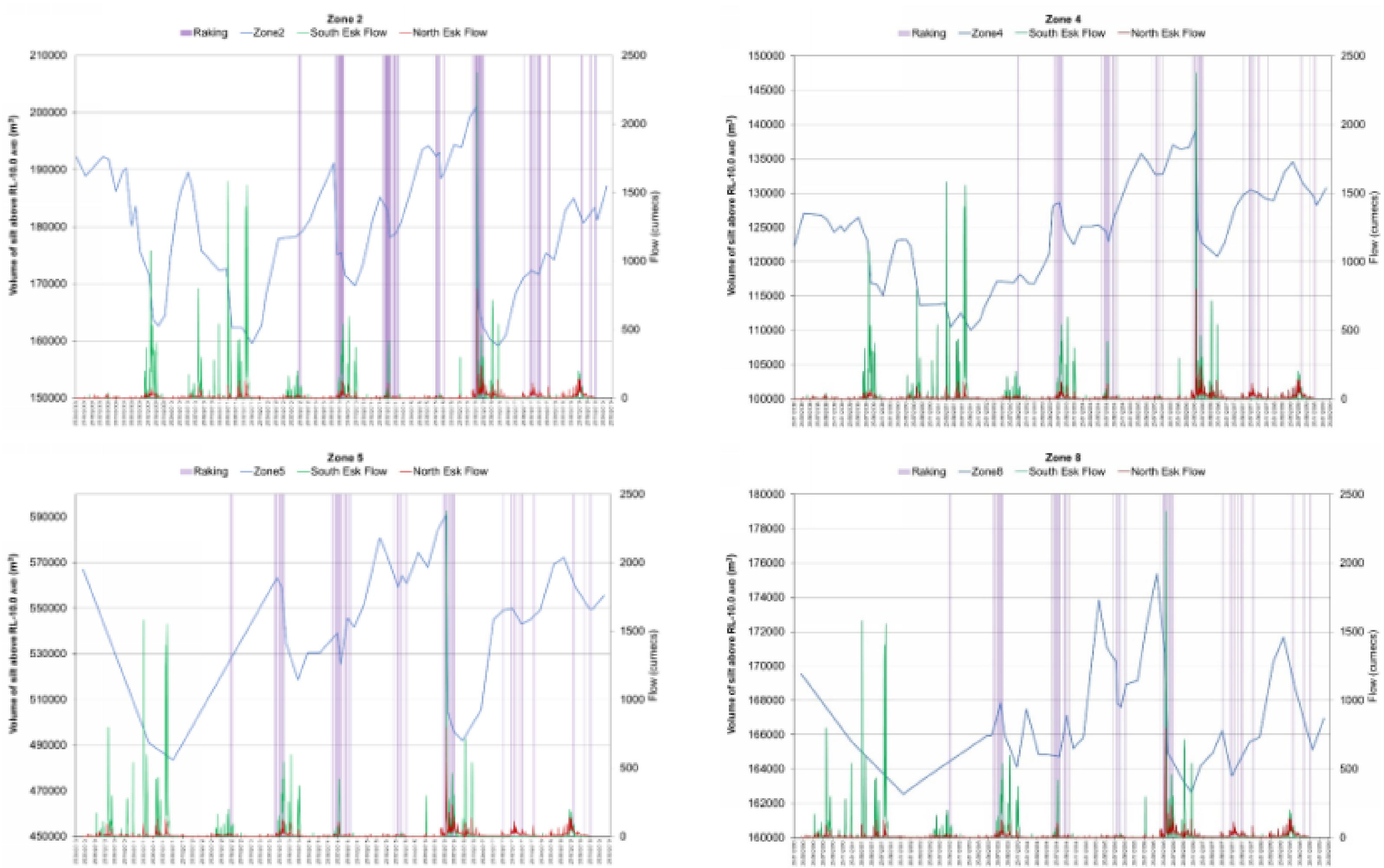


Figure 7: Sediment volume in the North Esk River and upper estuary channels

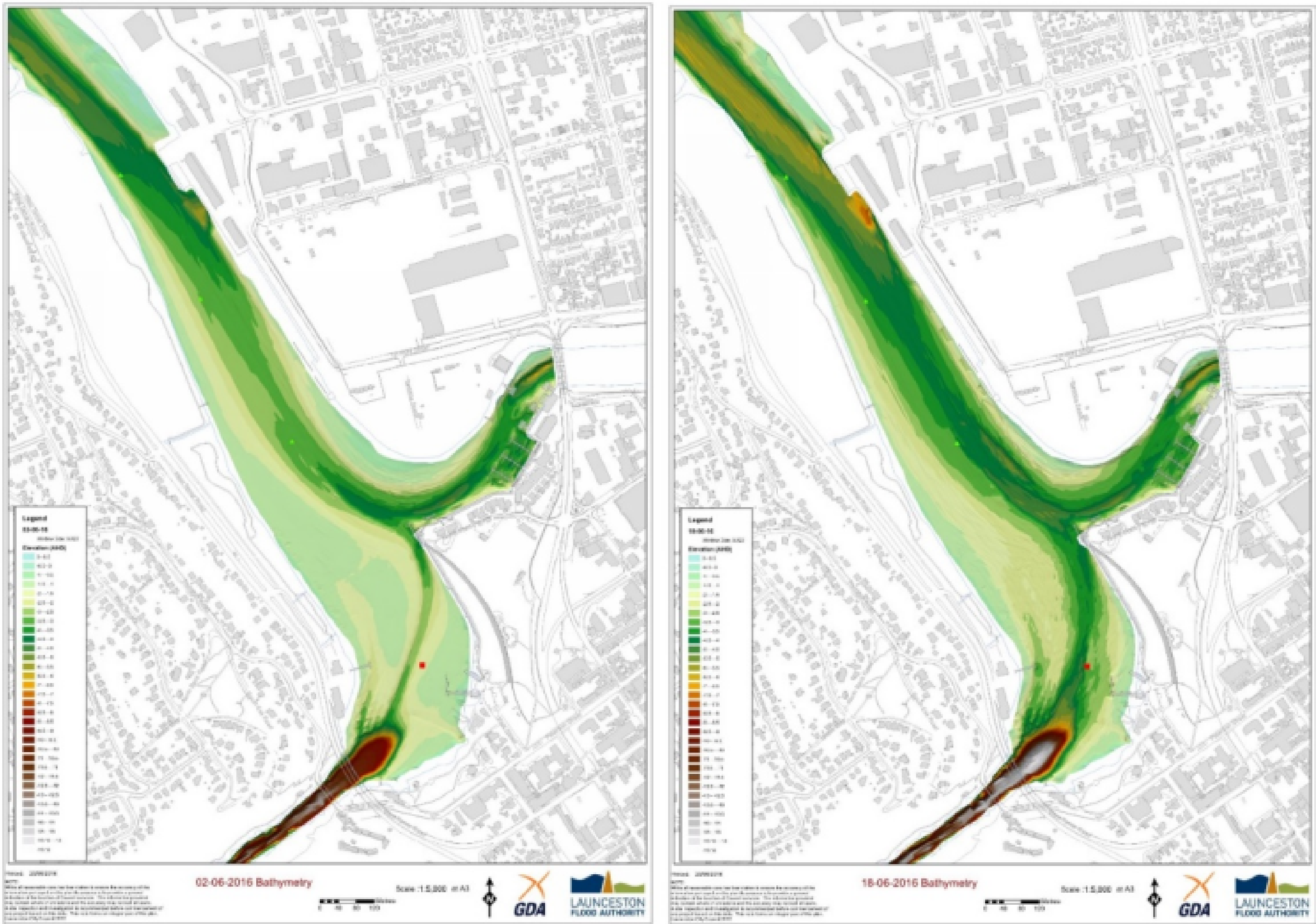


Figure 8: Example bathymetry charts: 2 June 2016 and 18 June 2016

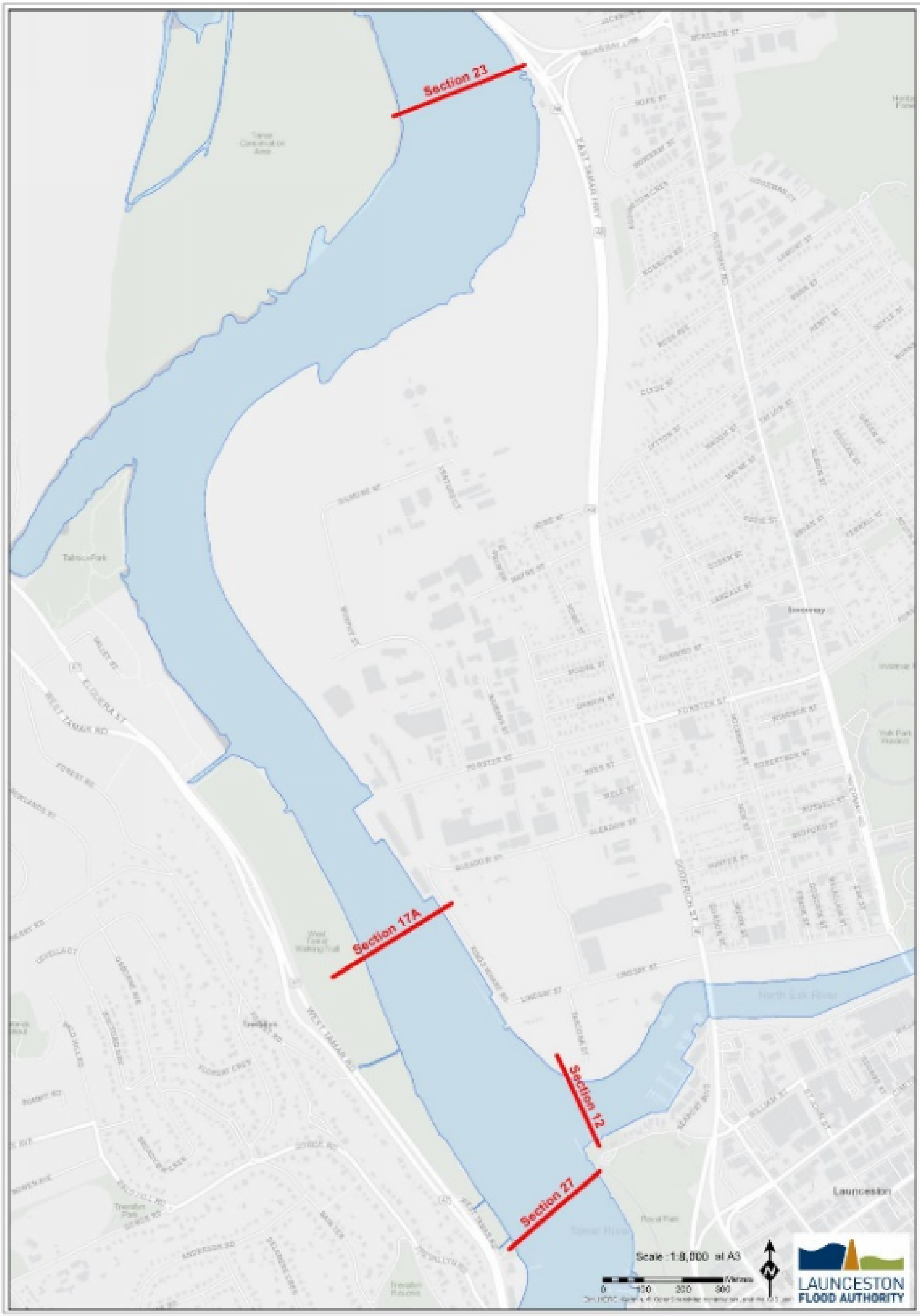


Figure 9: Estuary cross-section locations

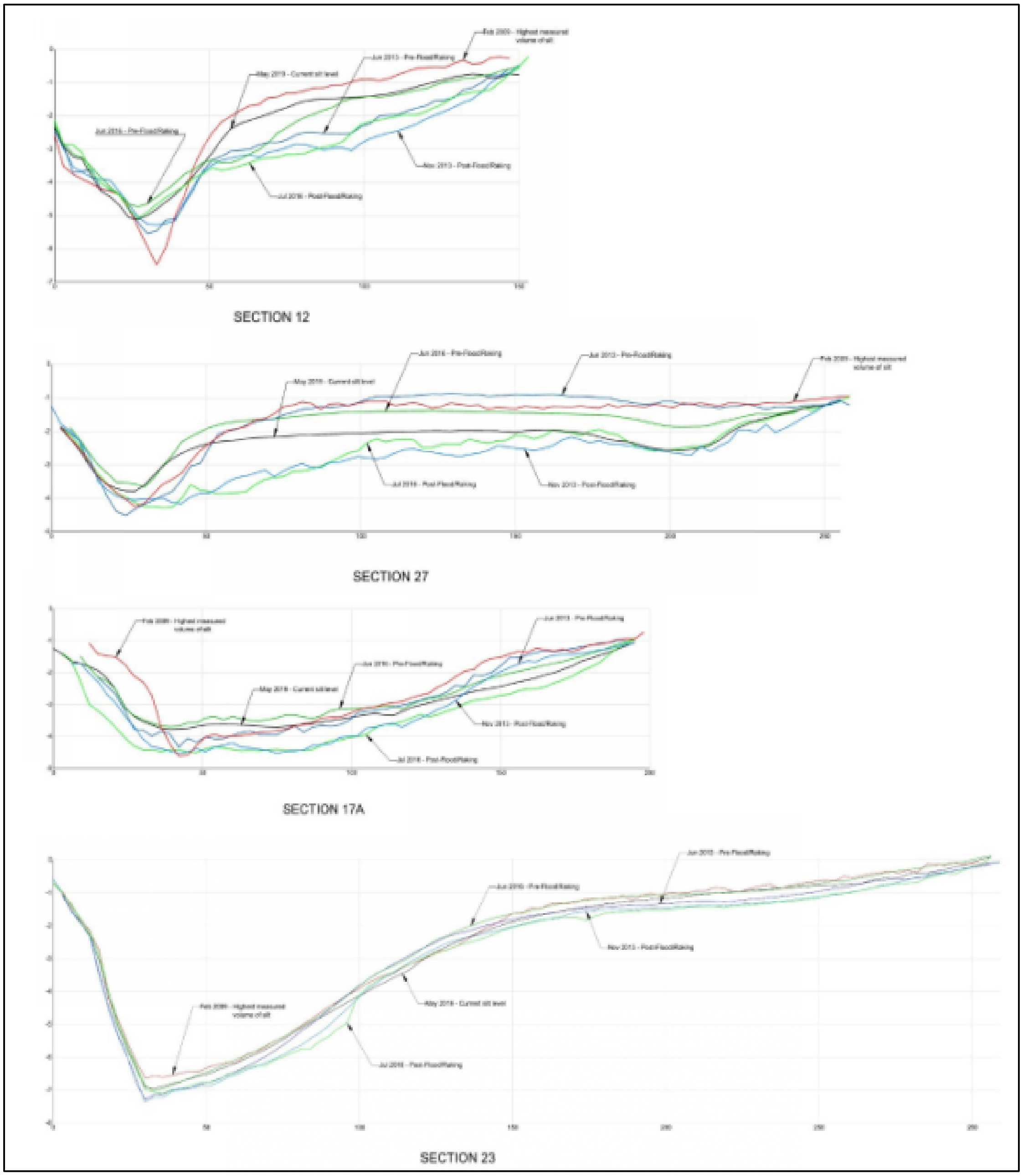


Figure 10: Estuary cross-sections (mAHD)

Bathymetry results show that sediment raking and prop washing have not achieved net loss of sediment from the upper estuary, which is the primary Key Performance Indicator (KPI) for the program Furthermore, the program has resulted in loss of navigational access (a secondary KPI), with flow-on impacts to commercial and recreational activities within the waterway.

### Water quality in the kanamaluka/Tamar River estuary

Water quality in the North and South Esk rivers is generally good or moderate in the cleared foothills and lowland plains, with variable grades (from poor through to very good) in the forested hills and highlands (Newall et al. 2012). Recreational water quality is generally very good, with popular swimming locations on both the North and South Esk rivers. In general, water quality at these sites (eg, First Basin on the South Esk and St Leonards on the North Esk) is suitable for swimming, unless there has been rain in the catchment in the days prior. It is well documented that rainfall in the catchment contributes pollutants and faecal contamination to the waterways from diffuse sources such as livestock and native wildlife.

Water quality parameters have been monitored in the kanamaluka/Tamar River estuary and the North and South Esk rivers since the 1970s, with historical data predating the Ti Tree Bend and Hoblers Bridge STPs. Thermotolerant coliforms in the North Esk River at Hoblers Bridge and in the Estuary at the Tamar Yacht Club were observed to be present in the millions of cells/100mL in the 1970s, with the highest count peaking at 8.8 million cells/100mL at Hoblers Bridge in June 1991 (CSOWG 2017).

Mirroring global observations, analysis of historical and current data indicates a strong trend of significantly improved water quality since the construction of wastewater treatment.

Water quality in the kanamaluka/Tamar River estuary improves with distance downstream towards the mouth of the estuary. The lower estuary is well flushed, and the volume of water and the tidal marine influence dilutes the concentration of pollutants from the upper reaches (Attard et al. 2012). In Zone 1 of the estuary, from Launceston to Tamar Island, the water quality consistently scores a C or D (Fair — Poor) in the Tamar Estuary Report Cards prepared by NRM North’s TEER Program. The grades are generally as a result of poor scores for Enterococci, turbidity, nutrients and metals. Diffuse sources from the catchment, and sewage treatment plants (STPs) and Launceston’s combined sewerage system contribute to the pollutant loads. Turbidity (a measure of suspended sediments) is strongly driven by diffuse sources in the catchment, contributing almost 100 per cent of the sediment to the estuary (TEER 2015).

### Impacts on water quality: sediment raking

There is a paucity of water quality data collected for sediment raking during the 5-year permit period for analysis. The data analysis undertaken by Dr Kelly therefore relied on additional external data collected by NRM North for the Ecosystem Health Assessment Program. A summary of Dr Kelly's analysis is provided below, with the full report attached as Appendix 2.

Water quality data during 2013 - 2015 were collected from the raking vessel: from the bow of the boat (upstream) and from the stern (plume), therefore there are no monitoring sites to map. In 2018-19 water quality data were collected at fixed sites: two upstream sites (North Esk and South Esk rivers) and two downstream sites (Kings Wharf and Ti Tree Bend). Monitoring sites are presented in  Figure 11.


Figure 11: Water quality monitoring sites: 2018-19

*Extract from Kelly (2019)*

Two sources of water quality data were used to assess the impacts of sediment raking on water quality:

- Data collected by the Launceston flood authority during silt raking campaigns immediately upstream and downstream of raking activities. This data provides information on the localised (temporal and spatial) impacts of silt raking on water quality.
- Data collected by the TEER EHAP program consisting of monthly grab samples collected for the length of the estuary (at 16 to 18 sites) over a ten year period. This data has some gaps where data was previously collected on a 2 year on-2 year off basis. While this data

was not collected for the purposes of evaluating the impacts of sediment raking it provides a useful source of long term data which can be used to look for evidence of longer term and broader spatial scale impacts.

Analysis of localised water quality impacts shows that sediment raking releases very large amounts of sediments, nutrients and heavy metals into the water column. Figures D and E show the increase in concentration in the plume of nutrients, TSS and total heavy metals respectively, immediately following sediment raking (note dissolved metals are not shown). These increases are seen across all total pollutants as well as for some dissolved pollutants. NOx and dissolved aluminium do not show an immediate increase in the plume, however both TN and total aluminium increase markedly, so it is likely that this initial impact reflects the large concentration of sediment and sediment attached pollutants, in the plume. There is some evidence that a delay in collecting samples, even by small amounts of time (ie. the difference in collecting samples in the plume from the sediment raking boat versus from a fixed point downstream of raking activities) is enough time for these pollutants to begin detaching from sediments and dissolved concentrations to begin to increase. Increases in pollutant concentrations are in many cases one to two orders of magnitude greater than the ANZECC default guideline value for the pollutant (and for aluminium closer to three orders of magnitude greater), indicating impacts on localised water quality that are likely to be associated with environmental harm and which are of a magnitude that may be toxic to aquatic life.

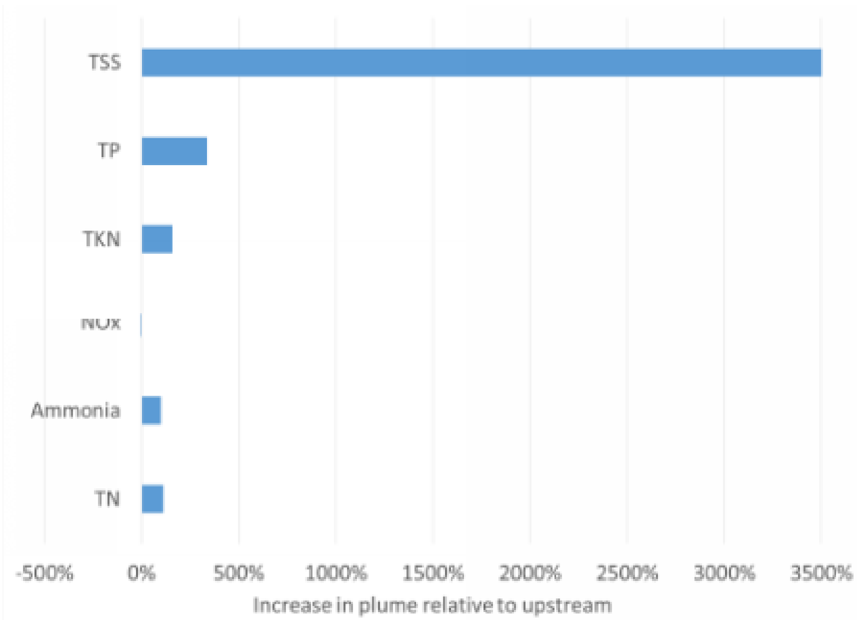


*Figure D. Increase of pollutant concentration in plume relative to upstream (note 100% increase = double upstream concentration)*

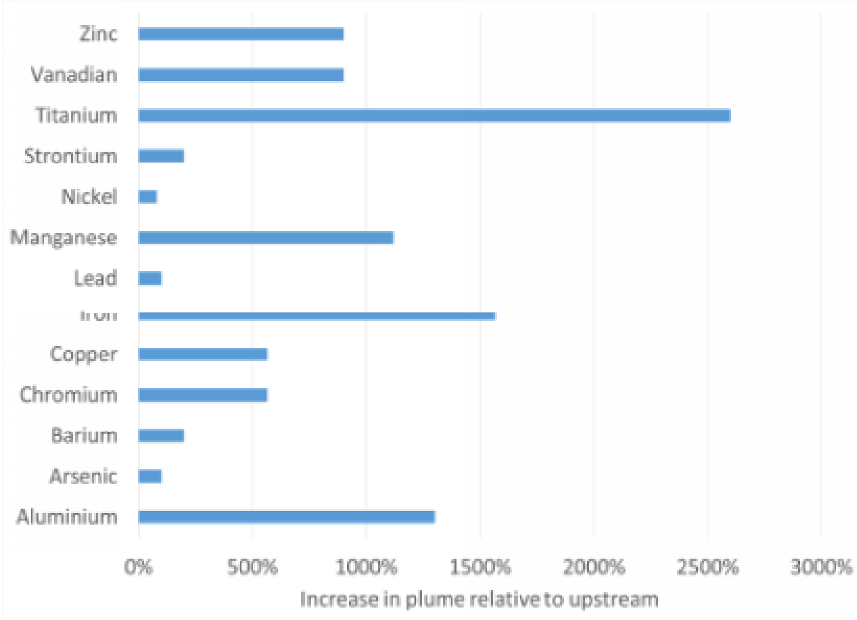


*Figure E. Increase of total heavy metal concentration in plume relative to upstream (note 100% increase = double upstream concentration)*

A further analysis looking for longer term and larger spatial scale impacts was then conducted using data collected as part of the Tamar Estuary and Esk Rivers (TEER) Ecological Health and Assessment Program (EHAP). This data consists of monthly ambient water quality samples collected on a two year on, two year off basis at 16 sites along the extent of the estuary. This data was never collected with the intention of assessing impacts of sediment raking and so is not 'fit-for-purpose' to reject the hypothesis that there have been water quality impacts. It is possible however to use this data to look for evidence of impacts of sediment raking. Data on heavy metals is particularly limited with significant temporal gaps (it was collected quarterly rather than monthly) and issues where data, particularly for dissolved metals, falls below the limits of reporting (even where the ANZECC default guideline value is less than the limits of reporting (LOR)). Two types of impacts were explored with this EHAP data – immediate impacts within the days following a raking event (up to a week); and, longer term impacts out to 3 weeks post sediment raking considering the relative sediment raking effort within that period. Results across nutrients, sediments and metals data showed very consistent patterns of impact. In general sediments and total pollutants increase in the upper estuary (to around Blackwall – T7) in the days after sediment raking (out to a week). Dissolved pollutants, turbidity and some heavy metals including total aluminium are then impacted over a longer time scale, with impacts seen further downstream as the length of the preceding period considered increases. Impacts on DRP, ammonia, NOx, turbidity, total aluminium and total iron are seen to Clarence Point when raking has occurred in the preceding two to three weeks. Importantly the relative effort of raking within the period impacts concentration, not just the presence or absence of raking in the period. Some nutrients and heavy metals also remain elevated in the upper estuary for at least 2 to 3 weeks after raking ceases. These impacts are demonstrated in Figures F to H, which shows the sites where a significant relationship occurs between concentration and sediment raking effort in the preceding period, using TSS, turbidity and dissolved reactive phosphorus (DRP) as examples. Tables A, B and C provide the full set of results for nutrients and heavy metals showing sites where pollutant concentration has a statistically significant relationship with sediment raking effort in the preceding period. These figures and tables clearly show the 'pulse' effect where initial impacts are focused in the upper estuary but impacts on dissolved nutrients, turbidity and some metals extend to the lower estuary over a longer period of time. The effects of flows on these relationships were also considered. It was found that in most cases where pollutant concentration is significantly correlated with sediment raking, catchment inflows are either not correlated with pollutant concentrations or act to reduce the impacts of sediment raking effort on concentrations, presumably through dilution of pollutants.

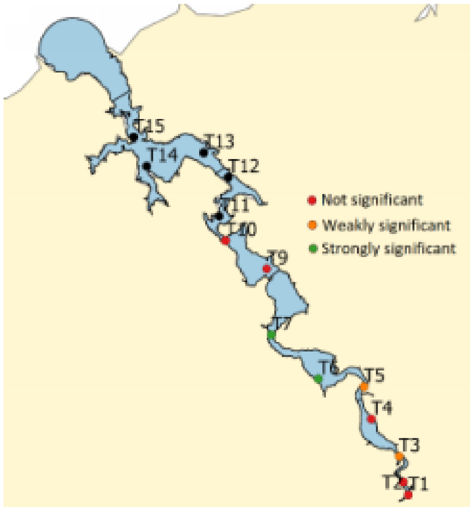


*Figure F. Relationship between TSS and sediment raking effort in the preceding 2 weeks*

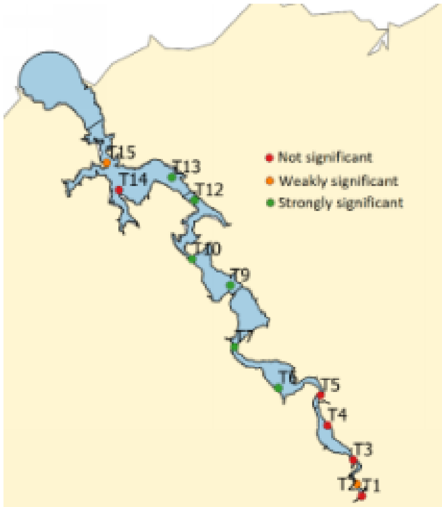


*Figure G. Relationship between turbidity and sediment raking effort in the preceding 2 weeks*


*Figure H. Relationship between dissolved reactive phosphorus and sediment raking effort in the preceding 2 weeks*

*Table A. Summary of statistical significance of regression models between pollutant concentration and weighted sediment raking effort (WSRE) in the preceding period given. 'N' is used to indicate where a model was not fit*

| Regression | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TSS** | | | | | | | | | | | | | |
| 7 days | | | | | | | | N | N | N | N | N | N |
| 10 days | | | | | | | | | | N | N | N | N |
| 14 days | | | | | | | | | | N | N | N | N |
| **Turbidity** | | | | | | | | | | | | | |
| 7 days | | | | | | | | | | | | | |
| 10 days | | | | | | | | | | | | | |
| 14 days | | | | | | | | | | | | | |
| **TP** | | | | | | | | | | | | | |
| 7 days | | | | | | | | N | N | N | N | N | N |
| 10 days | | | | | | | | | N | N | N | N | N |
| 14 days | | | | | | | | | | | | | |
| **DRP** | | | | | | | | | | | | | |
| 7 days | | | | | | | | N | N | N | N | N | N |
| 10 days | | | | | | | | | | N | N | N | N |
| 14 days | | | | | | | | | | | | | |
| **TN** | | | | | | | | | | | | | |
| 7 days | | | | | | | | N | N | N | N | N | N |
| 10 days | | | | | | | | | N | N | N | N | N |
| 14 days | | | | | | | | | | | | N | N |
| **NOX** | | | | | | | | | | | | | |
| 7 days | | | | | | | | N | N | N | N | N | N |
| 10 days | | | | | | | | | | N | N | N | N |
| 14 days | | | | | | | | | | | | | |
| **Ammonia** | | | | | | | | | | | | | |
| 7 days | | | | | | | | N | N | N | N | N | N |
| 10 days | | | | | | | | | | N | N | N | N |
| 14 days | | | | | | | | | | | | | |
| **Enterococci** | | | | | | | | | | | | | |
| 7 days | | | | | | | | N | N | N | N | N | N |
| 10 days | | | | | | | N | N | N | N | N | N | N |
| 14 days | | | | | | | | N | N | N | N | N | N |

*Table B. Impacts of presence and absence of sediment raking in the preceding period on metal concentrations*

| Total | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|
| **Total Aluminium** | | | | | | | |
| 3 days | | | | | | | |
| 7 days | | | | | | | |
| 10 days | | | | | | | |
| 14 days | | | | | | | |
| 21 Days | | | | | | | |
| **Total Zinc** | | | | | | | |
| 3 days | | | | | | | |
| 7 days | | | | | | | |
| 10 days | | | | | | | |
| 14 days | | | | | | | |
| 21 Days | | | | | | | |
| **Total manganese** | | | | | | | |
| 3 days | | | | | | | |
| 7 days | | | | | | | |
| 10 days | | | | | | | |
| 14 days | | | | | | | |
| 21 Days | | | | | | | |
| **Dissolved Manganese** | | | | | | | |
| 3 days | | | | | | | |
| 7 days | | | | | | | |
| 10 days | | | | | | | |
| 14 days | | | | | | | |
| 21 Days | | | | | | | |
| **Total iron** | | | | | | | |
| 3 days | | | | | | | |
| 7 days | | | | | | | |
| 10 days | | | | | | | |
| 14 days | | | | | | | |
| 21 Days | | | | | | | |
| **Dissolved iron** | | | | | | | |
| 3 days | | | | | | | |
| 7 days | | | | | | | |
| 10 days | | | | | | | |
| 14 days | | | | | | | |
| 21 Days | | | | | | | |

*Table C. Relationship of metal concentrations with raking effort in preceding 3 weeks*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Aluminium (ug/L) | | | | | | | | | | | | | |
| Total Zinc (ug/L) | | | | | | | | | | | | | |
| Total Manganese (ug/L) | | | | | | | | | | | | | |
| Dissolved Manganese (ug/L) | | | | | | | | | | | | | |
| Total Iron (ug/L) | | | | | | | | | | | | | |
| Dissolved Iron (ug/L) | | | | | | | | | | | | | |

This analysis also shows that the negative water quality impacts of sediment raking are felt down the length of the estuary to at least Clarence Point (T15). In particular there is evidence that dissolved nutrients and metals such as aluminium and iron are elevated in the lower estuary for weeks after a sediment raking event. The number of data points on which this observation is made are limited and the data have not been collected for the purpose of analysing the impacts of sediment raking, however considering the consistency of results, strength of the relationships found and the feasibility of findings given the way in which these pollutants are transported through the estuary, it is likely that these results reflect a true impact of raking on water quality.

It is also clear that in order to accurately determine what the impacts of sediment raking are in the estuary, a 'fit for purpose' monitoring regime requires data collection through the mid and lower estuary, should consider nutrients and metals as well as sediments and should be event based, measuring water quality before, during and for a period of several weeks after sediment raking.

## Impacts on water quality: prop washing

There are no water quality data for the prop washing during the 5-year permit period. In 2019 water quality data were collected at a site 100m upstream of Seaport Marina and at a site 185m downstream from the marina (Figure 11).

Water quality data were collected on 16 prop washing days in 2019. All raw data (including field measurements) are presented in Appendix 3. Summary data for suspended sediment and nutrient concentrations are presented in Table 5 below. Analysis of water quality data shows that as with sediment raking, prop washing releases large amounts of sediments and nutrients into the water column. The mean values for total suspended sediments at the downstream site was more than double the upstream value (Table 5), with some individual results almost four times as high (Table 8). Total suspended sediment at the upstream Similarly, total nutrient concentrations were much higher at the downstream site, with a 31% increase in total nitrogen and a 69% increase in total phosphorus (Figure 12). Dissolved reactive phosphorus concentration decreased by more than 30% at the downstream sites. This may be due to a combination of factors. The soluble phosphorus may bind with the additional silt and clay particles in the water column, and phosphorus-absorbing bacteria may be present in the silts which are then released into the water column with the sediment as a result of prop washing.

For all metals with concentrations higher than the limit of reporting there was a substantial increase in total metals within the sediment plume, and an increase in dissolved calcium, iron, potassium, magnesium, manganese and sodium (Figure 13).

The analysis indicates that the impact of prop washing on water quality is no different to the impact of sediment raking on water quality. Pollutant concentrations are elevated above the ANZECC 2000 default guidelines for disturbed systems; total phosphorus at times is seven times higher than the guideline trigger value of 0.05mgP/L. The impact on localised water quality is likely to be associated with environmental harm, including fish migration and the concentrations may be of a magnitude that they are toxic to aquatic life.

Table 5: Suspended sediments and nutrient concentrations: 2019 prop washing, Seaport Marina

| Sample date | Total Suspended Sediment (mg/L) | | Total Nitrogen (mg/L) | | Total Phosphorus (mg/L) | | Nitrate (mg/L) | | Nitrite (mg/L) | | Ammonia (mg/L) | | Dissolved Reactive Phosphorus (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CSB | 1TP | CSB | 1TP | CSB | 1TP | CSB | 1TP | CSB | 1TP | CSB | 1TP | CSB | 1TP |
| Mean | 58 | 133 | 0.95 | 1.24 | 0.13 | 0.21 | 0.32 | 0.29 | 0.005 | 0.006 | 0.090 | 0.102 | 0.014 | 0.013 |
| SD | 22 | 53 | 0.20 | 0.29 | 0.05 | 0.07 | 0.11 | 0.14 | 0.001 | 0.002 | 0.082 | 0.039 | 0.007 | 0.005 |
| Median | 60 | 115 | 0.91 | 1.25 | 0.14 | 0.22 | 0.36 | 0.30 | 0.005 | 0.006 | 0.075 | 0.097 | 0.013 | 0.013 |
| Min | 21 | 64 | 0.62 | 0.75 | 0.04 | 0.09 | 0.04 | 0.04 | 0.003 | 0.002 | 0.029 | 0.053 | 0.006 | 0.006 |
| Max | 105 | 216 | 1.50 | 1.80 | 0.23 | 0.35 | 0.44 | 0.51 | 0.008 | 0.008 | 0.370 | 0.160 | 0.033 | 0.023 |
| 20th | 42 | 84 | 0.83 | 0.95 | 0.08 | 0.15 | 0.24 | 0.21 | 0.004 | 0.005 | 0.038 | 0.064 | 0.008 | 0.009 |
| 80th | 72 | 199 | 1.00 | 1.40 | 0.15 | 0.28 | 0.41 | 0.41 | 0.006 | 0.007 | 0.095 | 0.150 | 0.018 | 0.016 |
| 25th | 42 | 92 | 0.83 | 0.97 | 0.09 | 0.16 | 0.24 | 0.23 | 0.004 | 0.005 | 0.044 | 0.068 | 0.010 | 0.010 |
| 75th | 66 | 183 | 0.99 | 1.40 | 0.14 | 0.28 | 0.41 | 0.39 | 0.006 | 0.006 | 0.091 | 0.135 | 0.017 | 0.015 |

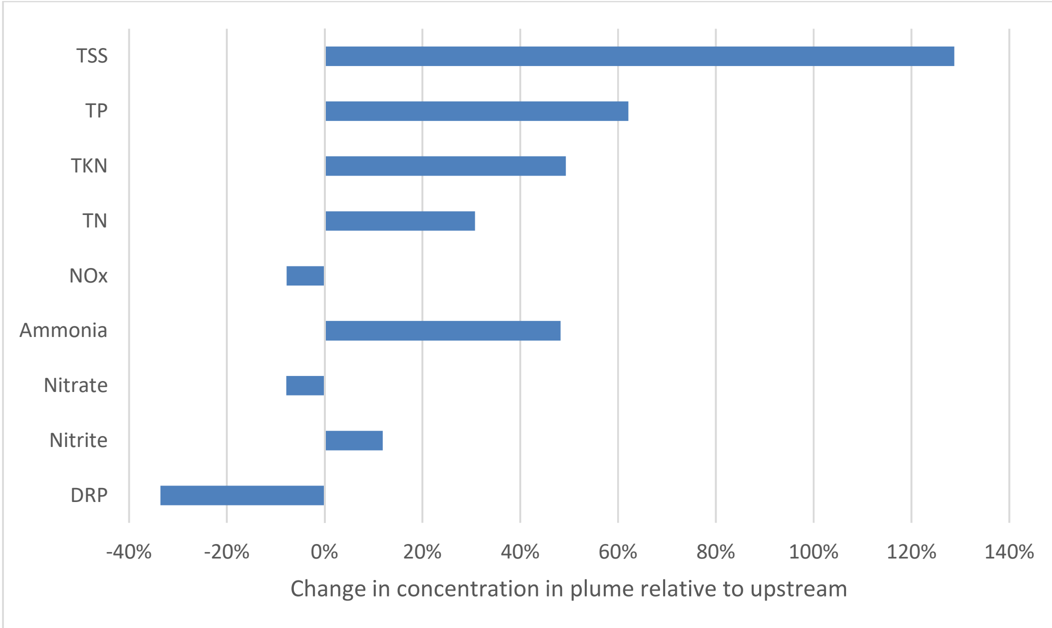


Figure 12: Change in pollutant concentration in prop wash plume relative to upstream (note 100% increase = double upstream concentration)

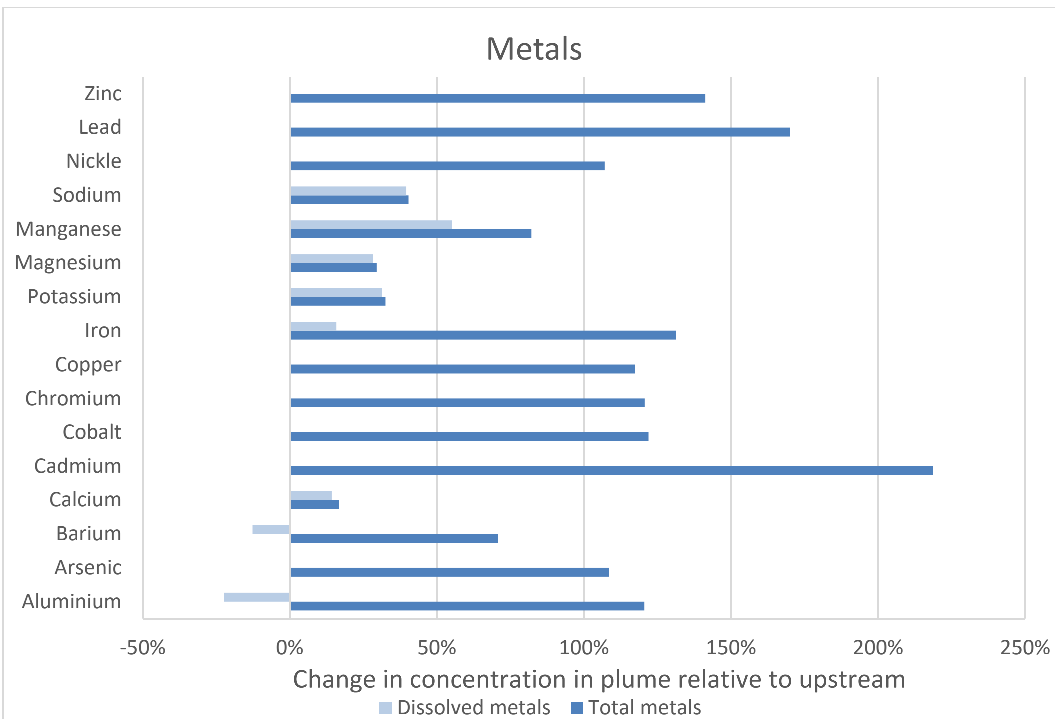


Figure 13: Change in metals' concentration in prop wash plume relative to upstream (note 100% increase = double upstream concentration)

# Key Performance Indicators

Sediment raking and prop washing undertaken by the Launceston Flood Authority in the upper reaches of the kanamaluka/Tamar River estuary has three key performance indicators:

- Net loss of sediment measured by before and after bathymetric surveys;
- Improved visual amenity measured by net reduction of the tidal shoals at low tide; and
- Improved usability of the river, as reported by regular river users such as the rowing clubs and yacht club.

### No net loss of sediment measured by before and after bathymetric surveys

Sediment raking mobilises benthic sediments, suspending them in the water column, but it does not result in mass movement out of the upper estuary. In the two years prior to the June 2016 flood, sediment volume consistently climbed, despite repeated raking campaigns which resulted in only very short-term falls in sediment volume in the upper estuary. Prior to the June 2016 flood, despite 223 days of raking, sediment volume in the Yacht Basin was only 3188m$^3$ lower than the maximum sediment volume prior to the commencement of raking (Table 6). For all areas of the kanamaluka/Tamar River estuary, the lowest sediment volumes are observed several months after the June 2016 flood. The lowest volumes, which persisted through the 2016/17 summer months, coincided with periods of high flow down both the North and South Esk rivers and no raking. Data from the program's final bathymetry survey, conducted on 13 September 2019, shows that sediment volume within each of the broad estuary zones is again approaching the pre-raking levels (Figure 14).

Table 6 Sediment volume in the upper kanamaluka/Tamar River estuary

| | Yacht Basin | | Extended Yacht Basin | | Kings Wharf | | Seaport | |
|---|---|---|---|---|---|---|---|---|
| | Date | Volume | Date | Volume | Date | Volume | Date | Volume |
| Max volume | 23-Apr-09 | 263,950 | 23-Apr-09 | 693,371 | 2-Jun-16 | 217,581 | 12-Mar-13 | 67,323 |
| Min volume | 14-Sep-16 | 58,467 | 14-Sep-16 | 429,052 | 16-Sep-16 | 73,035 | 1-Jul-14 | 57,891 |
| Pre-raking trial (Aug '12) | 22-Aug-12 | 207,090 | 22-Aug-12 | 618,943 | | no data | | no data |
| Post-raking trial (Oct '12) | 9-Oct-12 | 202,537 | 9-Oct-12 | 607,251 | | no data | | no data |
| Pre-raking (May '13) | 17-May-13 | 239,616 | 17-May-13 | 655,977 | | no data | 17-May-13 | 58,840 |
| Pre-prop washing (June '14) | | | | | | | 28-May-14 | 62,236 |
| Pre-June 2016 flood | 2-Jun-16 | 260,762 | 2-Jun-16 | 677,017 | 2-Jun-16 | 217,581 | 2-Jun-16 | 58,412 |
| Post-June 2016 flood | 23-Jul-16 | 72,308 | 23-Jul-16 | 444,323 | 23-Jul-16 | 79,139 | 23-Jul-16 | 58,540 |
| Final survey (Sept '19) | 13-Sep-19 | 182,766 | 13-Sep-19 | 614,839 | 13-Sep-19 | 189,037 | 13-Sep-19 | 60,879 |

Riverine inflows greater than 500 cumecs are efficient at removing and maintaining sediment volume in the upper estuary. In the period 1901 - 2016, annual maximum flow has exceeded this magnitude 64% of the time, and more than 75% of years had an annual maximum flow of >400 cumecs (BMT 2018). Average flow from Trevallyn Dam to the Tailrace is 83.5 cumecs (BMT 2018), which is insufficient to remove sediment from the upper estuary even if all South Esk River flows were returned to the Cataract Gorge (i.e. the Trevallyn Dam was removed). Such a diversion of flow would come at significant economic cost to the State. A report commissioned by the Tamar Estuary Management Taskforce (TEMT) to consider the potential for targeted flow releases from Lake Trevallyn to manage sedimentation around Launceston found that insufficient water can be released from Trevallyn Dam to achieve the required flows to effectively remove sediment (BMT 2019). There was no net movement of sediment from the upper estuary under any of the modelled scenarios.

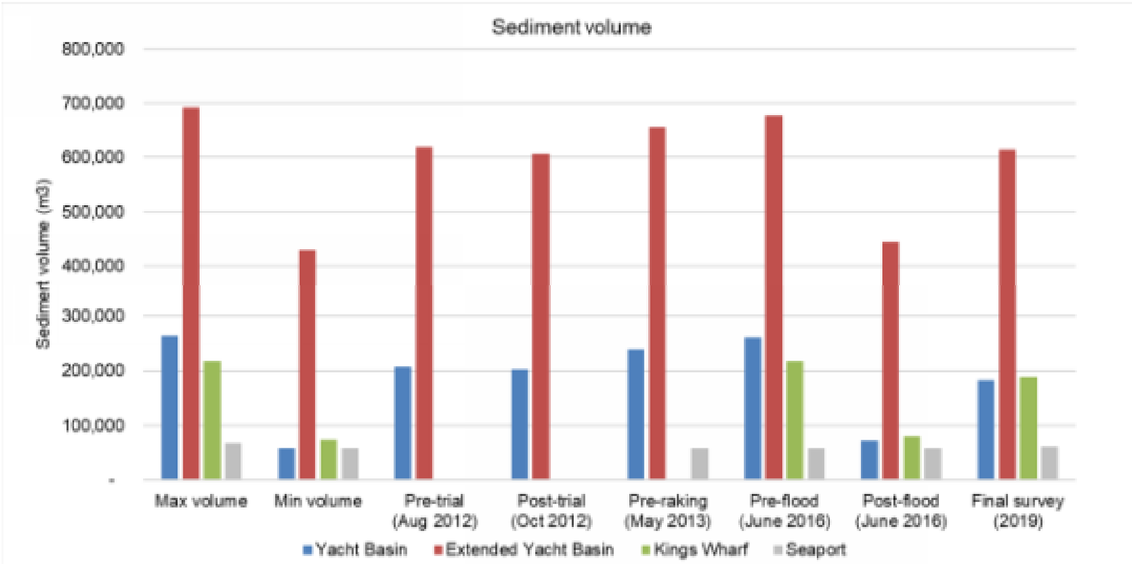


Figure 14: Sediment volume within broad zones of the upper estuary 2009 - 2019

Movement of sediment out of the Yacht Basin is dependent upon elevated inflow from the Esk rivers. The data suggest that mobilised sediment as a result of sediment raking is not exported out of Zone 1 of the estuary, but rather settles in the deeper channels between the Yacht Club and the Tailrace.

It is evident from the data collected from September 2012 to September 2019 that raking and prop washing have not met the objective for net loss of sediment from the upper estuary.

### Improved visual amenity measured by net reduction of the tidal shoals at low tide

Bathymetry charts and estuary cross-sections demonstrate that sediment raking and prop washing have resulted in short-term reduction of the extent of mudflats and shoals at low tide. For Seaport Marina in particular, this is an obvious outcome of the prop washing, with a clear and obvious change at low tide. The marina is a depositional zone which infills to the extent that moored boats are beached at low tide (Figure 15). The West Tamar shoal was targeted during sediment raking, as it contains a large volume of sediment. Water depth in this area has increased substantially at times due to the combined action of raking and significant riverine inflow, with water depths of up to 3m AHD achieved.

Sediment raking and prop washing has achieved short-term improved visual amenity on the West Tamar Shoal and Seaport Marina.

Figure 15: Seaport Marina at low tide, July 2015 (Source: The Examiner Newspaper)

### Improved usability of the river, as reported by regular river users

Bathymetry charts and cross-sections demonstrate that sediment raking and prop washing have resulted in substantial infilling of the navigation channels in the upper estuary and a redistribution of a large volume of sediment. The entrance to the North Esk River is now 1.5m shallower than it was in February 2009 when sediment volume was at its highest; at Kings Wharf the water is now 1m shallower and in the Yacht Basin it is 0.5m shallower. The loss of 0.5m depth in the Yacht Basin (from 4.2m to 3.7m) means that the navigation channel is now too shallow at low tide for boats to travel from the North Esk River to the Kings Bridge in the South Esk River. The Tamar River Cruises, a commercial tourism operator at Home Point, has reported numerous occasions where cruises have had to be cancelled due to an inability to leave their wharf or tourists have been stranded onboard when the boats ran aground in the channel (Figure 16).

Figure 16: Tamar River Cruise vessel run aground in the upper estuary channel, March 2019

Redistribution of the sediment has resulted in changes to the location of the channels and shoals. There is now a large deposit of sediment on the inside bend of the North Esk-kanamaluka/Tamar confluence. As a result the new pontoon for the Silos Hotel rests on the mudflats at low tide (Figure 17). Reports from Southern Marine Shiplift at Kings Wharf indicate that sediment raking campaigns are associated with rapid infilling of the berth at the wharf, requiring more frequent dredging to maintain access for ships (S. Richardson, [Southern Marine Shiplift] 2019 pers. comm.).

Prop washing in Seaport Marina provides short-term improvements in navigational access to the marina, as it results in up to 2.5m of water at the berths at low tide; without prop washing, the marina rests on the mudflats at low tide. This requires constant maintenance, and is a trade-off with navigation access at the North Esk River confluence, as sediment moved from Seaport creates a barway in the North Esk River and contributes to the confluence shoal (Figure 18).

Sediment raking has not achieved improved usability of the upper estuary.

Figure 17: North Esk River confluence shoal (L) and Silos Hotel pontoon at low tide, February 2019 (R)

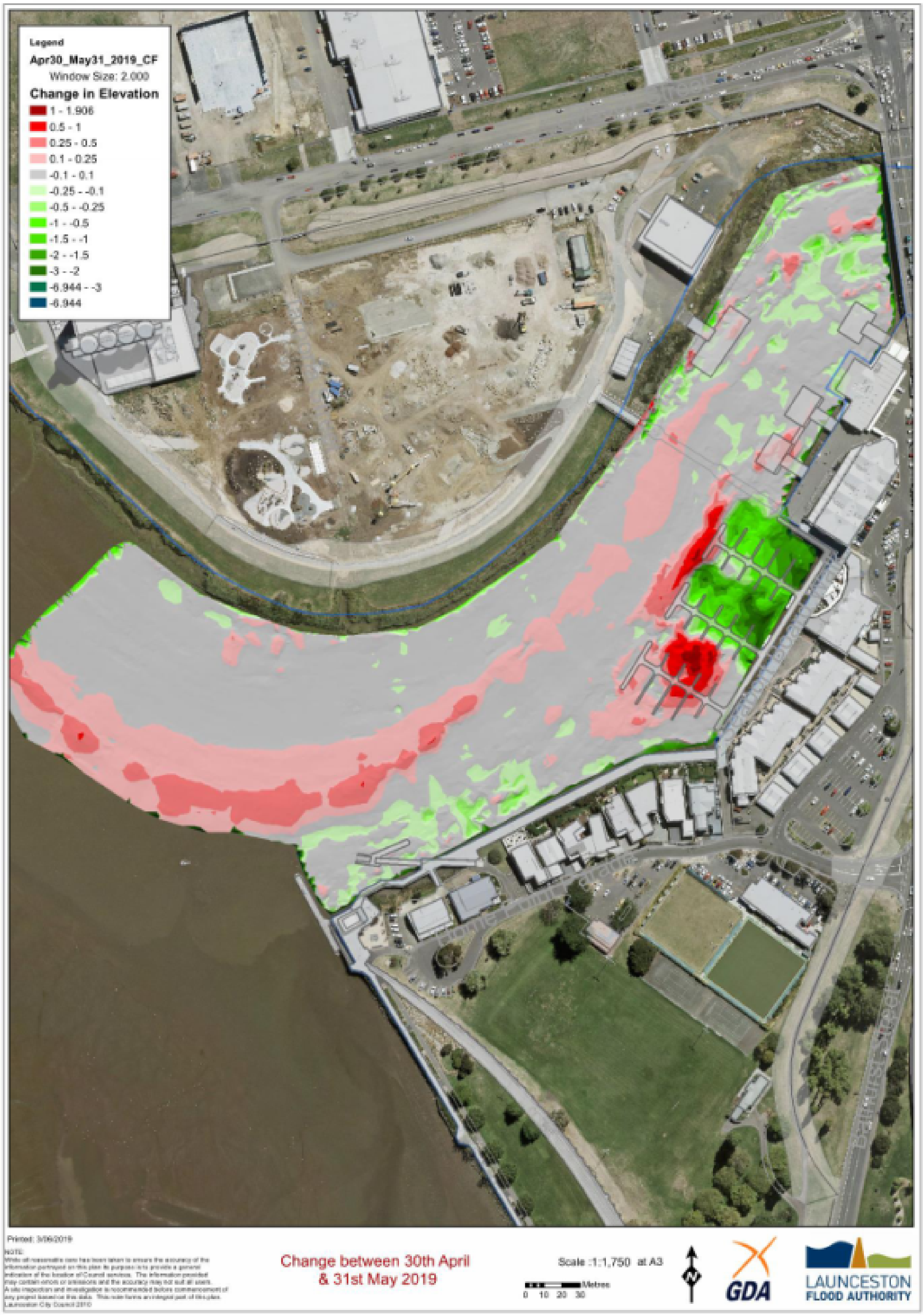


Figure 18: Change in depth at the North Esk River confluence after 9 days prop washing at Seaport Marina, May 2019. Note developing barway at the North Esk River confluence.

## Conclusion

Results of the review indicate that sediment raking and prop washing have not achieved the primary goal of net loss of sediment from the upper estuary for the purposes of flood defence. The program has resulted in loss of navigational access, with flow-on impacts to commercial and recreational activities within the waterway. Raking and prop-washing has achieved short-term gains in visual amenity (loss of mudflats at low tide) at the West Tamar Shoal and Seaport Marina.

The estuary has significant natural values, including numerous threatened flora and fauna, migratory bird habitat, and a shark and ray nursery. The data demonstrate that the mobilisation of sediments in the water column has a long-lasting negative impact on water quality along the length of the estuary. While data does not exist to quantify the flow-on impact of degraded water quality on the Tamar River Conservation Area and the environmental values within it, it can be reasonably inferred that the ecosystem has been detrimentally affected by the raking and prop washing program.

The program has come at considerable social, financial and environmental cost, with long-term impacts on water quality and ecological health identified.

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The Examiner Newspaper July 2015 (photo credit)

# Appendices

## Appendix 1 Grants of Authority

23/09 2009 11:37 0363448109 PARKS AND WILDLIFE SERVICE #2393 P.002 /005

Tasmania

Department of Primary Industries, Parks, Water and Environment

PO Box 46, Kings Meadows TAS 7249
Ph (03) 6336 5267 Fax (03) 6344 8109
Web www.parks.tas.gov.au

Enquiries: Liz Regent
Phone: 63365375
Facsimile: 63448109
Email: Elizabeth.regent@parks.tas.gov.au
Our ref:
Your ref:

23rd September 2009

Rod Sweetnam
Launceston City Council
PO Box 396
LAUNCESTON TAS 7250

Re: **Reserve Activity Assessment (2268) for Silt Raking Trial within the Tamar River, Tamar Conservation Area**

Dear Mr Sweetnam

The Parks and Wildlife Service Northern Region ('Parks') has completed an assessment of your Reserve Activity Assessment (RAA2268) application for a Silt Raking Trial within the Tamar River, Tamar Conservation Area. Based on this assessment, Parks has approved the application subject to conditions.

Please find attached an 'Approval and Authority to Undertake Works' and associated conditions, granted to Council under Regulation 17 of the National Parks and Reserved Lands Regulations 2002. This document provides Council with the legal authority required to undertake the activity. All conditions of this authority must be implemented as part of the approved activity.

In order to comply with the conditions of the authority it is recommended that you undertake the following:

- Contact the Biodiversity Conservation Branch (ph. 03 6233 6556) for information regarding any permits required under the *Threatened Species Protection Act 1995*.
- Contact Inland Fisheries Service (ph. 03 6261 8050) for information regarding any permits required under the *Inland Fisheries Act 1995*.
- Contact Marine and Safety Tasmania (MAST) in regard to any requirements.
- Contact Parks and Wildlife Service - Prospect (ph. 6336 5375), the Australian Maritime College (Troy Gaston, ph. 6324 3827), University of Tasmania, Tamar Estuary and Esk River Program (Amanda Locatelli, ph. 63337783) and the Environmental Protection Authority (John Gorrie, ph. 6233 3380) to arrange a meeting to inform the establishment of a monitoring program.

The development and implementation of a credible monitoring program for this trial is considered critical to improving understanding of the likely success and potential impacts of silt raking in the river. Monitoring will also assist Parks and other approval agencies in assessing any future proposals in regard to this activity.

Where required by Council, Parks provides consent (under Section 52 of the *Land Use Planning and Approvals Act*) for Council to submit a Development Application (DA) for this proposal to the Launceston City Council. The approved RAA and authority conditions must form the basis of any DA.

23/09 2009 WED 11:34 [TX/RX NO 8125] 002

Please note that in addition to the relevant Local and State Government permits, you may also need approval under the *Environment Protection and Biodiversity Conservation Act 1999* if the activity is likely to have a significant effect on a matter of national environmental significance. The approval body for such an activity is the Australian Government, Department of Environment Water Heritage and the Arts.

The RAA that was submitted contained very limited information and did not make reference to the various reports that have been undertaken in relation to environmental issues associated with the Tamar River. This will now need to be addressed through the development of a monitoring program.

Please note that Council will be required to provide comprehensive information in relation to any future activities proposed on reserved land, where an RAA is required.

If you would like to discuss the above mentioned matters further, please don't hesitate to contact Liz Regent on 63365375.

Yours sincerely

Chris Colley
Regional Manger- North
Parks and Wildlife Service

# Approval and Authority To Undertake Works Associated with Silt Raking Trial within the Tamar River on Reserved Land

***Granted to:***
Relevant staff and workers of Launceston City Council or their nominated contractor.

Authority issued in accordance with Regulation 17 of the National Parks and Reserved Land Regulations 1999 to undertake works, subject to the conditions listed below, that would otherwise be prohibited under Regulations 4, 6, and 12(3) of the *National Parks and Reserved Land Regulations 1999.*

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***Authority or approval valid:*** *From:21 September 2009 To:21 December 2009*

***Conditions***

- This Authority only allows for the undertaking of a silt raking trial in the Tamar River within those areas of the Tamar Conservation Area shown on the attached plan (A1).
- All works and activities are to be undertaken in accordance with the approved Reserve Activity Assessment (2268) – Tamar River Silt Raking Trial. Any commitments and mitigating strategies within the RAA must be fully implemented.
- Prior to undertaking works associated with this authority, a detailed description of the activity (eg. type of vessel, raking equipment, raking depth and procedure, timetable for works) and the parameters under which the works will be undertaken (eg. river flow or level), must be prepared and submitted to the Parks and Wildlife Service. Silt raking must not disturb contaminants (eg. heavy metals) with the potential to adversely impact on the river's natural environment.
- All silt raking works must be undertaken consistent with the proceeding description and parameters for works, unless otherwise approved by the Parks and Wildlife Service.
- Prior to undertaking silt raking works, a monitoring program must be prepared and submitted to the Parks and Wildlife Service. Preparation of the monitoring program should include consultation with the Parks and Wildlife Service, University of Tasmania, Tamar Estuary and Esk River program, Australian Maritime College and the Environment Protection Agency. All works must be undertaken in accordance with the approved monitoring program, which must address the following matters:
    - Monitoring for any displaced contaminants within the disturbed silt and resulting environmental impacts.
    - Monitoring of the geographic movement and settling of silt displaced as part of the silt raking activity
    - Processes for evaluating trial success (eg. provision of goals and measurable performance criteria)
    - Mitigation and remediation responses in regard to potential contaminant disturbance or environmental impacts.
    - Reporting of monitoring results.

- Prior to the commencement of works, Council must obtain all necessary Permits required under the *Land Use Planning and Approvals Act 1993.*
- Prior to the commencement of works, Council must obtain all necessary Permits required under the *Threatened Species Protection Act 1995.*
- Council must provide public notification of the timing and extent of the activity before the works commence. Council should consult with relevant commercial operators to ensure minimal impact on their operations. Where possible, silt raking activities should minimise disturbance to commercial and community activities within the reserve.
- Prior to the commencement of works, Council must obtain all necessary Permits required under the *Inland Fisheries Act 1995.*
- Prior to the commencement of works, Council must ensure any Marine and Safety Tasmania (MAST) requirements are met.
- Prior to the commencement of works, council must investigate infrastructure above or below the river bed that may be affected by the works. Silt raking activities must not adversely impact on any such infrastructure.
- This permit may be cancelled by notice in writing from the Director of National Parks and Wildlife Tasmania.
- This authority must be carried at all times during the undertaking of works associated with this authority and produced if required by an authorised person or an authorised officer under the *National Parks and Reserves Management Act 2002* to do so.
- Council must exercise due caution, care and respect for other users of the reserved land to ensure that other users are not displaced or have their experience diminished through the exercise of this authority. Council is responsible for ensuring that work activities and machinery do not cause a hazard to the public.

***Disclaimer***

Persons entering or conducting activities on reserved land pursuant to this authority do so entirely at their own risk. Liability is not accepted by the State of Tasmania or the Department of Primary Industry, Parks, Water and the Environment for any injury, loss or damage suffered by any such person, whether resulting from negligence or any other cause.

..............................................

***Signed by Chris Colley being the Regional Manager, North pursuant to an Instrument of Delegation dated 10 April 2008.***

***Date: 23 September 2009***

To be printed on the back of the authority:

Your personal information will be used for the primary purpose for which it is collected, and may be disclosed to contractors and agents of the Department of Primary Industry, Parks, Water and Environment (DPIPWE), law enforcement agencies, courts and organisations authorised to collect it.

Your basic personal information may be disclosed to other public sector bodies where necessary for the efficient storage and use of the information. Personal information will be managed in accordance with the *Personal Information Protection Act 2004* and may be accessed by the individual to whom it relates on request to the DPIPWE. You may be charged a fee for this service.

23/09 2009 WED 11:34 [TX/RX NO 8125] 005

APPROVAL AND AUTHORITY TO UNDERTAKE WORKS ASSOCIATED WITH SILT RAKING TRIAL WITHIN THE TAMAR RIVER ON RESERVED LAND

***Granted to:***

Andrew Fullard, General Manager
Jason Jones, Technical Operations Manager
Launceston Flood Authority
or nominated contractor.

Pursuant to Regulation 28 of the National Parks and Reserved Land Regulations 2009, this authority is granted to undertake works, subject to the conditions listed below that would otherwise be prohibited under Regulations 4, and 6 of the National Parks and Reserved Land Regulations 2009.

***Authority or approval valid:*** *From: 19 September 2012* *To: 20 October 2012*

***Conditions***

- This Authority allows for the trial raking of 30,000 cubic meters of silt in the Tamar Conservation Area within those areas shown as *silt raking trial zone* on the attached plan.
- The first day of silt raking must be limited to the disturbance of less than 2,000 cubic metres of sediment. Silt raking must then cease until the Director, EPA has approved the continuation of the trial in writing. This approval will only be considered after the results of the sampling on the first day of the trial have been submitted to the Director, EPA.
- Prior to undertaking works associated with this authority, a scoping document detailing the activity (type of vessel, raking equipment, raking depth and procedure, timetable for works) and the parameters under which the works will be undertaken (river flow and level) must be submitted to the Parks and Wildlife Service.
- All silt raking works must be undertaken consistent with the proceeding description and parameters for works, unless otherwise approved by the Parks and Wildlife Service.
- Silt raking must only be conducted on an ebb tide when the total tidal flow is at least 200 cubic metres per second within the area being raked.
- Unless otherwise approved in writing by the Director, EPA, a monitoring program must be conducted during sediment disturbance caused by the silt raking trial.
- The sampling program must include, but not be limited to
    - Collection of water samples at 15 minute periods downstream from the silt raking. Four consecutive samples may be composited to form one sample.
    - The location of the sample points must be as close as reasonably practical to the raking and collected from within the plume caused by the raking.
    - At least two grab samples must be collected upstream of the silt raking during each day on the ebb tide.
    - Samples must be analysed for total suspended solids, total and dissolved metals, total and dissolved nutrients including ammonia.
    - Field measurements of dissolved oxygen, pH, and conductivity must be collected on average at 30 minute time intervals through the water column within the plume.
    - The location of all sampling must be recorded.
    - Visual monitoring of the extent of the plume must be undertaken.

- Any sample or measurement required to be obtained under these conditions must be taken and processed in accordance with the following:
  - Australian Standards, NATA approved methods, the American Public Health Association Standard Methods for the Analysis of Water and Waste Water or other standard(s) approved in writing by the Director;
  - samples must be tested in a laboratory accredited by the National Association of Testing Authorities (NATA), or a laboratory approved in writing by the Director, for the specified test;
  - results of measurements and analysis of samples and details of methods employed in taking measurements and samples must be retained for at least three years after the date of collection

- Additionally in consultation with the Parks and Wildlife Service, University of Tasmania, Australian Maritime College, and the Environmental Protection Authority the Launceston Flood Authority must address the following matters:
  - Monitoring of the geographic movement and settling of silt displaced as part of the silt raking activity.
  - Processes for evaluating trial success such as provision of goals and measurable performance criteria
  - Mitigation and remediation responses in regard to potential contaminant disturbance or environmental impacts
  - Reporting of monitoring results

- Prior to the commencement of works, the Launceston Flood Authority must obtain all necessary permits required under the *Land Use Planning and Approvals Act 1993, Threatened Species Protection Act 1993* and ensure any Marine and Safety Tasmania (MAST) requirements are met.
- The Launceston Flood Authority must provide public notification and timing and extent of the activity before works commence. The Launceston Flood Authority should consult with relevant commercial operators to ensure minimal impact on their operations. Where possible and as far as is practical silt raking activities should minimise disturbance to commercial and community activities within the reserve.
- Prior to the commencement of works, Launceston Flood Authority must investigate services and infrastructure above or below the river bed that may be affected by the works. Silt raking activities must not adversely impact on any such infrastructure.
- This Authority may be cancelled by notice in writing from the Director of National Parks and Wildlife Tasmania.
- This Authority must be carried at all times during the undertaking of works associated with this authority, and produced if required to do so, by an authorised person or an authorised officer under the *National Parks and Reserves Management Act 2002.*
- The Launceston Flood Authority must exercise due caution, care and respect for other users of the reserved land to ensure that other users are not displaced or have their experience diminished through the exercise of this authority. Launceston Flood Authority is responsible for ensuring that work activities and machinery do not cause a hazard to the public.

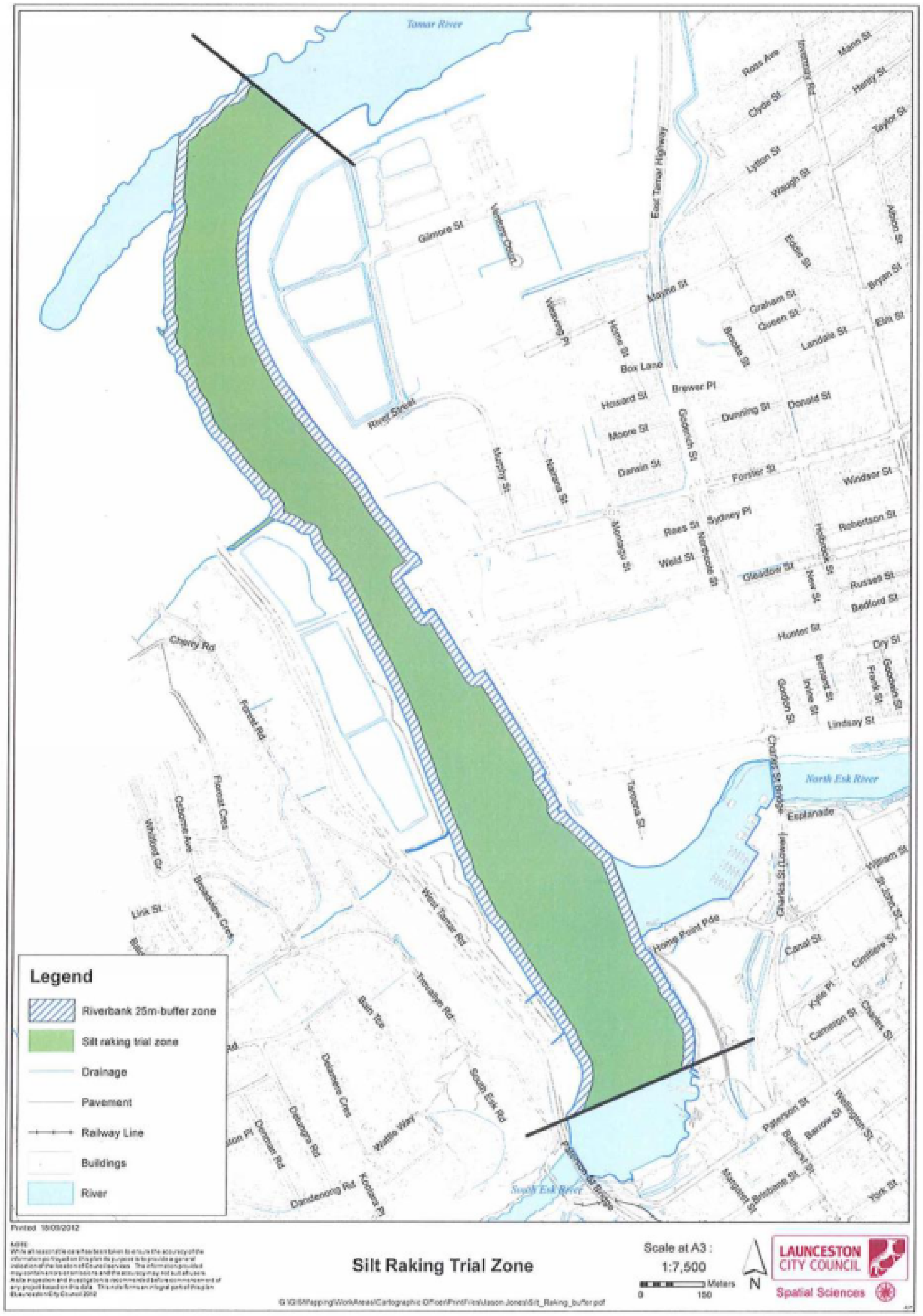
***Disclaimer***
Persons entering or conducting activities on reserved land pursuant to this authority do so entirely at their own risk. Liability is not accepted by the State of Tasmania or the Department of Primary Industry, Parks, Water and the Environment for any injury, loss or damage suffered by any such person, whether resulting from negligence or any other cause.

***Signed by Stan Matuszek being the Acting Regional Manager, North pursuant to an Instrument of Delegation under the National Parks and Reserve Management Act 2002 dated 10th April 2008.***

***Date: 19th September 2012***

Your personal information will be used for the primary purpose for which it is collected, and may be disclosed to contractors and agents of the Department of Primary Industry, Parks, Water and Environment (DPIPWE), law enforcement agencies, courts and organisations authorised to collect it.

Your basic personal information may be disclosed to other public sector bodies where necessary for the efficient storage and use of the information. Personal Information will be managed in accordance with the *Personal Information Protection Act 2004* and may be accessed by the individual to whom it relates on request to the DPIPWE. You may be charged a fee for this service.


Legend
Riverbank 25m-buffer zone
Silt raking trial zone
Drainage
Pavement
Railway Line
Buildings
River
Silt Raking Trial Zone
Scale at A3 :
1:7,500
LAUNCESTON CITY COUNCIL
Spatial Sciences

Scanned, Signed Copy

APPROVAL AND AUTHORITY TO UNDERTAKE WORKS ASSOCIATED WITH SEDIMENT RAKING PROGRAM WITHIN THE TAMAR CONSERVATION AREA

***Granted to:***
Andrew Fullard, General Manager
Launceston Flood Authority
or nominated contractor.

Pursuant to Regulation 28 of the National Parks and Reserved Land Regulations 2009, this authority is granted to undertake works, subject to the conditions listed below that would otherwise be prohibited under Regulations 4(1)(b), 4(1)(c) and 4(7)(c) of the National Parks and Reserved Land Regulations 2009.

***Authority or approval valid**: From: 20 May 2013 To: 19 May 2018*

*This authority is subject to review of the Sediment Raking Monitoring Plan and Sediment Raking Scoping Document, operations and conditions following the first two years of operation and may be subject to further conditions and amendment at the discretion of the Director Parks and Wildlife Service and or Director EPA.*

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*Conditions*

1. Prior to undertaking any sediment raking activities, a Sediment Raking Monitoring Plan (the Plan) must be submitted to the Director, EPA for approval. The Plan must include, but not be limited to:
   a. Details of monitoring to assess the success of the sediment raking; and
   b. Details of a monitoring strategy to assess potential impact on the receiving environment.
2. Unless otherwise approved in writing by the Director EPA, the sediment raking must be implemented in accordance with the approved Sediment Raking Monitoring Plan.
3. All sediment raking works must be undertaken consistent with the Sediment Raking Scoping Document and Sediment Raking Monitoring Plan unless otherwise approved by the Parks and Wildlife Service.
4. Prior to the commencement of works, the Launceston Flood Authority must obtain all necessary permits required under the *Land Use Planning and Approvals Act 1993, Threatened Species Protection Act 1993* and ensure any Marine and Safety Tasmania (MAST) requirements are met.
5. The Launceston Flood Authority must provide public notification and timing and extent of the activity before works commence. The Launceston Flood Authority must consult with relevant commercial operators to ensure minimal impact on their operations. Where possible and as far as is practical sediment raking activities should minimise disturbance to commercial and community activities within the reserve.
6. Prior to the commencement of works, Launceston Flood Authority must investigate and identify services and infrastructure above or below the river bed that may be affected by the raking program. Sediment raking activities must not adversely impact on any such infrastructure.
7. This Authority may be cancelled by notice in writing from the Director of National Parks and Wildlife Tasmania.

8. This Authority must be carried at all times during the undertaking of works associated with this authority, and produced if required to do so, by an authorised person or an authorised officer under the *National Parks and Reserves Management Act 2002.*

9. The Launceston Flood Authority must exercise due caution, care and respect for other users of the reserved land to ensure that other users are not displaced or have their experience diminished through the exercise of this authority. Launceston Flood Authority is responsible for ensuring that work activities and machinery do not cause a hazard to the public.

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***Signed by Stan Matuszek being the Regional Operations Manager, North pursuant to an Instrument of Delegation under the National Parks and Reserve Management Act 2002 dated 10th April 2008.***

Matuszek

***Date: 20th May 2013***

Your personal information will be used for the primary purpose for which it is collected, and may be disclosed to contractors and agents of the Department of Primary Industry, Parks, Water and Environment (DPIPWE), law enforcement agencies, courts and organisations authorised to collect it.

Your basic personal information may be disclosed to other public sector bodies where necessary for the efficient storage and use of the information. Personal Information will be managed in accordance with the *Personal Information Protection Act 2004* and may be accessed by the individual to whom it relates on request to the DPIPWE. You may be charged a fee for this service.

Approval and Authority To Undertake Works Associated with Sediment Raking Program within the Tamar Conservation Area

***Granted to:***
Kathryn Pugh
or nominated contractor
Launceston Flood Authority
City of Launceston

Pursuant to Regulation 26 of the National Parks and Reserved Land Regulations 2009, this authority is granted to undertake works, subject to the conditions listed below that would otherwise be prohibited under Regulations 4(1)(b), 4(1)(c) and 4(7)(c) of the National Parks and Reserved Land Regulations 2009.

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***Authority or approval valid**: From: 8th August 2018 To: 22nd August 2018*

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***Conditions***

1. Unless otherwise approved in writing by the Director EPA, the sediment raking must be implemented in accordance with the approved 2013 Sediment Raking Monitoring Plan.
2. All sediment raking works must be undertaken consistent with the Sediment Raking Scoping Document and Sediment Raking Monitoring Plan (attached) unless otherwise approved by the Parks and Wildlife Service.
3. Prior to the commencement of works, the Launceston Flood Authority must obtain all necessary permits required under the *Land Use Planning and Approvals Act 1993, Threatened Species Protection Act 1993* and ensure any Marine and Safety Tasmania (MAST) requirements are met.
4. The Launceston Flood Authority must provide public notification and timing and extent of the activity before works commence. The Launceston Flood Authority must consult with relevant commercial operators to ensure minimal impact on their operations. Where possible and as far as is practical sediment raking activities should minimise disturbance to commercial and community activities within the reserve.
5. Prior to the commencement of works, Launceston Flood Authority must investigate and identify services and infrastructure above or below the river bed that may be affected by the raking program. Sediment raking activities must not adversely impact on any such infrastructure.
6. This Authority may be cancelled by notice in writing from the Director of National Parks and Wildlife Tasmania.
7. This Authority must be carried at all times during the undertaking of works associated with this authority, and produced if required to do so, by an authorised person or an authorised officer under the *National Parks and Reserves Management Act 2002.*
8. The Launceston Flood Authority must exercise due caution, care and respect for other users of the reserved land to ensure that other users are not displaced or have their experience diminished through the exercise of this authority. Launceston Flood Authority is responsible for ensuring that work activities and machinery do not cause a hazard to the public.

*Disclaimer*
Persons entering or conducting activities on reserved land pursuant to this authority do so entirely at their own risk. Liability is not accepted by the State of Tasmania or the Department of Primary Industry, Parks, Water and the Environment for any injury, loss or damage suffered by any such person, whether resulting from negligence or any other cause.

***Signed by Stanley Matuszek being the Acting Regional Manager, North pursuant to an Instrument of Delegation dated 25th September 2015***

***Date: 7th August 2018***

Your personal information will be used for the primary purpose for which it is collected, and may be disclosed to contractors and agents of the Department of Primary Industry, Parks, Water and Environment (DPIPWE), law enforcement agencies, courts and organisations authorised to collect it.

Your basic personal information may be disclosed to other public sector bodies where necessary for the efficient storage and use of the information. Personal Information will be managed in accordance with the *Personal Information Protection Act 2004* and may be accessed by the individual to whom it relates on request to the DPIPWE. You may be charged a fee for this service.

## Approval and Authority To Undertake Works Associated with Sediment Raking Program within the Tamar Conservation Area

***Granted to:***
Kathryn Pugh
or nominated contractor
Launceston Flood Authority
City of Launceston

Pursuant to Regulation 26 of the National Parks and Reserved Land Regulations 2009, this authority is granted to undertake works, subject to the conditions listed below that would otherwise be prohibited under Regulations 4(1)(b), 4(1)(c) and 4(7)(c) of the National Parks and Reserved Land Regulations 2009.

***Authority or approval valid:*** *From: 22 September 2018 To: 21 September 2019*

***Conditions***

1. Unless otherwise approved in writing by the Director EPA, the sediment raking must be implemented in accordance with the approved 2013 Sediment Raking Monitoring Plan.
2. All sediment raking works must be undertaken consistent with the Sediment Raking Scoping Document and Sediment Raking Monitoring Plan (attached) unless otherwise approved by the Parks and Wildlife Service.
3. Prior to the commencement of works, the Launceston Flood Authority must obtain all necessary permits required under the *Land Use Planning and Approvals Act 1993, Threatened Species Protection Act 1993* and ensure any Marine and Safety Tasmania (MAST) requirements are met.
4. The Launceston Flood Authority must provide public notification and timing and extent of the activity before works commence. The Launceston Flood Authority must consult with relevant commercial operators to ensure minimal impact on their operations. Where possible and as far as is practical sediment raking activities should minimise disturbance to commercial and community activities within the reserve.
5. The Launceston Flood Authority must notify the Director of the Environmental Protection Authority, West Tamar Council and Van Diemen Aquaculture prior to the each silt raking activity commencing and provide details on the timing and extent of the activity.
6. Ninety days prior to the expiry of this permit the Launceston Flood Authority must provide a review of data collected under the Sediment Raking Monitoring Plan that incorporates data collected under the granted permit between 20 May 2013 and 20 May 2018 and where practical data collected under this permit.
7. The Launceston Flood Authority must provide data reports to the Director of the Environmental Protection Authority as soon as practical after each silt raking campaign.
8. Prior to the commencement of works, Launceston Flood Authority must investigate and identify services and infrastructure above or below the river bed that may be affected by the raking program. Sediment raking activities must not adversely impact on any such infrastructure.
9. The Launceston Flood Authority must maintain a complaints register and provide this to Parks and Wildlife Service Tasmania on request.
10. This Authority may be cancelled by notice in writing from the Director of National Parks and Wildlife Tasmania.

11. This Authority must be carried at all times during the undertaking of works associated with this authority, and produced if required to do so, by an authorised person or an authorised officer under the *National Parks and Reserves Management Act 2002*.

12. The Launceston Flood Authority must exercise due caution, care and respect for other users of the reserved land to ensure that other users are not displaced or have their experience diminished through the exercise of this authority. Launceston Flood Authority is responsible for ensuring that work activities and machinery do not cause a hazard to the public.

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***Signed by Robert Buck being the Acting Regional Operations Manager, North pursuant to an Instrument of Delegation dated 25th September 2015***

***Date: 21 September 2018***

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LAUNCESTON
FLOOD AUTHORITY

## 2013 SEDIMENT RAKING SCOPING DOCUMENT

**SCOPE OF WORKS:**

| | |
|---|---|
| Location: | In the North Esk River from the confluence of the North Esk and the Tamar Rivers to the Charles Street Bridge, and in the Tamar River extending north to 100 metres beyond the Tailrace junction in the Tamar River estuary, maintaining minimum 20 metre buffer to all riverbank edges within the conservation area. |
| Duration: | Monthly campaigns centred around the new moon tide or flood event. Each campaign will rake for 10 days and or nights on each ebb tide. |
| Process: | Raking to occur at beginning of ebb tide utilising velocity from ebb tide flows of approximately 200 cumecs or greater. |
| Sampling & Monitoring: | Detailed in Monitoring Plan as approved by EPA. |

**VESSEL DETAILS:**

| | |
|---|---|
| Owner/Captain: | Karl Krause<br>0428 573 076 |
| Vessel Name: | FV Karmin (2002) |
| Size: | 16m steel hull |
| Powered by: | 330 hp |
| Propeller dimensions: | 4.5/1 propeller reduction<br>52" diameter propeller<br>42.5" pitch |

**RAKE DETAILS:**

| | |
|---|---|
| Weight: | 1.5 tonne |
| Dimensions: | 4.0m long x 2.0m wide |
| Raking Tines: | 1.0m tines (400 mm- effective rake depth) at 55mm centres |

LAUNCESTON
FLOOD AUTHORITY

**2013 SEDIMENT RAKING MONITORING PLAN**

**MONITORING TO ASSESS THE SUCCESS OF SEDIMENT RAKING:**

**Key Indicators:**

a. ***Volume of sediment removed.***

Bathymetric surveys will be conducted by LCC and volumetric assessment of sediment will be determined. Surveys will consist of historical cross sections from the Yacht Basin to north of Stephenson's Bend with full survey taken from the Yacht Basin to Kings Wharf. Bathymetric surveys will be undertaken at the following times:

- Prior to first raking campaign to establish baseline condition
- Following first raking campaign to assess volume of sediment removed
- Prior to second raking campaign to assess accumulation between campaigns
- Thereafter following each monthly campaign

b. ***Location of Re-deposition.***

Passive Sampling shall be undertaken at four (4) locations as agreed with the EPA downstream of the raking. Each sampler shall have a collecting surface of 17,675mm² and shall be assessed for the following properties after a seven (7) day collection period during raking campaigns and during non-raking periods. Properties to be assessed are:

- Particle size of sediments deposited
- Total mass and settling rate

A bulk sample will be collected from the area to be raked. Properties to be assessed are:

- Particle size of sediments deposited
- Total mass and settling rate

Data collected will be compared with and used for calibration of the BMT WBM Hydraulic Model of the Tamar River estuary when the 3D version is available.

**WATER QUALITY MONITORING:**

Water quality will be monitored for:

| | |
|---|---|
| Field: | Dissolved Oxygen, pH, conductivity |
| Analysis: | Total Nitrogen, Total Phosphorous, Ammonia, Metals, Nitrate ($NO_3$) and Nitrite ($NO_2$)<br>Dissolved Nitrogen, Phosphorous, Ammonia, Metals |

Grab samples must be collected:

- Upstream of the sediment raking, during each day, during the ebb tide
- Downstream during the raking where four (4) samples collected at 15 minute intervals shall be composited to form one sample.

The location and time of all samples taken must be recorded.

APPROVAL AND AUTHORITY TO UNDERTAKE WORKS ASSOCIATED WITH SEDIMENT RAKING PROGRAM WITHIN THE TAMAR CONSERVATION AREA

***Granted to:***
Kathryn Pugh
or nominated contractor
Launceston Flood Authority
City of Launceston

Pursuant to Regulation 26 of the National Parks and Reserved Land Regulations 2009, this authority is granted to undertake works, subject to the conditions listed below that would otherwise be prohibited under Regulations 4(1)(b), 4(1)(c) and 4(7)(c) of the National Parks and Reserved Land Regulations 2009.

***Authority or approval valid**: From: 22nd August 2019 To: 27th September 2019*

***Conditions***

1. This Authority may be cancelled by notice in writing from the Director of National Parks and Wildlife Tasmania.
2. The Launceston Flood Authority must provide a review of data collected under the Sediment Raking Monitoring Plan that incorporates data collected under the granted permit between 20 May 2013 and 20 May 2018 and where practical data collected under this permit. This review must be provided prior to the expiry of this permit.

***Disclaimer***
**Persons entering or conducting activities on reserved land pursuant to this authority do so entirely at their own risk. Liability is not accepted by the State of Tasmania or the Department of Primary Industry, Parks, Water and the Environment for any injury, loss or damage suffered by any such person, whether resulting from negligence or any other cause.**

***Signed by Stanley Matuszek being the Regional Operations Manager, North pursuant to an Instrument of Delegation dated 25th September 2015***

***Date: 22nd August 2019***

**Your personal information will be used for the primary purpose for which it is collected, and may be disclosed to contractors and agents of the Department of Primary Industry, Parks, Water and Environment (DPIPWE), law enforcement agencies, courts and organisations authorised to collect it.**

**Your basic personal information may be disclosed to other public sector bodies where necessary for the efficient storage and use of the information. Personal information will be managed in accordance with the *Personal Information Protection Act 2004* and may be accessed by the individual to whom it relates on request to the DPIPWE. You may be charged a fee for this service.**

**Appendix 2 Kelly 2019 An analysis of the impacts of sediment raking on the kanamaluka/Tamar River Estuary**

Tamar Estuary and Esk Rivers

# An analysis of the impacts of sediment raking on the kanamaluka/Tamar River Estuary

Dr Rebecca Kelly

August 2019

**CITATION:**

Kelly, R. (2019). An analysis of the impacts of sediment raking on the kanamaluka/Tamar River Estuary, Report to City of Launceston and the Tamar Estuary and Esk Rivers (TEER) Program, August 2019.

# Executive Summary

Sedimentation in the upper kanamaluka/Tamar River Estuary is commonly cited as an issue of concern by community members. In particular the presence of visible mudflats in and around Launceston has frequently been raised as a concern. Visible mudflats and sedimentation were a feature of the estuary before European settlement. Extensive dredging between the 1880's and 1960's was used to reduce sedimentation and increase navigability of the estuary to allow large ships to navigate to the port in Launceston. In the 1960's the port facilities were moved to Bell Bay and the need for large scale dredging for navigation ceased. Dredging recommenced in 1988 in areas south of the Ship lift with a smaller scale program which ran until 2009. This program ceased due to the costs being unsustainable.

In 2012 the Launceston Flood Authority (LFA) ran a trial of sediment raking. This involves agitation of bottom sediments using a scallop dredge with the intention that these unconsolidated sediments are then able to be dispersed downstream with river flows. In 2013 the LFA received a 5-year permit from the EPA for allowing them to continue sediment raking activities[1]. This permit required water quality monitoring in the vicinity of the sediment rake during and immediately following sediment raking activities (upstream and in the plume).

A comprehensive analysis of the extent to which sediment raking has achieved its objectives and the nature and extent of its impacts on water quality has not previously been undertaken. This report contains a review of data to assess these two factors. A working group was formed under the Tamar Estuary and Esk Rivers (TEER) Program to provide advice on the scope of the review and the objectives against which sediment raking should be assessed. These objectives covered aesthetics with regard to the visible sediment shoals around the western bank, Royal Park, North bank and Seaport, recreational access and navigability of the channel, and mitigation of flood risks through reduced sedimentation in the Yacht basin and upper estuary. Other impacts raised as important to consider by the working group related to water quality and ecosystem health.

## Did sediment raking achieve its objectives?

This report details comprehensive analysis of bathymetry data from the upper estuary around Launceston. This analysis considers changes in sediment volumes and average depths in nine regions of the upper estuary extending from Kings Bridge to just past the Ship lift and into the lower North Esk and Seaport. The analysis focuses on three historic periods – the period of data before sediment raking commenced (Jan 2008 to Jun 2013 – note this includes the small sediment raking trial in Sept 2012); the period after sediment raking commenced until the 2016 flood (Jul 2013 to early Jun 2016); and the period after the flood which also included sediment raking (mid Jun 2016 to Nov 2018). The period after the commencement of the sediment raking was split to before and after the 2016 flood to reflect the large impact a flood event of this scale[2] would be expected to have on sedimentation regardless of any sediment raking activities.

[1] Information in this section has been taken from LFA (2016).

[2] The June 2016 flood was a 1 in 200 year event in the North Esk and 1 in 50 year event in the South Esk. During the flood there were 4 consecutive days of more than 1500 cumecs of total flow entering the Tamar Estuary from the two river systems.

This analysis shows that:

- Aesthetics - Sediment levels in the West Bank have been reduced as a result of sediment raking. Sediment raking has not had a sustained benefit in terms of reduced visible shoals around Royal Park and North bank, with greater levels of sediment in these areas by the end of the period of raking just before the 2016 flood than was the case pre-raking.
- Navigation and access – sediment raking has led to significant infilling of the main channel with between 0.5m to 1m of additional sediment in the channel compared to pre-raking. The 2016 flood was not able to reduce sediment levels in parts of the channel to pre-raking levels. Sediment levels in the channels have continued to increase since this flood. These increases are likely to be impacting on the navigability of the channel, particularly with regards to access to the Seaport, for the Home Point tourist boat and to the Ship lift.
- Flood risk – a detailed assessment of the impacts on sediment raking on flood risk was not within the scope of this project. In the past mass movement of sediment out of the upper estuary has been used as the primary indicator for assessing changes in flood risk. Sediment raking did not lead to mass movement of sediments out of the upper estuary, with sediment volumes just before the 2016 flood higher than volumes recorded in the period before raking commenced. The 2016 flood did mobilise large volumes of sediment out of the upper estuary but much of this sediment has since returned even with continued sediment raking programs through this period. The significant infilling of the channel and reduced effectiveness of large scale flood events such as the 2016 flood to scour the channel that has occurred since sediment raking commenced is not consistent with reduced flood risk.
- Seaport and North Esk - reduced sediment levels in the Seaport have been achieved by frequent prop washing of sediments from the marina into the North Esk. The data shows that sediment returns relatively rapidly to this area between interventions but that repeat prop washing is able to maintain reduced sediment levels in the Seaport. Access to the Seaport has however been compromised with infill of channels in the North Esk and around its confluence with the Tamar estuary likely as a result of sediments washed out of the Seaport marina into the North Esk channel as well as unconsolidated sediments in the Tamar estuary being pushed into the North Esk on incoming tides.

The analysis of the bathymetry data shows clearly that sediment raking has not achieved the majority of objectives for which it has been proposed in the past and that there are substantial trade-offs between achieving objectives associated with aesthetics of the shoals and navigability of the channels associated with sediment raking activities.

## What impacts has sediment raking had on water quality?

Two sources of water quality data were used to assess the impacts of sediment raking on water quality:

- Data collected by the Launceston flood authority during sediment raking campaigns immediately upstream and downstream of raking activities. This data provides information on the localised (temporal and spatial) impacts of sediment raking on water quality.
- Data collected by the TEER Ecosystem Health Assessment Program (EHAP) consisting of monthly grab samples collected for the length of the estuary (at 16 to 18 sites) over a ten year period. This data has gaps where data was previously collected on a 2 year on-2 year off basis. While this data was not collected for the purposes of evaluating the impacts of sediment raking it provides a useful source of long term data which can be used to look for evidence of longer term and broader spatial scale impacts.

Analysis of localised water quality impacts shows that sediment raking releases large concentrations of sediments, nutrients and heavy metals into the water column. Increases are seen across all total water quality parameters as well as for some dissolved parameters. Increases in parameter concentrations are in many cases one to two orders of magnitude greater than the ANZECC default guideline value for the parameter (and for aluminium closer to three orders of magnitude greater), indicating impacts on localised water quality that are likely to be ecologically significant.

A further analysis looking for longer term and larger spatial scale impacts has also been conducted using data collected as part of the TEER EHAP. This data consists of monthly ambient water quality samples collected on a two year on, two year off basis at 16 sites along the extent of the estuary. This data was never collected with the intention of assessing impacts of sediment raking and so is not 'fit-for-purpose' to reject the hypothesis that there have been water quality impacts. It is possible however to use this data to look for evidence of impacts of sediment raking on water quality. Data on heavy metals is particularly limited with significant temporal gaps (it was collected quarterly rather than monthly) and issues where data, particularly for dissolved metals, falls below the limits of reporting. Two types of impacts were explored with this EHAP data – immediate impacts within the days following a raking event (up to a week); and, longer term impacts out to 3 weeks post sediment raking considering the relative sediment raking effort within that period. While there were limited data points from which to develop regression models for each water quality parameter, results across nutrients, sediments and metals data showed very consistent patterns of impact, increasing the confidence that can be placed on findings. In general, sediments and total pollutants increase in the upper estuary (to around Blackwall) in the days after sediment raking (out to a week after sediment raking ceases). Dissolved pollutants, turbidity and some heavy metals including total aluminium are then impacted over a longer time scale, with impacts seen further downstream as the length of the preceding period considered increases. Impacts on DRP, ammonia, NOx, turbidity, total aluminium and total iron are seen to Clarence Point when raking has occurred in the preceding two to three weeks. Importantly the relative effort of raking within the period impacts concentration, not just the presence or absence of raking in the period. Some nutrients and heavy metals also remain elevated in the upper estuary for at least 2 to 3 weeks after raking ceases. Results show a 'pulse' effect where initial impacts are focused in the upper estuary but impacts on dissolved nutrients, turbidity and some metals extend to the lower estuary over a longer period of time. The effects of flows on these relationships were also considered. It was found that in most cases where parameter concentration is significantly correlated with sediment raking, catchment inflows are either not correlated with parameter concentrations or act to reduce the impacts of sediment raking effort on concentrations, presumably through dilution of water quality parameters.

The results also show that in order to accurately determine what the impacts of sediment raking or similar activities in the upper estuary, a ‘fit for purpose’ monitoring regime requires data collection through the mid and lower estuary, should consider nutrients and metals as well as sediments and should be event based, measuring water quality before, during and for a period of several weeks after sediment raking.

# Contents

## List of figures

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## List of acronyms

ANZECC - Australian and New Zealand Environment and Conservation Council

DGV – default guideline value

DRP - dissolved reactive phosphorus

EHAP - Ecosystem Health Assessment Program

EPA - Environment Protection Authority

IMAS – Institute of Marine and Antarctic Studies (at University of Tasmania)

LFA - Launceston Flood Authority

LOR – limits of reporting

NOx - nitrate plus nitrite

NRM – Natural Resource Management

STC - Scientific and Technical Committee

TEER - Tamar Estuary and Esk Rivers

TKN – Total Kjedahl Nitrogen

TN - Total Nitrogen

TP - Total Phosphorus

TSS - Total Suspended Sediment

WQO – Water Quality Objective

# 1 Introduction

Sedimentation in the upper kanamaluka/Tamar River Estuary is commonly cited as an issue of concern by community members. In particular the presence of visible mudflats in and around Launceston has frequently been raised as a concern. Visible mudflats and sedimentation were a feature of the estuary before European settlement. Extensive dredging between the 1880's and 1960's was used to reduce sedimentation and increase navigability of the estuary, to allow large ships to navigate to the port in Launceston. In the 1960's the port facilities were moved to Bell Bay and the need for large scale dredging for navigation ceased. Dredging recommenced in 1988 in areas south of the Ship lift with a smaller scale program which ran until 2009. This program ceased due to the costs being unsustainable.

In 2012 the Launceston Flood Authority ran a trial of sediment raking. This involves agitation of bottom sediments with a scallop dredge with the intention that these unconsolidated sediments are then able to be dispersed downstream with river flows. In 2013 the LFA received a 5-year permit allowing them to continue sediment raking activities[3]. This permit had requirements for water quality monitoring in the vicinity of the sediment rake during sediment raking activities (upstream and in the plume). A tracer study was also commissioned by the LFA (AMCS, 2015). This study was designed to 'assess the dispersal and fate of fine sediment including determining whether any material accumulates or settles out in sensitive areas of the estuary'. The study involved releasing two tracers in the estuary to mimic raked and natural fine sediments. The study found that for the conditions monitored (low flow), raking 'is not as effective as assumed and not facilitating movement of material as far down estuary as expected or wanted'. Results from the 'natural' tracer indicated that during higher flow conditions more typical of winter, raked material could potentially be transported to and be visible in the lower estuary.

Despite the monitoring data and tracer study, there is relatively little information on where sediments mobilised by sediment raking go, the extent to which sediment raking has met its various objectives and the impacts it has on water quality longer term and outside the immediate area where sediment raking occurs. In particular the impact of raking on pollutants other than fine sediment in the mid to lower estuary has not been assessed.

This report summarises an analysis of historical data to assess:

- the extent to which sediment raking has achieved its objectives, and
- the nature and extent of unintended impacts on water quality.

## 1.1 Working group

In order to define the scope of the project and the objectives for which sediment raking has been proposed and against which it should be assessed, a working group was formed under the Tamar Estuary and Esk Rivers (TEER) Program Scientific and Technical Committee (STC). This working group was tasked in the first instance with scoping out the objectives, impacts of concern and available data sets that could be used in the analysis. Working group members included representatives from IMAS, EPA, Hydro Tasmania, City of Launceston, Petuna, West Tamar Council and NRM North.

[3] Information in this section has been taken from LFA (2016).

## 1.2 Potential objectives for sediment raking

Objectives which have previously been cited for sediment raking which were identified by the working group are:

- Flood defence and to ensure the flood levees are working appropriately (funded primary objective).
- To achieve mass movement of sediment from all areas of the upper reaches of Zone 1 (ie. around Launceston).
- Improved aesthetics in particular ensuring that it's not possible to see the expanse of mudflats at low tide or mud in and around the Seaport.
- Navigation in particular keeping the main channel open such that vessels are not getting stuck in the mud at low tide.
- Ecosystem health (an original objective of sediment raking stated in the Tamar River Recovery Plan).
- Recreational access in particular such that Tamar Rowing Club, Tamar Yacht Club, and Seaport Marina have improved useability of their facilities.
- To enable activities around the Ship lift to occur (eg. ensuring boats can access this facility).
- To ensure access for the Home point tourist boat (Tamar cruises), to reduce shoals which are impacting on access and ensure navigability for the boat.

## 1.3 Potential unintended impacts which should be considered

The second major consideration in reviewing past sediment raking programs is the extent and nature of unintended impacts it may have caused. Key possible impacts of concern identified by the working group are:

- Downstream ecosystem impacts
  - Water quality – ecosystems should be protected and within the range of water quality guidelines.
  - Sediment quality and biological condition, including smothering.
- Increased visible shoals and loss of aesthetics in the West Tamar.
- Impacts on aquaculture
  - Potential for increased stress on fish and possible fish kills associated with sediment raking during warmer months.
  - Impacts on fish health due to pollutants in the water column, especially heavy metal toxicity.
- Impacts on Grayling migration (negatively impacted by poor water quality and high turbidity).
- Navigation in lower parts of Zone 1, especially around Riverside and Legana with channel infill and shoals.
- Water quality including pathogens and metals with the potential for sediment raking to disperse pollutants bound in the sediment into the water column.
- Release of acid downstream where exposed sediments and shoals occur.

## 1.4 Scope of the analysis

With the data currently available it is not possible to analyse the impact of sediment raking on all objectives and potential unintended consequences. A scope of works was developed in consultation with the working group and has been grouped into the following components:

- Sediment movement
    - Within the upper estuary
    - Out of the upper estuary and its impacts downstream (constrained by the limited spatial extent of bathymetry data).
- Water quality
    - Immediate impacts of sediment raking on water quality
    - Assessment of sediment raking impacts on longer-term trends in water quality.

While of significant interest, it was deemed that a detailed assessment of the impacts on flood mitigation is outside the scope of the project given the considerable expense in modelling these scenarios. Notwithstanding the Launceston Flood Authority used 'net sediment loss from the upper estuary' as their key measure of the success of sediment raking in providing flood protection. As such some conclusions about the impacts of sediment raking on flood defence are able to be made using this metric.

This report first considers the impacts of sediment raking on sediment levels in the upper estuary using bathymetry data provided by City of Launceston. The next two major sections consider water quality impacts, first localised and short term in the vicinity of raking activities, then at larger spatial and temporal scales. The final section provides a summary of the extent to which sediment raking has met the objectives outlined above and caused unintended impacts on water quality.

## 2 Impacts on Bathymetry

This section summarises results of analysis of bathymetry data provided by City of Launceston for the upper kanamaluka/Tamar River Estuary. This data covers the period before and after sediment raking commenced in the estuary (the final date for bathymetry data analysed is 21 November 2018). Previously this data has been used to consider mass movement of sediment into and out of the upper estuary (covering the whole of Sections 1 to 4 in Figure 1 below). In this report, the data has been reanalysed for a series of spatial areas in the upper estuary to consider the movement of sediment between sections of the upper estuary. Figure 1 shows the location of sections used for this analysis. Note that data before sediment raking is largely limited to Sections 1 to 4.


| Section number | Name |
|---|---|
| 1 | Royal Park |
| 2 | Upper Channel |
| 3 | Upper West Bank |
| 4 | Mid Channel |
| 5 | Lower Channel |
| 6 | Lower West Bank |
| 7 | North Bank |
| 8 | North Esk |
| 9 | Seaport |

*FIGURE 1. LOCATION OF SECTIONS USED IN THIS ANALYSIS*

Data on sediment raking and flows from the North Esk and South Esk Rivers are used to inform the analysis. Data on the sediment raking program is sparse, with at most only descriptive qualitative information available on the focus area of effort on a specific day. In this analysis, sediment raking is treated as a 'yes' or 'no' for the individual day with sediment raking effort over a period being considered the number of days of raking. It is likely that locational differences and time spent raking on days has an impact on outcomes which are not assessed in this analysis.

## 2.1 Changes in sedimentation in sections 1 to 4 of the Upper Tamar Estuary

This section describes the changes in sediment levels as a result of sediment raking and the major flood event in June 2016 in Sections 1 to 4 of the estuary. A range of analysis is conducted to describe changes in each section. For ease of interpretation results are described for a section of the estuary at a time. A synthesis of these results and the trade-offs between raking objectives is provided later in the report. For all sections, 3 time periods are considered in the analysis:

- Pre-raking: (Jan 2008 to Jun 2013). The period before raking began noting that the sediment raking trial in 2012 is included in this period as it was relatively small scale and had a small and very temporary impact on sediment volumes.
- Raking before the flood: (Jul 2013 to early Jun 2016). The period during which raking occurred before the major floods in June 2016.
- Raking after the flood: (mid Jun 2016 to Nov 2018). The period after the 2016 flood.

The period after the commencement of the sediment raking was split to before and after the 2016 flood to reflect the large impact a flood event of this scale[4] would be expected to have on sedimentation regardless of any sediment raking activities.

### 2.1.1 Total for Sections 1 to 4

Figure 2 shows the total volume of sediment in Sections 1 to 4 above RL-10[5], relative to flows and sediment raking effort. Flows plotted on these figures are the total flow down the North and South Esk rivers on the day. Days where sediment raking occurred are also shown. Bathymetry data was collected at intervals varying between 6 and 133 days with measurements usually taken at an interval of between one and two months. Trend lines have been estimated for the 3 periods – pre-raking; sediment raking before the 2016 flood; and sediment raking after the 2016 flood. Note that regression parameters and statistics of fit for these trend lines are provided in

[4] The June 2016 flood was a 1 in 200 year event in the North Esk and 1 in 50 year event in the South Esk. During the flood there were 4 consecutive days of more than 1500 cumecs of total flow entering the Tamar Estuary from the two river systems.

[5] RL-10 refers to the river level minus 10m. Discussions of sediment depth are in height above this 10m depth.

Table 1. As can be seen in this figure:

- The commencement of sediment raking in 2013 coincided with large flow volumes. The combined effect of this was to reduce sediment volumes to their lowest level to date in the time series. Larger flows than those in 2013 were experienced without raking in 2009 but resulted in a smaller decrease in sediment.
- The trend line for the period before the commencement of sediment raking is only weakly significant ($p$-value ~0.08) and is negative.
- Sediment levels dropped substantially when sediment raking commenced. After this large drop in sediment volumes, there was a steep and significant trend of increasing sediment until the 2016 floods. Note that sediment raking and flow events in this period did decrease sediment volumes temporarily but the overall trend was an increase of sediment volume of approximately 80m$^3$ per day. Just prior to the 2016 floods total sediment volumes in these 4 sections had increased to just over their peak level before sediment raking commenced.
- The 2016 flood led to very large decreases in sediment volumes in Sections 1 to 4, more than 20,000m$^3$ below the previous low after the commencement of raking. This was followed by a steep and statistically significant upward trend of approximately 73m$^3$ per day. Note that this trend appears to have been slowed by sediment raking campaigns in 2017 and 2018. Sediment volumes have returned to levels greater than after the commencement of sediment raking but as of the end of the time series (November 2018) had not yet returned to pre-sediment raking levels.

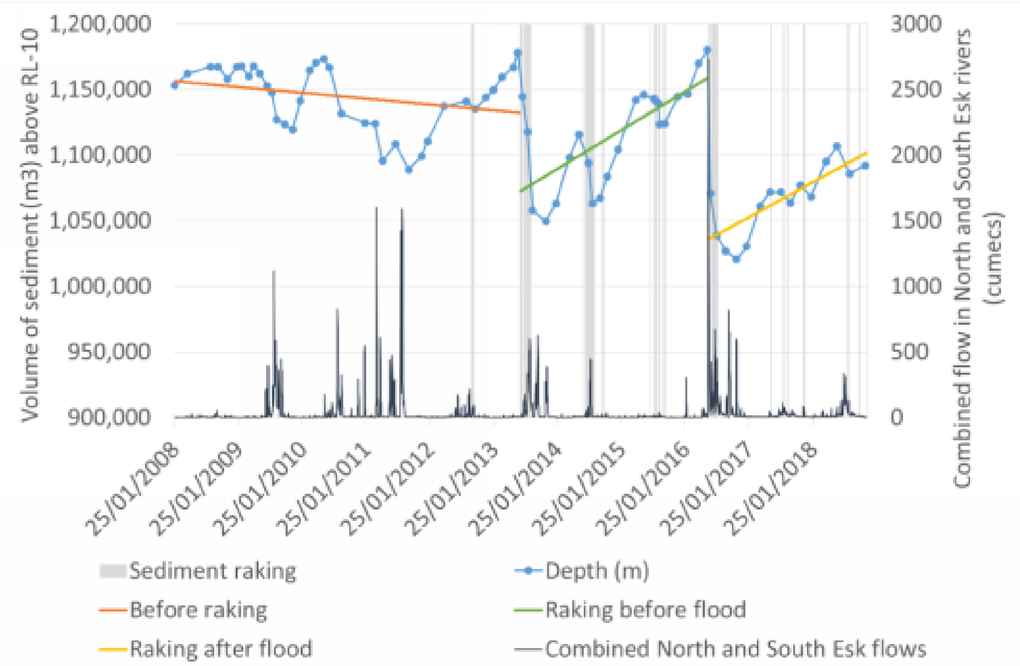



*FIGURE 2. TOTAL SEDIMENT VOLUME (M3) AND TRENDS BEFORE RAKING, RAKING BEFORE THE 2016 FLOOD AND RAKING AFTER THE 2016 FLOOD IN SECTIONS 1 TO 4 VERSUS COMBINED DAILY FLOW FROM NORTH AND SOUTH ESK AND SEDIMENT RAKING PERIOD*

*TABLE 1. TREND REGRESSION PARAMETERS FOR TOTAL SECTIONS 1 TO 4 (NOTE GREEN=STATISTICALLY SIGNIFICANT TREND AT 95% LEVEL OF CONFIDENCE, ORANGE=WEAKLY SIGNIFICANT TREND BETWEEN 85% AND 95%, RED=NO SIGNIFICANT TREND)*

| | Before Raking | Raking before flood | Raking after flood |
|---|---|---|---|
| $R^2$ | 0.085 | 0.491 | 0.633 |
| F significance | 0.084 | 0 | 0 |
| Intercept | 1156312 | 1072138 | 1035573 |
| Trend ($m^3$ per day) | -12.2 | 80.6 | 72.9 |
| *p*-value Intercept | 8.12E-50 | 3.34E-29 | 6.39E-22 |
| *p*-value Trend | 0.0837 | 0.0002 | 0.0004 |

Figure 3 shows a box plot of the data for the total sediment volume in Sections 1 to 4. This shows that the period of raking before the flood was characterised by a broader range of sediment volumes, with maximum levels just above those for the period before raking and minimum values well below. The median, 75th and 25th percentiles were all well below those from before raking. The period of raking after the flood corresponds to lower values than the period of raking before the flood, noting that it is unlikely that the sediment volumes have finished trending upwards and reached an equilibrium.

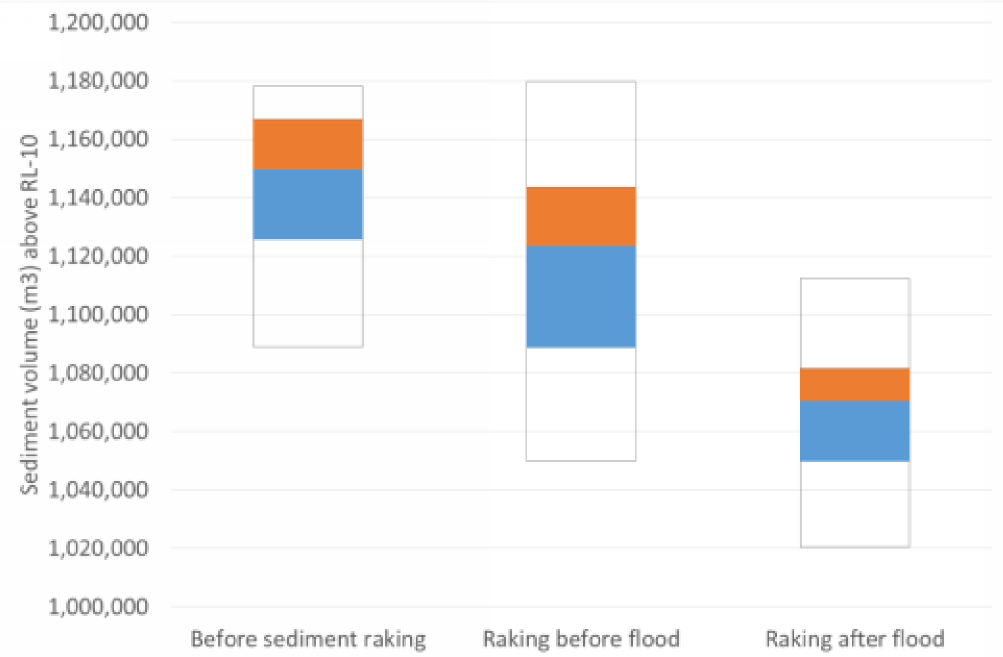



*FIGURE 3. TOTAL SEDIMENT VOLUME ABOVE RL-10 FOR SECTIONS 1 TO 4: BOX PLOT COMPARISON FOR THREE PERIODS. CLEAR BOXES INDICATE RANGE (MAX AND MIN VALUE), BLUE IS THE 1ST QUARTILE TO MEDIAN VALUE, ORANGE IS MEDIAN VALUE TO 3RD QUARTILE.*

### 2.1.2 Section 1 – Royal Park

This section analyses changes in sediment levels in Section 1 – Royal Park. Note that these levels and trends are described here using an average depth over the section (in metres) so as to allow more meaningful comparisons between sections given their different areas. Total volumes of sediment moved in and out of sections are also described in the text using volumes of sediment ($m^3$).

Figure 4 shows the trends in sediment depth in Section 1 – Royal Park in the 3 periods – before sediment raking, during sediment raking before the 2016 flood and after the 2016 flood. As was the case for total sediment volumes, sediment raking effort and flows down the North Esk and South Esk Rivers are also shown. Regression parameters and statistics of fit for the trend lines are given in Table 2. A box-plot summarising data from each of the 3 periods is shown in Figure 5.

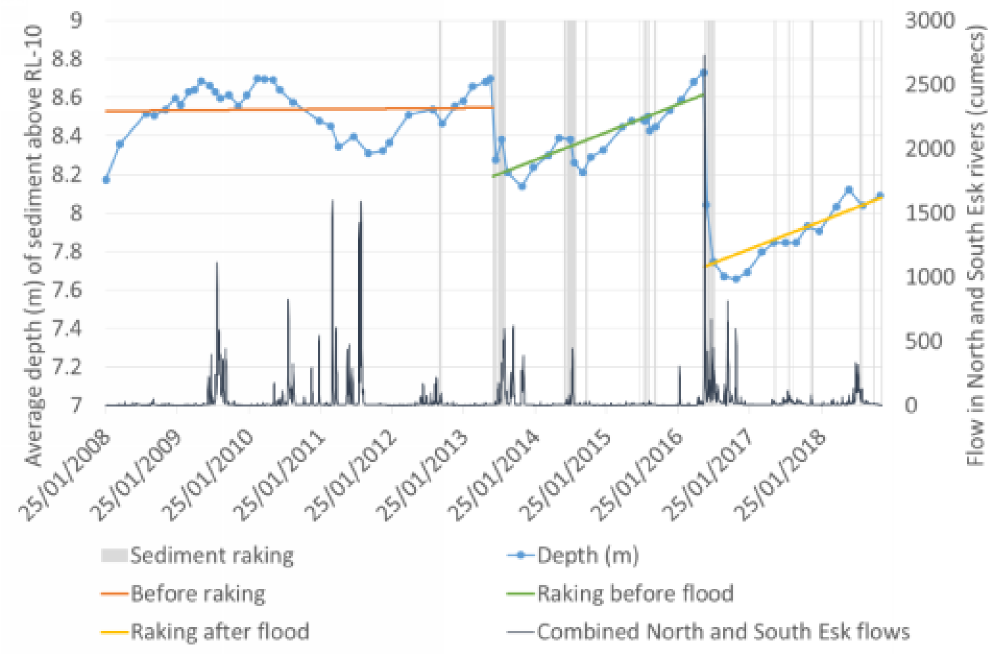



*FIGURE 4. SECTION 1 – ROYAL PARK: TRENDS IN AVERAGE SEDIMENT DEPTH ABOVE RL-10 (M) BEFORE RAKING, DURING THE RAKING PERIOD BEFORE THE 2016 FLOODS AND AFTER THE 2016 FLOODS VERSUS COMBINED DAILY FLOW FROM NORTH AND SOUTH ESK AND SEDIMENT RAKING*

*TABLE 2. TREND REGRESSION PARAMETERS FOR SECTION 1 – ROYAL PARK*

| | Before raking | Raking before flood | Raking after flood |
|---|---|---|---|
| $R^2$ | 0.001 | 0.727 | 0.522 |
| F significance | 0.825 | 0 | 0.002 |
| Intercept | 8.53 | 8.19 | 7.72 |
| Trend (m per day) | 8.56E-06 | 0.000395 | 0.000396 |
| *p*-value Intercept | 8.22E-54 | 7.41E-38 | 2.09E-22 |
| *p*-value Trend | 0.825 | 2.4E-07 | 0.00235 |

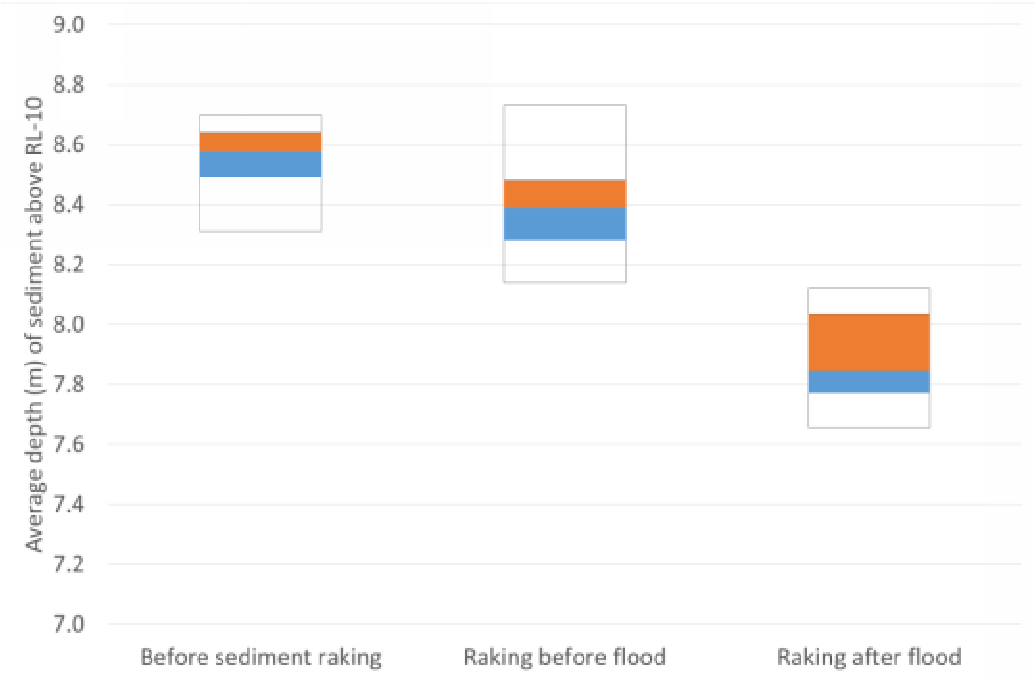



*Figure 5. Section 1 – Royal Park: Box plot comparison for three periods. Clear boxes indicate range (max and min value), blue is the 1st quartile to median value, orange is median value to 3rd quartile.*

These figures show:

- Before sediment raking commenced sediment levels in the Royal Park area were relatively stable with no significant trend.
- The commencement of raking combined with a substantial flow event led to an immediate drop of over 0.5m in sediment levels. This period then saw a steady increasing trend in sediment levels with temporary drops after sediment raking campaigns and flow events (~0.2m after combined sediment raking and flow versus approx. 0.07m from sediment raking alone). The trend in sediment during this period of sediment raking before the flood is statistically significant and equivalent to approximately 5.4m$^3$ of sediment accumulation per day or 25.3 days per cm of sediment accumulated in this section of the estuary. The box plot shows that while the median, minimum and quartiles of sediment levels during this period are less than before sediment raking, the maximum sediment level is greater.
- The 2016 flood and associated sediment raking led to a very substantial drop in sediment levels in the Royal Park section, with sediment levels immediately after this event 0.7m below the minimum level before sediment raking commenced, and 0.5m below the minimum following the commencement of sediment raking before the flood. Sediments levels since the flood have been steadily increasing with a significant trend equivalent to the rate of accumulation following the commencement of raking. Median, minimum, maximum and quartile sediment values after the flood are all significantly lower than for both periods before the flood.  It is expected that the trend to increased sediment levels is likely to continue up until an equilibrium level of sedimentation is reached unless or until a

significant flow event occurs, given the previous behaviour of the system in this section of the estuary.

### 2.1.3 Section 2 – Upper Channel

Figure 6 shows the trend in sediment levels in the Upper Channel (Section 2) versus flows and sediment raking effort. Trend parameters and statistics of fit are provided in Table 3. Figure 7 is a box plot summary of data for the three periods: before sediment raking; sediment raking before the 2016 flood; and sediment raking after the 2016 flood.

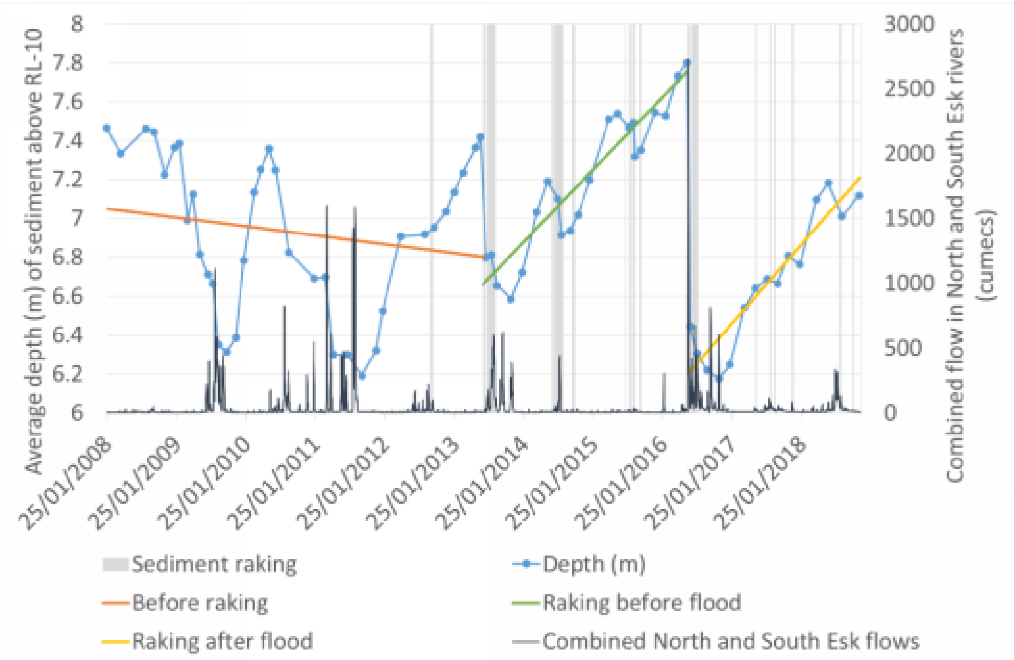



*FIGURE 6. SECTION 2 – UPPER CHANNEL: TRENDS IN AVERAGE SEDIMENT DEPTH ABOVE RL-10 (M) BEFORE RAKING, DURING THE RAKING PERIOD BEFORE THE 2016 FLOODS AND AFTER THE 2016 FLOODS VERSUS COMBINED DAILY FLOW FROM NORTH AND SOUTH ESK AND SEDIMENT RAKING FROM THE PRECEDING PERIOD*

*TABLE 3. TREND REGRESSION PARAMETERS FOR SECTION 2 – UPPER CHANNEL*

| | Before raking | Raking before flood | Raking after flood |
|---|---|---|---|
| $R^2$ | 0.033 | 0.875 | 0.863 |
| F significance | 0.291 | 0 | 0 |
| Intercept | 7.05 | 6.66 | 6.2 |
| Trend (m per day) | -0.0001 | 0.0010 | 0.0011 |
| *p*-value Intercept | 1.1E-34 | 1.01E-31 | 2.71E-20 |
| *p*-value Trend | 0.291 | 6.26E-11 | 5.53E-07 |

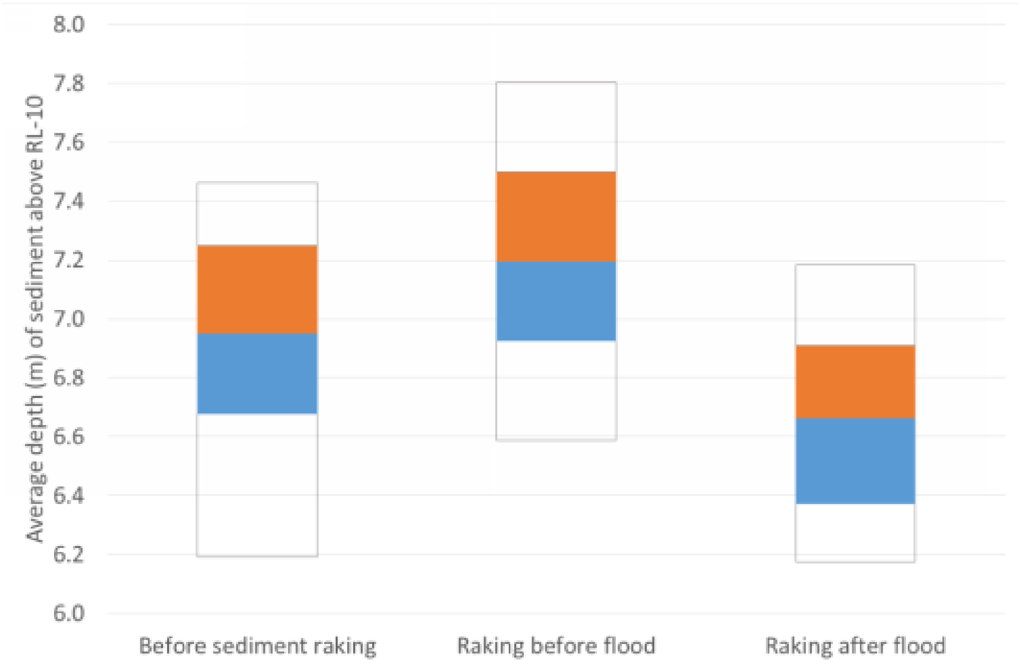



*FIGURE 7. SECTION 2 – UPPER CHANNEL: BOX PLOT COMPARISON FOR THREE PERIODS. CLEAR BOXES INDICATE RANGE (MAX AND MIN VALUE), BLUE IS THE 1ST QUARTILE TO MEDIAN VALUE, ORANGE IS MEDIAN VALUE TO 3RD QUARTILE.*

These figures show:

- Before the commencement of sediment raking there was no significant trend in sediment levels (the trend line fitted has a negative coefficient value but p-value is 0.291 so this is not significant). Flow events are seen to lead to very substantial decreases in sediment levels in the Upper Channel during this period. The two sustained periods of high flow (winters of 2009 and 2011) both saw sediment levels in the Upper Channel drop by over 1m.
- The commencement of sediment raking in 2013 coinciding with a period of substantial flow led to an immediate drop in sediment levels of approximately 0.6m. This was followed by a sharp and statistically significant increasing trend in sediment levels in the Upper Channel of 26.3$m^3$/day of sediment accumulated in the Upper Channel or 9.8 days to accumulate 1cm of sediment in this section of the estuary. Flow and sediment raking events show an immediate impact on sediment levels in this section of the estuary but this is seen to be smaller than that experienced for similar flow conditions before the commencement of sediment raking and is followed by a sharp increase in sediment, with levels returning quickly to or above those before the flow and raking event. The box plot shows that all measures of sediment level in this period are higher than before sediment raking commenced. The minimum value is 0.4m higher than the minimum before the commencement of sediment raking. The median and 1st quartile are 0.2m higher and the maximum and 3rd quartile are 0.3m higher than before sediment raking commenced.
- The 2016 flood led to a substantial and immediate decrease in sediment levels of 1.6m. This was followed by a sharp and significant increasing trend in sediment levels as was seen after the commencement of sediment raking. The trend in sediment accumulation in this section of the estuary is approximately 28.7$m^3$ per day since the flood, equivalent to less than 9 days

per 1 cm of sediment accumulated. As was the case in the previous period combined flow and sediment raking events have a much smaller impact on sediment levels than equivalent flows before sediment raking, with any decrease rapidly offset by an increase back to or above previous levels. The box plots show all data summary statistics post-flood are less than the previous period but this is likely to be partly because the Upper Channel is still infilling following the 2016 flood.

### 2.1.4 Section 3 – Upper West Bank

Figure 8 shows the trend in sediment levels in the Upper West Bank (Section 3) versus flows and sediment raking effort. Trend parameters and statistics of fit are provided in Table 4. A box plot summarising data from the three periods is given in Figure 9.

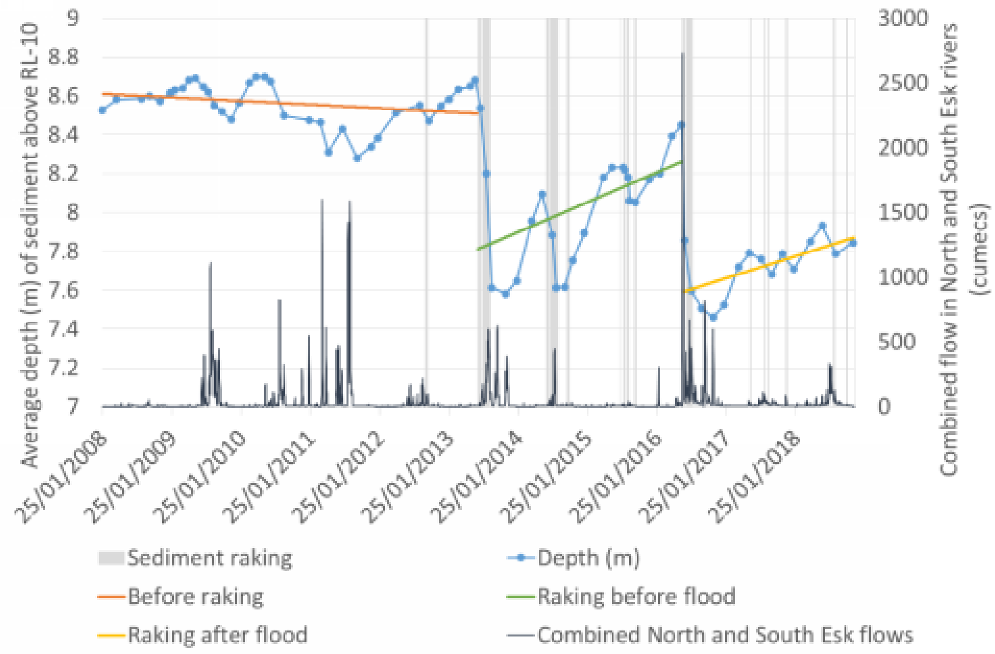



*FIGURE 8. SECTION 3 – UPPER WEST BANK: TRENDS IN AVERAGE SEDIMENT DEPTH ABOVE RL-10 (M) BEFORE RAKING, DURING THE RAKING PERIOD BEFORE THE 2016 FLOODS AND AFTER THE 2016 FLOODS VERSUS COMBINED DAILY FLOW FROM NORTH AND SOUTH ESK AND SEDIMENT RAKING*

*TABLE 4. TREND REGRESSION PARAMETERS FOR SECTION 3 – UPPER WEST BANK*

| | Before raking | Raking before flood | Raking after flood |
|---|---|---|---|
| $R^2$ | 0.071 | 0.23 | 0.385 |
| F significance | 0.115 | 0.021 | 0.014 |
| Intercept | 8.61 | 7.81 | 7.59 |
| Trend (m per day) | -0.000051 | 0.00042 | 0.00031 |
| *p*-value Intercept | 6.4E-57 | 6.33E-27 | 3.8E-22 |
| *p*-value Trend | 0.115186 | 0.020688 | 0.013546 |

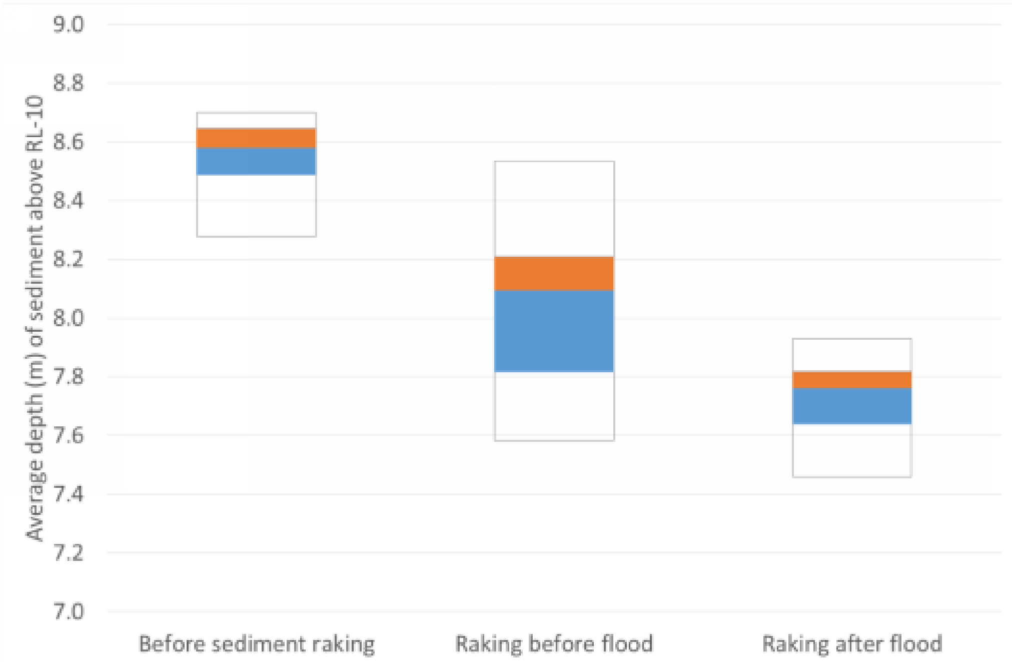



*FIGURE 9. SECTION 3 – UPPER WEST BANK: BOX PLOT COMPARISON FOR THREE PERIODS. CLEAR BOXES INDICATE RANGE (MAX AND MIN VALUE), BLUE IS THE 1ST QUARTILE TO MEDIAN VALUE, ORANGE IS MEDIAN VALUE TO 3RD QUARTILE.*

These figures show:

- Before sediment raking commenced there was a weak decreasing trend (*p*-value 0.11) in sediment levels in the Upper West Bank. Flow events during this period are seen to decrease sediment levels by between 0.2m and 0.4m but these rise quickly back to previous levels during low flow periods. Sediment levels are largely stable over this period with the box plot showing a relatively narrow band between maximum and minimum values as well as between 1st and 3rd quartiles.
- The commencement of sediment raking led to a rapid and substantial drop in sediment levels of over 1m. Later flow and sediment raking events during this period have decreased sediment levels back to this minimum level with sediment accumulating rapidly during periods of low flows. The period of sediment raking before the 2016 flood is associated with an overall significant increasing trend in sediment levels from equivalent to 35.8m$^3$ per day or 23.9 days to accumulate 1cm of sediment in this section of the estuary over the period. The maximum level of sediment in this section of the estuary remains below the pre-raking maximum for the entire period (by 0.3m).
- The 2016 flood and associated sediment raking campaigns led to an immediate drop in sediment levels in the Upper West Bank of approximately 1.1m. Since then there has been a statistically significant increasing trend in sediment levels in this part of the estuary of 26.4m$^3$ per day, equivalent to 32.3 days for 1cm of sediment accumulation in this section. While the small flow and sediment raking events since the floods have led to immediate decreases in sediment levels of less than 0.1m, sediment has generally returned rapidly to or above previous levels. The box plot shows that all summary statistics for this period are well below the other two periods. If the upward trend in sediment levels continues this effect

may reduce but levels can be expected to remain lower than pre-sediment raking for some time given the rate of return.

### 2.1.5 Section 4 – Mid Channel

Figure 10 shows the trend in sediment levels in the Mid Channel (Section 4) before sediment raking commenced as well as for the two raking periods versus average flows and sediment raking effort over the preceding period. Trend parameters and statistics of fit are given in Table 5. A box plot showing summary statistics for data over the 3 periods is provided in Figure 11.

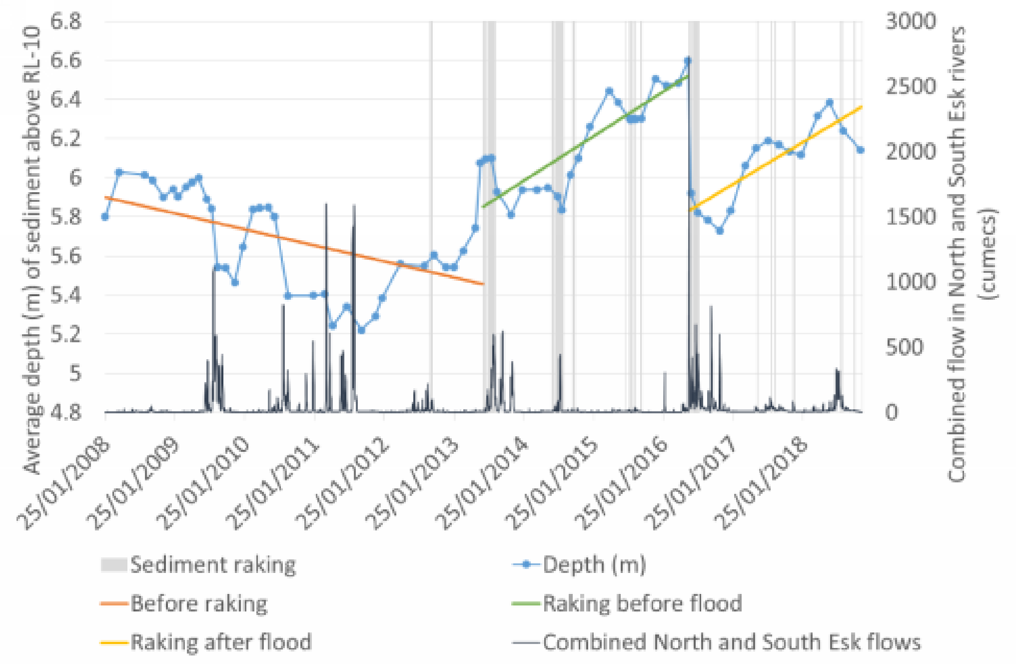



*FIGURE 10. SECTION 4 – MID CHANNEL: TRENDS IN AVERAGE SEDIMENT DEPTH ABOVE RL-10 (M) BEFORE RAKING, DURING THE RAKING PERIOD BEFORE THE 2016 FLOODS AND AFTER THE 2016 FLOODS VERSUS COMBINED DAILY FLOW FROM NORTH AND SOUTH ESK AND SEDIMENT RAKING*

*TABLE 5. TREND REGRESSION PARAMETERS FOR SECTION 4 – MID CHANNEL*

| | Before raking | Raking before flood | Raking after flood |
|---|---|---|---|
| $R^2$ | 0.266 | 0.726 | 0.678 |
| F significance | 0.001 | 0 | 0 |
| Intercept | 5.9 | 5.85 | 5.83 |
| Trend (m per day) | -0.00022 | 0.00062 | 0.00059 |
| *p*-value Intercept | 7.11E-41 | 1.3E-30 | 1.86E-20 |
| *p*-value Trend | 0.00128 | 2.45E-07 | 0.00016 |

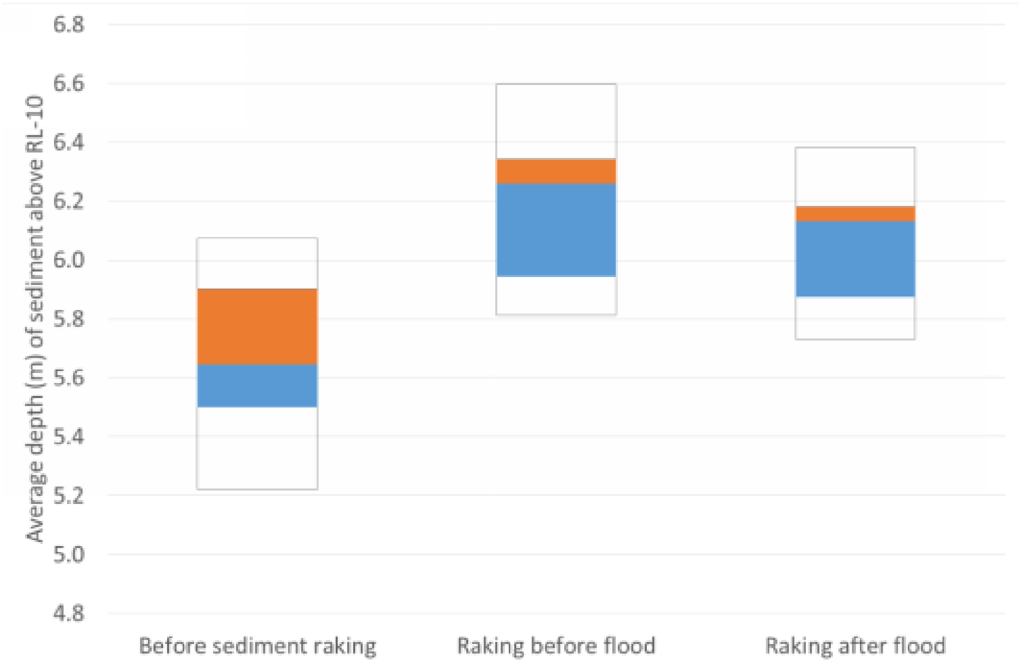



*Figure 11. Section 4 –Mid Channel: Box plot comparison for three periods. Clear boxes indicate range (max and min value), blue is the 1st quartile to median value, orange is median value to 3rd quartile.*

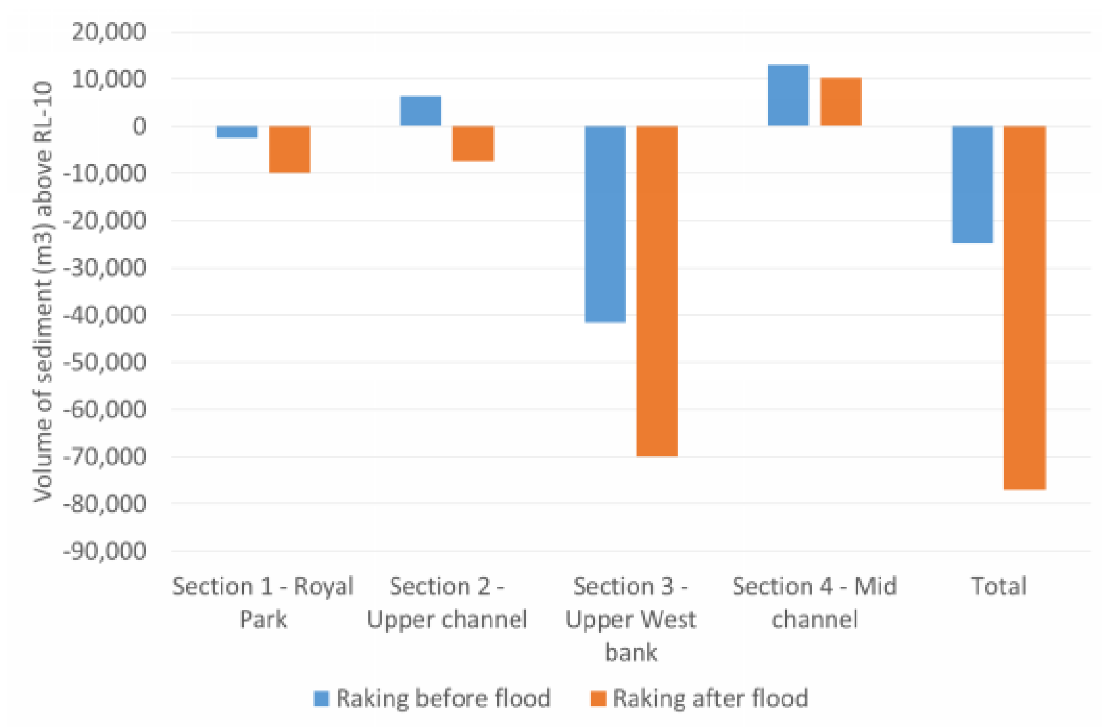
These Figures show:

- Before sediment raking commenced, the Mid Channel was experiencing a statistically significant decrease in sediment levels, with 4.7m$^3$ of sediment per day leaving this section of the estuary (or 1cm of sediment every 44.6 days). Periods of high flow during this time are seen to lead to substantial decreases in sediment levels (between 0.2m and 0.5m) which are followed by increases in sediment that are generally to levels lower than previous.
- The commencement of sediment raking led to an immediate increase in sediment levels in the Mid Channel (of approximately 3cm) with subsequent large flows reducing sediment levels in the Mid Channel by approximately 0.3m. The period of raking before the 2016 flood is characterised by a rapid increase in sediment levels with raking events during this period being followed by increasing sediment levels. On average an additional 13.2m$^3$ per day of sediment was accumulated in the Mid Channel section of the estuary, equivalent to 1cm of sediment every 16 days. Note that unlike other sections of the estuary this increase happens on a higher base level. All summary statistics for this period are greater than for the period before sediment raking commenced by between 0.4m and 0.6m.
- The 2016 flood and associated sediment raking decreased sediment levels in the Mid Channel to levels similar to just before the commencement of sediment raking (approximately 0.9m). This was followed by a rapid increase in sediment levels, on average over the period equal to 12.4m$^3$ per day or 1cm every 17 days. All summary statistics for this period are higher than for before sediment raking commenced by between 0.3m and 0.5m but are less than the period of raking before the 2016 flood. It may be that increasing sediment levels in this section of the estuary will continue and have an effect on these statistics over time.

### 2.1.6 Total volume changes in Sections 1 to 4

Figure 12 to Figure 14 summarise the difference in median, minimum and maximum sediment volume and depth for the two raking periods relative to pre-raking respectively across Section 1 to 4 of the estuary.

*Volume (m3)*




*Depth (m)*

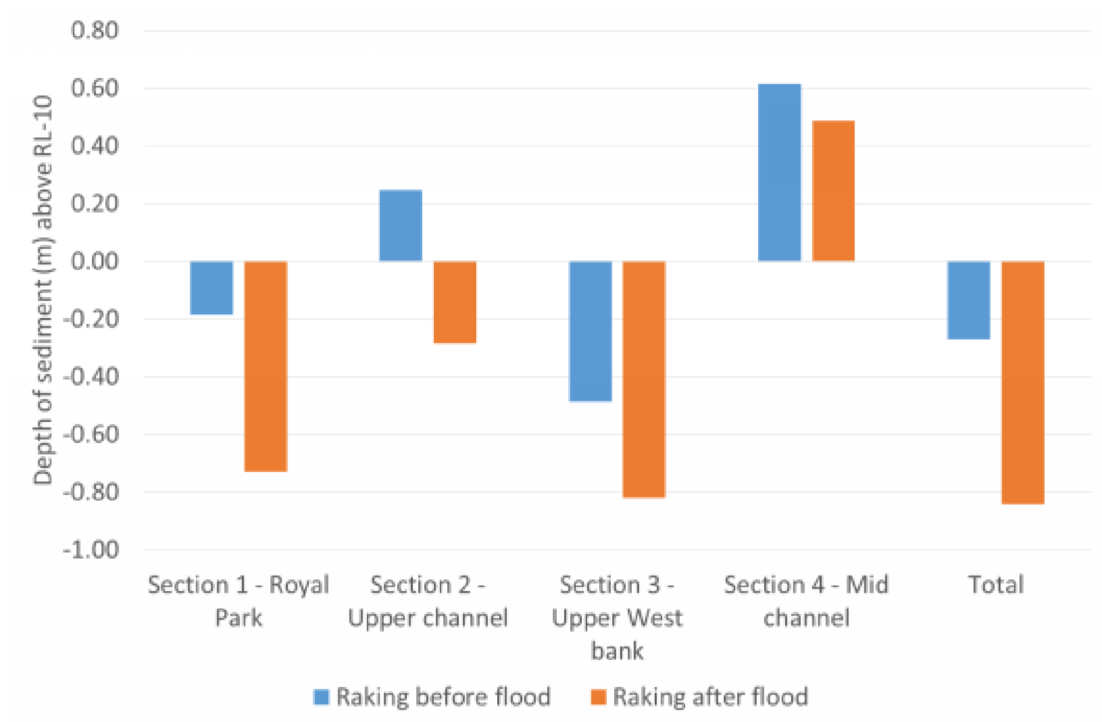



*FIGURE 12. COMPARISON OF MEDIAN VOLUME AND DEPTH DIFFERENCES FROM PRE-RAKING ACROSS SECTION 1 TO 4*

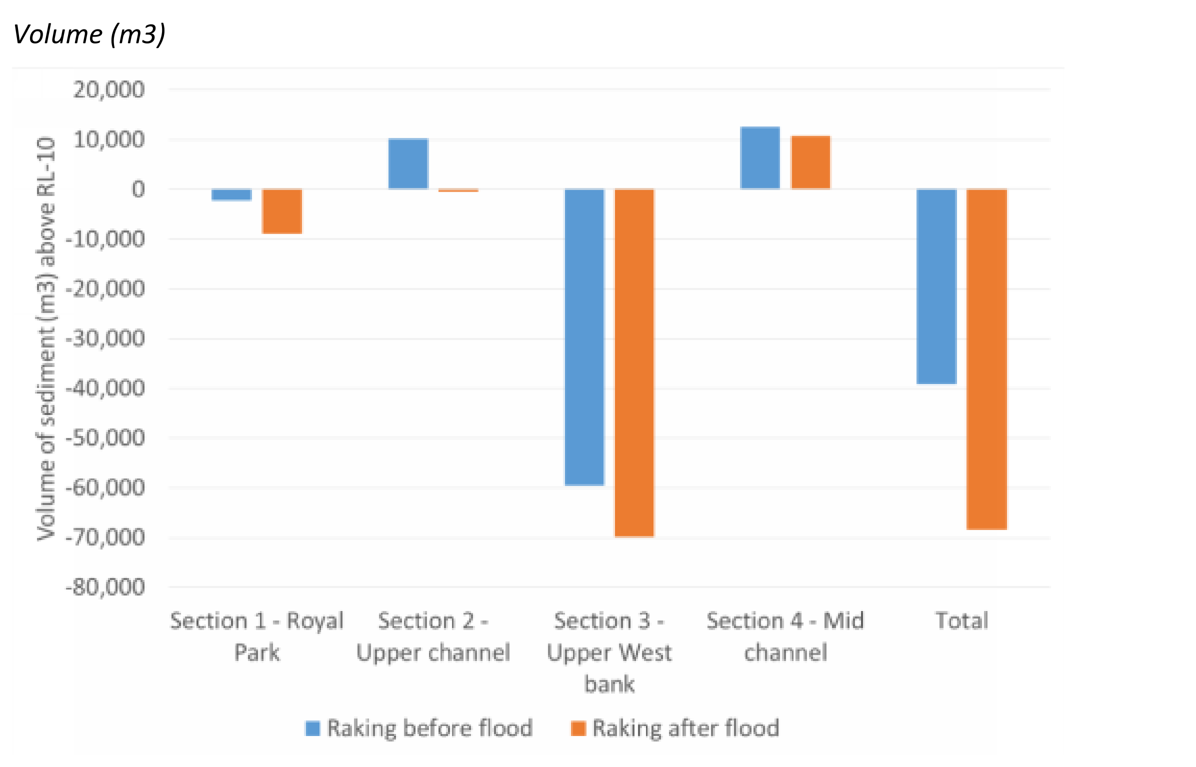
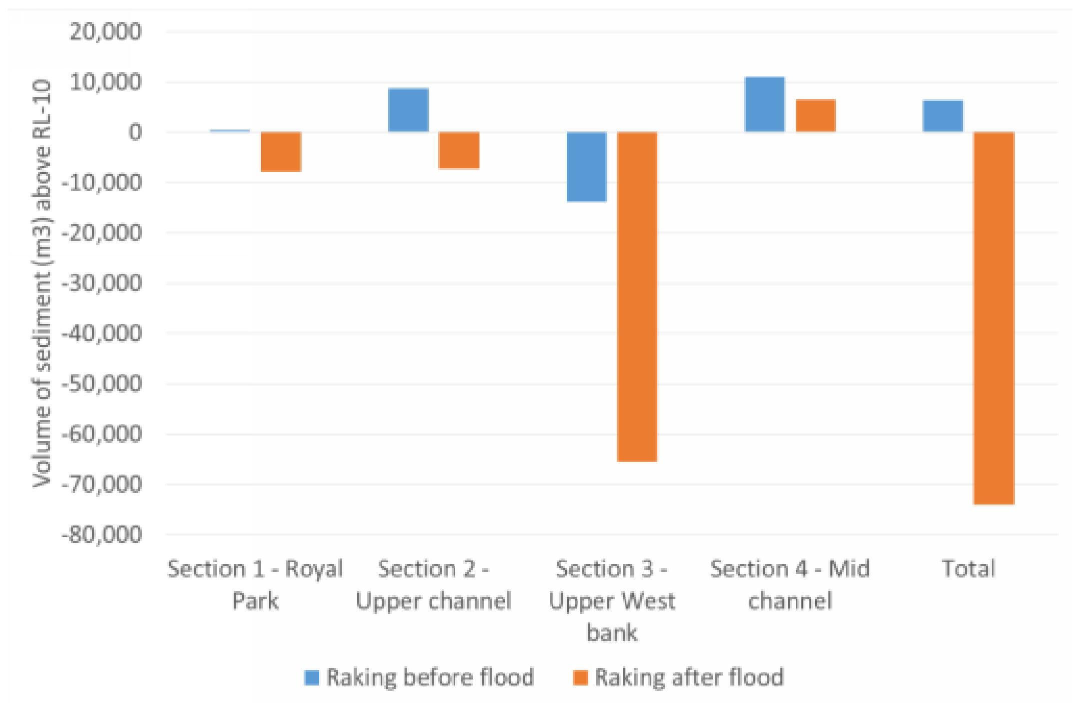




*FIGURE 13. COMPARISON OF MINIMUM VOLUME AND DEPTH DIFFERENCES FROM PRE-RAKING ACROSS SECTION 1 TO 4*

*Volume (m3)*




*Depth (m)*

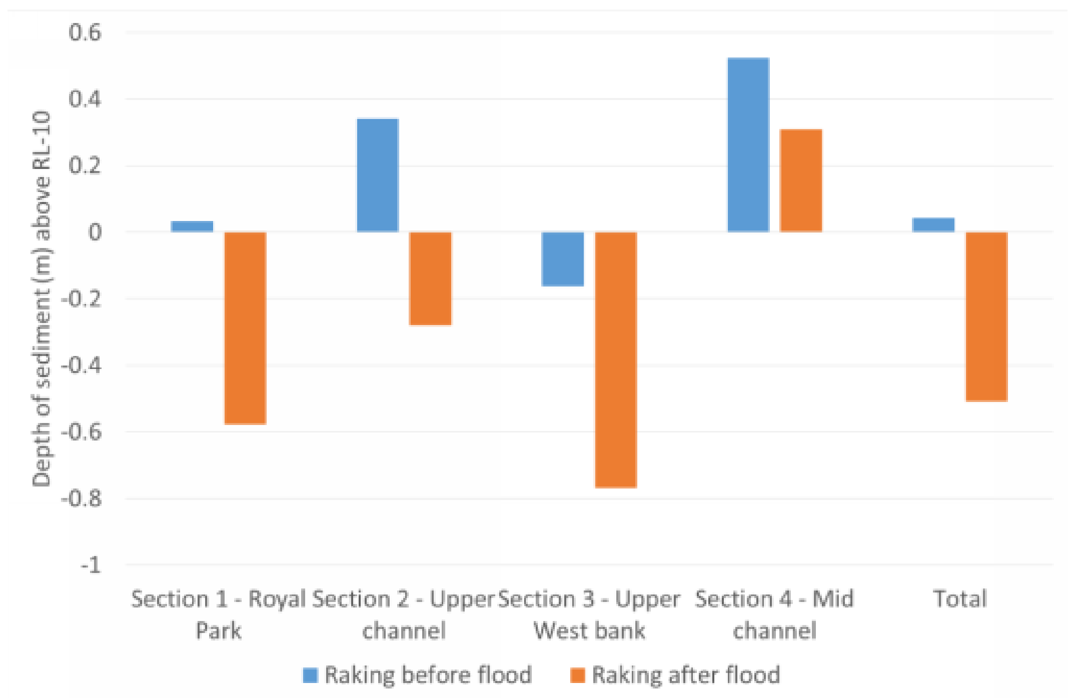



*FIGURE 14. COMPARISON OF MAXIMUM VOLUME AND DEPTH DIFFERENCES FROM PRE-RAKING ACROSS SECTION 1 TO 4*

These figures show the clear trade-off between sediment raking objectives around aesthetics (particularly sediment levels in the West Bank) and navigation in terms of sediment in the channel. Before the 2016 flood, the net effect of sediment raking on sediment levels across all 4 zones was a small increase in total sediment volumes across this part of the estuary. Maximum sediment levels show that only the Upper West Bank experienced a sustained drop in sediment levels, with maximum levels in Royal Park slightly greater than pre-raking and maximum levels in the Upper and Mid Channel significantly greater than pre-raking. Even the 2016 flood which was described as 'catastrophic' and the largest flood since 1969 did not achieve reductions of sediment in the Mid Channel down to levels before sediment raking, with all comparisons showing 0.5m more sediment in the Mid Channel for median, minimum and maximum levels. Royal Park is seen to have maximum levels return to above pre-sediment raking levels immediately before the 2016 flood. It is likely that sediment accumulation processes after the flood are continuing and that, without another significant flood event, results will over time mimic those from before the flood, with more sediment overall in this part of the estuary and increasing sediment depths around Royal Park and in the channels.

## 2.2 Impacts on sections 5 to 9

Bathymetry data before the commencement of sediment raking in the upper estuary for Sections 5 to 9 is sparse. This section provides similar analysis to previous sections however comparisons with data before sediment raking commenced should be considered to have high levels of uncertainty given the patchy data available. Median values for data points in the period before sediment raking commenced are plotted instead of trends as trends fitted through such limited data points can be misleading.

### 2.2.1 Section 5 – Lower Channel

Figure 15 shows the time series of sediment levels in the Lower Channel (Section 5) over time with trends for data for the periods of raking before and after the flood plotted. Trend parameters and statistics of fit are provided in Table 6. Note that no trend is fitted to data before the commencement of sediment raking as there are only 3 data points for this period. The line shown is the median of the available data (noting that this is likely to be well below the true median given 2 of the 3 data points available correspond to high flow periods). Figure 16 shows a box plot of the available data. Given the sparse data before raking commenced care should be taken in interpreting any change from pre-raking to after the commencement of sediment raking. The available data does show that the Lower Channel appears to have responded to the flow event after raking commenced with a large drop during the high flow period. After this there was a very steady increase in sediment levels until the 2016 flood. The minimum level of sediment after the commencement of sediment raking is greater than the available measurements before raking with two of the three data points corresponding to high flow periods which were related to the minimum sediment levels before raking in both the Upper and Mid Channel (ie. these data are likely to be representative of minimum sediment levels before the commencement of raking). Even after the 2016 floods the minimum sediment level was higher than the minimum recorded before raking commenced. Trend values are equivalent to 44.7$m^3$ and 80.7$m^3$ of sediment accumulation per day or 20.4 days and 11.3 days to accumulate 1cm of sediment for the sediment raking periods before and after the 2016 flood respectively.

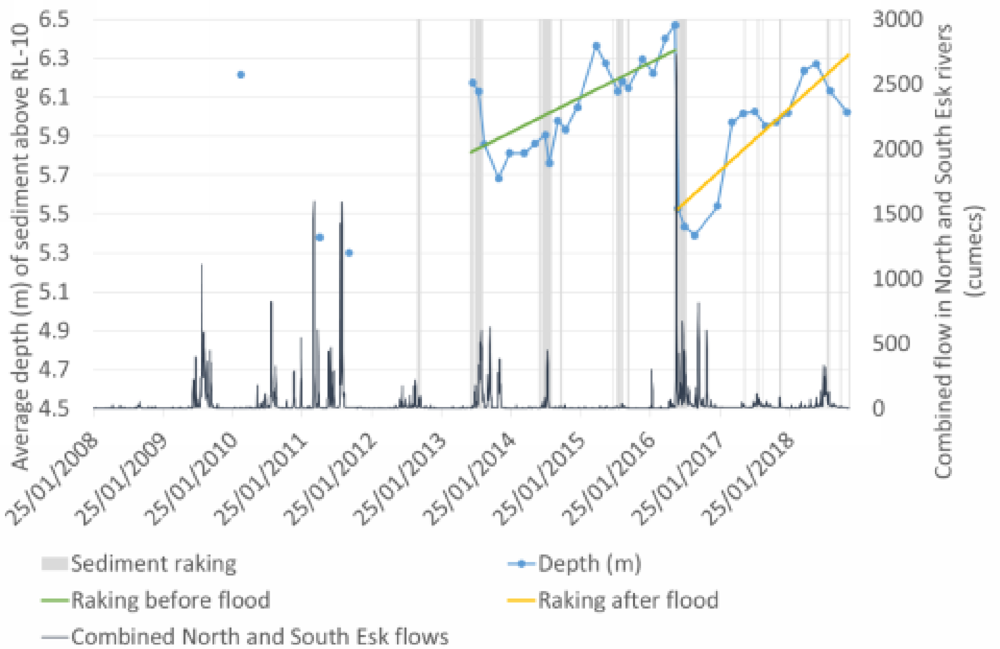



*FIGURE 15. SECTION 5 –LOWER CHANNEL: TRENDS IN AVERAGE SEDIMENT DEPTH ABOVE RL-10 (M) DURING THE RAKING PERIOD BEFORE THE 2016 FLOODS AND AFTER THE 2016 FLOODS. LINE BEFORE FLOOD IS THE MEDIAN VALUE. PLOTTED AGAINST COMBINED DAILY FLOW FROM NORTH AND SOUTH ESK AND SEDIMENT RAKING*

*TABLE 6. TREND REGRESSION PARAMETERS FOR SECTION 5 – LOWER CHANNEL*

| | Raking before flood | Raking after flood |
|---|---|---|
| $R^2$ | 0.519 | 0.732 |
| F significance | 0.000232 | 9.61E-05 |
| Intercept | 5.82 | 5.51 |
| Trend (m per day) | 0.00049 | 0.00088 |
| *p*-value intercept | 2.88E-26 | 4.61E-17 |
| *p*-value Trend | 0.000232 | 9.61E-05 |

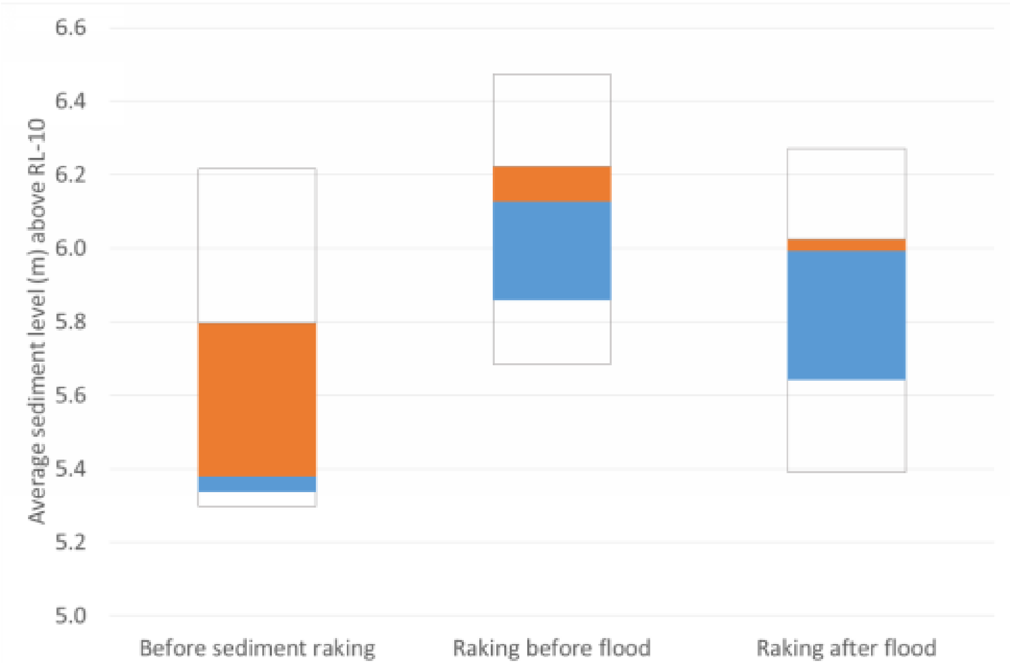



*FIGURE 16. SECTION 5 –LOWER CHANNEL: BOX PLOT COMPARISON FOR THREE PERIODS. CLEAR BOXES INDICATE RANGE (MAX AND MIN VALUE), BLUE IS THE 1ST QUARTILE TO MEDIAN VALUE, ORANGE IS MEDIAN VALUE TO 3RD QUARTILE.*

### 2.2.2 Section 6 - Lower West Bank

Figure 17 shows the time series data for sediment levels in the Lower West Bank (Section 6). Figure 18 shows the box plot for data from the 3 periods. Trends for sediment raking before and after the 2016 flood are shown with the line before the commencement of sediment raking showing the median of available data. Trend parameters and statistics of fit are provided in Table 7. This shows that there is no significant trend in data during the period of sediment raking before the flood but that since the flood there has been a significant increasing trend in sediment levels from a low base, equivalent to an average of 34m$^3$ per day of sediment accumulation of 26.9 days for 1cm of sediment to accumulate. Sediment levels after the flood briefly returned to just over the minimum of pre-flood raking levels but have recently dropped again in response to flow events.

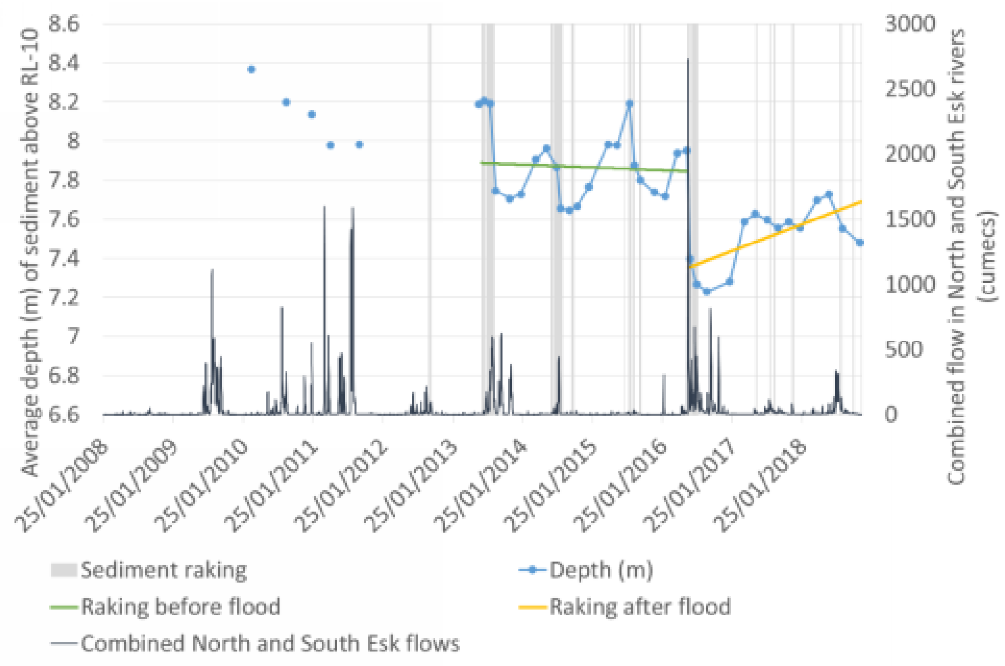



*Figure 17. Section 6 – Lower West Bank: Trends in average sediment depth above RL-10 (m) during the raking period before the 2016 floods and after the 2016 floods. Line before the commencement of raking is the median of available data. Plotted against combined daily flow from North and South Esk and sediment raking*

*Table 7. Trend regression parameters for Section 6 – Lower West Bank*

| | Raking before flood | Raking after flood |
|---|---|---|
| $R^2$ | 0.006 | 0.449 |
| F significance | 0.743 | 0.009 |
| Intercept | 7.888 | 7.351 |
| Trend (m per day) | -0.00004 | 0.00037 |
| *p*-value Intercept | 7.35E-28 | 6.45E-20 |
| *p*-value Trend | 0.7429 | 0.0087 |

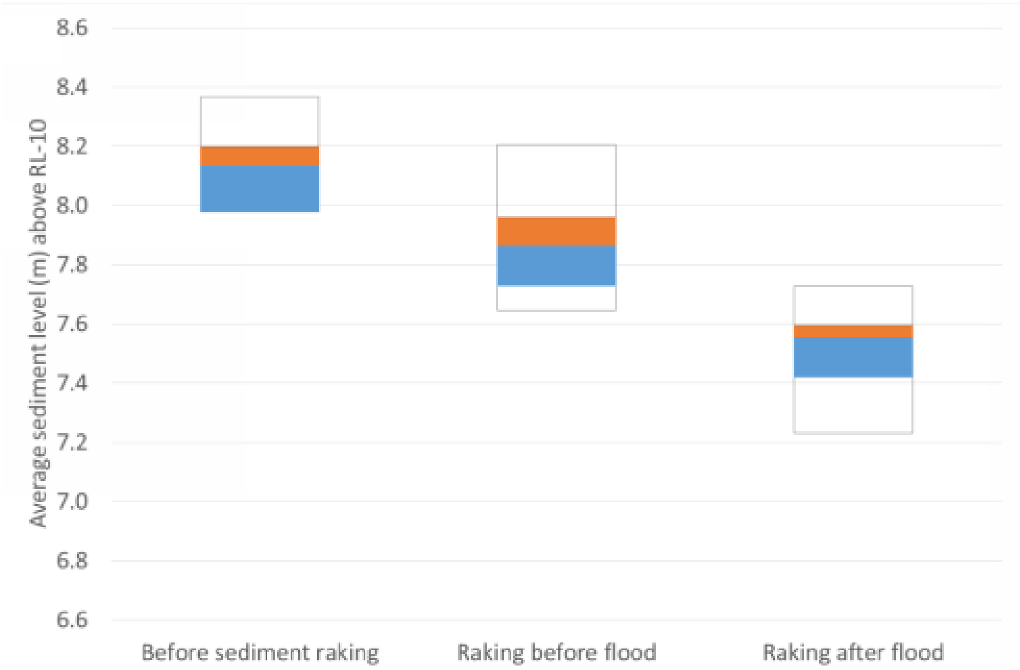



*FIGURE 18. SECTION 6 –LOWER WEST BANK: BOX PLOT COMPARISON FOR THREE PERIODS. CLEAR BOXES INDICATE RANGE (MAX AND MIN VALUE), BLUE IS THE 1ST QUARTILE TO MEDIAN VALUE, ORANGE IS MEDIAN VALUE TO 3RD QUARTILE.*

### 2.2.3 Section 7 – North Bank

Figure 19 shows the time series of sediment levels in the North Bank/Riverbend section of the upper Tamar. Trends for sediment raking periods before and after the flood are given with the median value pre-e sediment raking shown given the sparse available data. Trend parameters and statistics of fit are provided in Table 8. Figure 20 shows the box plot of data for each of the periods. These figures show while sediment levels in the North Bank section experienced a substantial drop when sediment raking first commenced, neither the commencement of sediment raking nor the 2016 flood were sufficient to return sediment levels to the minimum level measured pre-raking. The initial drop in levels after raking commenced was followed by a statistically significant upward trend in sediment levels, equivalent to an average of 18.6m$^3$ per day or 1cm of sediment accumulation every 17.2 days. During this period, sediment raking appears to have led to large initial decreases in sediment levels regardless of flow volume, although sediment returns fairly rapidly and often to a higher level than before sediment raking. The 2016 floods led to a sharp decrease in the level of sediment in this section of the Tamar followed by a very significant and rapid increase in sediment levels equivalent to 61.9m$^3$ per day or 1cm every 5.2 days of sediment accumulation. Maximum levels since the 2016 flood are slightly greater than those from the sediment raking period before the flood but over 0.5m less than the measured pre-sediment raking maximum (potentially not the true maximum given the sparsity of data collection in this period).

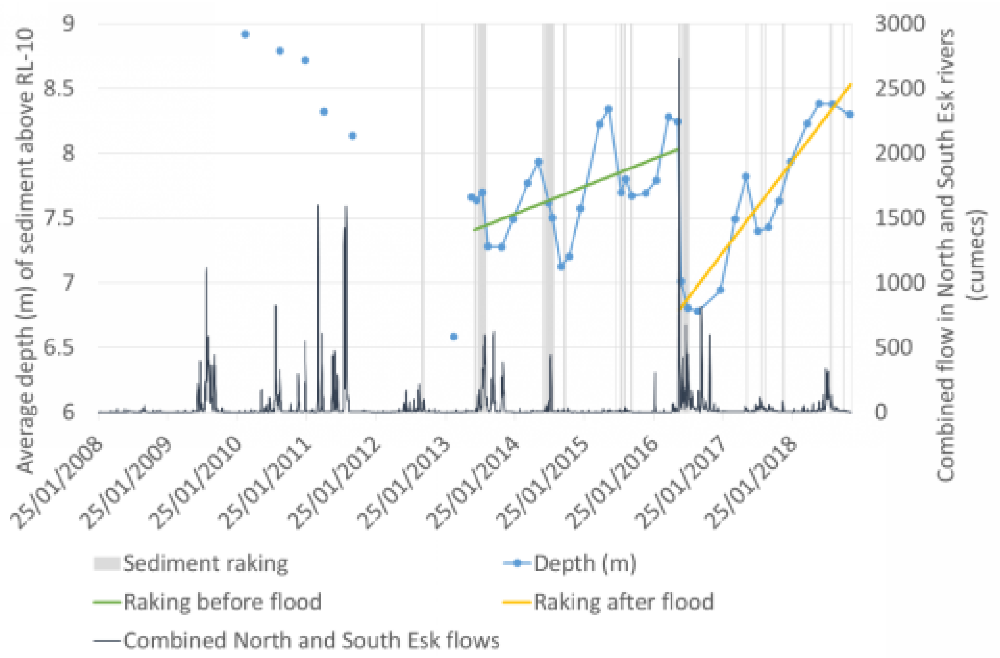



*Figure 19. Section 7 – North Bank: Trends in average sediment depth above RL-10 (m) during the raking period before the 2016 floods and after the 2016 floods. Line before the commencement of raking is the median of available data. Plotted against combined daily flow from North and South Esk and sediment raking. Note scale difference on primary axis from other Sections (3m not 2m)*

*Table 8. Trend regression parameters for Section 7 – North Bank*

| | Raking before flood | Raking after flood |
|---|---|---|
| $R^2$ | 0.31 | 0.88 |
| F significance | 0.00891 | 6.52E-07 |
| Intercept | 7.405616 | 6.783847 |
| Trend (m per day) | 0.000581 | 0.001928 |
| *p*-value Intercept | 3.17E-23 | 1.06E-16 |
| *p*-value Trend | 0.00891 | 6.52E-07 |

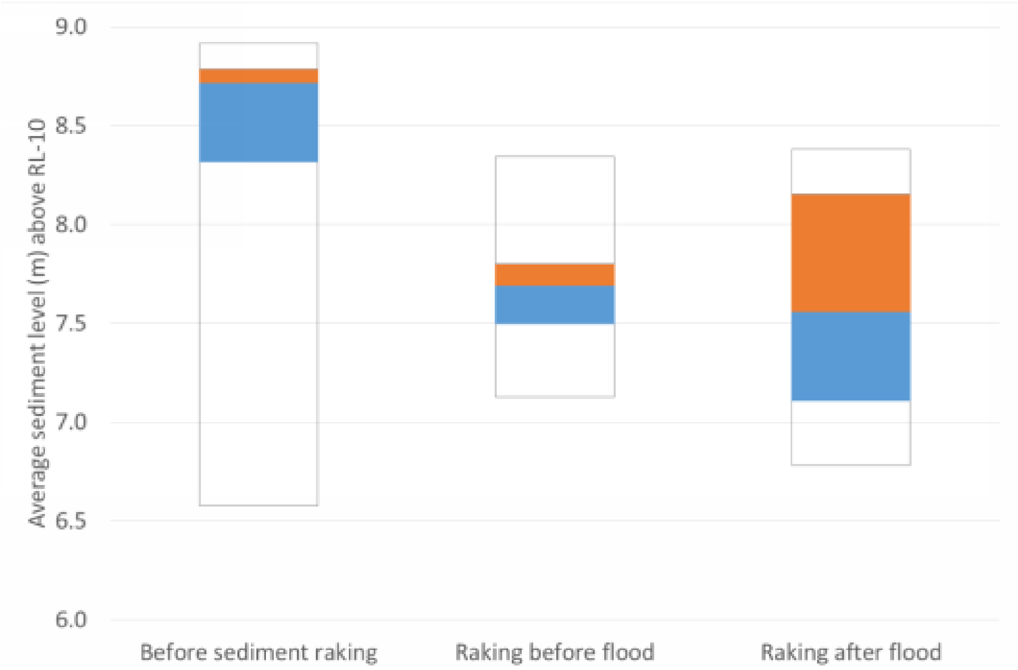



*FIGURE 20. SECTION 7 – NORTH BANK: BOX PLOT COMPARISON FOR THREE PERIODS. CLEAR BOXES INDICATE RANGE (MAX AND MIN VALUE), BLUE IS THE 1ST QUARTILE TO MEDIAN VALUE, ORANGE IS MEDIAN VALUE TO 3RD QUARTILE.*

### 2.2.4 Section 8 – North Esk

Figure 21 shows the time series of sediment levels in the North Esk section of the estuary (Section 8). Trend lines are shown for the sediment raking periods before and after the flood with a median of values pre-raking period shown, reflecting the sparsity of available data. Trend parameters and statistics of fit are provided in Table 9. Figure 22 provides a box plot of values for the 3 periods.

These figures show that the minimum sediment level pre-sediment raking commenced is less the minimum with experienced with raking, both before and after the flood. Median levels have also increased under raking though it is less clear that this result is not an artefact of the sparse data available before raking commenced. The commencement of raking coincided with an increase in sediment levels until the large flow period that began roughly 3 months after sediment raking commenced. Sediment levels then appeared to fluctuate around a stable value before commencing a rapid increase at the beginning of 2015. Overall this period saw an increase of sediment levels on average equivalent to 6.4m$^3$ of accumulation per day, or 1cm of sediment in 42.3 days. The 2016 flood then saw a substantial decrease in sediment levels (6.2m$^3$ per day or 1cm in 44.2 days) to just above the minimum measured level before raking commenced followed by a significant trend of increasing sediment levels. Sediment levels in this period appear to fluctuate substantially in response to flow and raking events. Sediment levels after the flood are still lower than the maximum levels experienced under sediment raking before the flood.

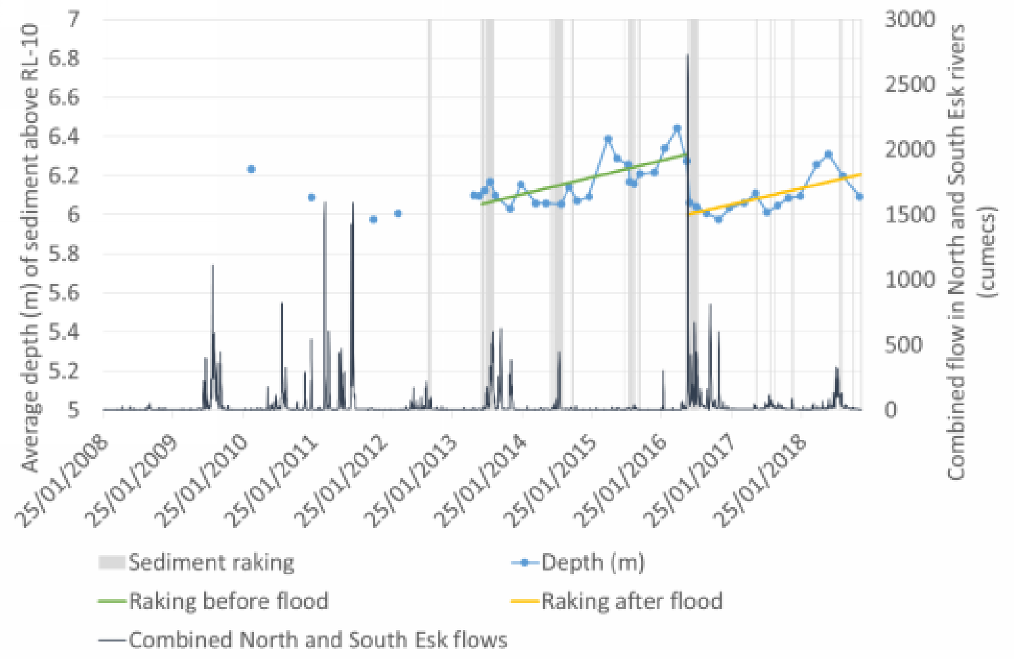



*Figure 21. Section 8 – North Esk: Trends in average sediment depth above RL-10 (m) during the raking period before the 2016 floods and after the 2016 floods. Plotted against combined daily flow from North and South Esk and sediment raking*

*Table 9. Trend regression parameters for Section 8 – North Esk*

| | Raking before flood | Raking after flood |
|---|---|---|
| $R^2$ | 0.474 | 0.467 |
| F significance | 0.00056 | 0.00495 |
| Intercept | 6.05 | 6.00 |
| Trend (m per day) | 0.00024 | 0.00023 |
| *p*-value Intercept | 1.23E-31 | 1.59E-23 |
| *p*-value Trend | 0.0006 | 0.0050 |

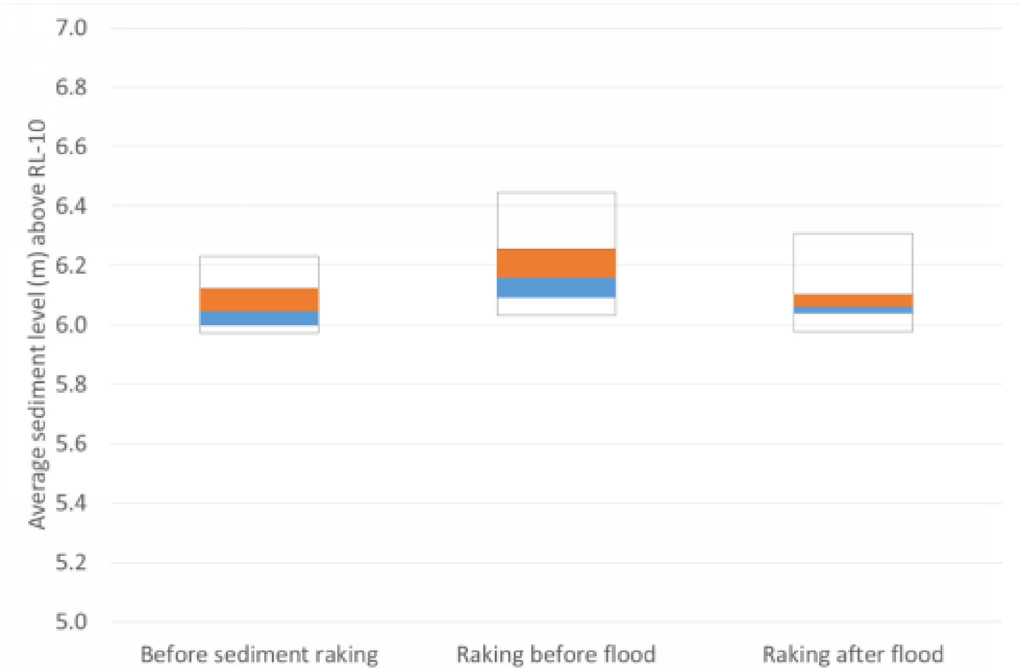



*FIGURE 22. SECTION 8 – NORTH ESK: BOX PLOT COMPARISON FOR THREE PERIODS. CLEAR BOXES INDICATE RANGE (MAX AND MIN VALUE), BLUE IS THE 1ST QUARTILE TO MEDIAN VALUE, ORANGE IS MEDIAN VALUE TO 3RD QUARTILE.*

### 2.2.5 Section 9 – Seaport

Figure 23 shows the time series of sediment levels in the Seaport section of the estuary. Trend lines for the sediment raking periods before and after the 2016 floods are shown. The median value before the commencement of sediment raking is also plotted. Trend parameters and statistics of fit are provided in Table 10. Figure 24 provides a box plot of data from each of the 3 periods. These figures show that sediment levels in the Seaport have dropped substantially with the commencement of sediment raking. While no trend line has been fitted for sediment before raking given the sparse data available, it appears that sediment was accumulating in this section of the estuary over this period. The sediment raking period before the flood saw no statistically significant trend in levels although each sediment raking period saw a substantial drop in sediment levels followed by a rapid increase to around the minimum sediment levels before the commencement of sediment raking. This shows that while prop washing (the method used to move sediment from the Seaport) is effective at moving sediment out of the marina, it rapidly returns so that frequent prop washing is required to maintain navigation and aesthetic values in the Seaport. The 2016 flood saw a sharp decrease in sediment levels to just above the minimum levels experienced during sediment raking before the flood, followed by a rapid increase back to levels similar to those in the sediment raking period before the flood. This post flood raking period saw a statistically significant trend in sediment levels of $3m^3$ per day or 22.6 days for 1 cm of sediment accumulation. The median sediment level in the Seaport is over 1m lower post sediment raking than it was before sediment raking commenced. The median level before and after the 2016 flood is very similar.

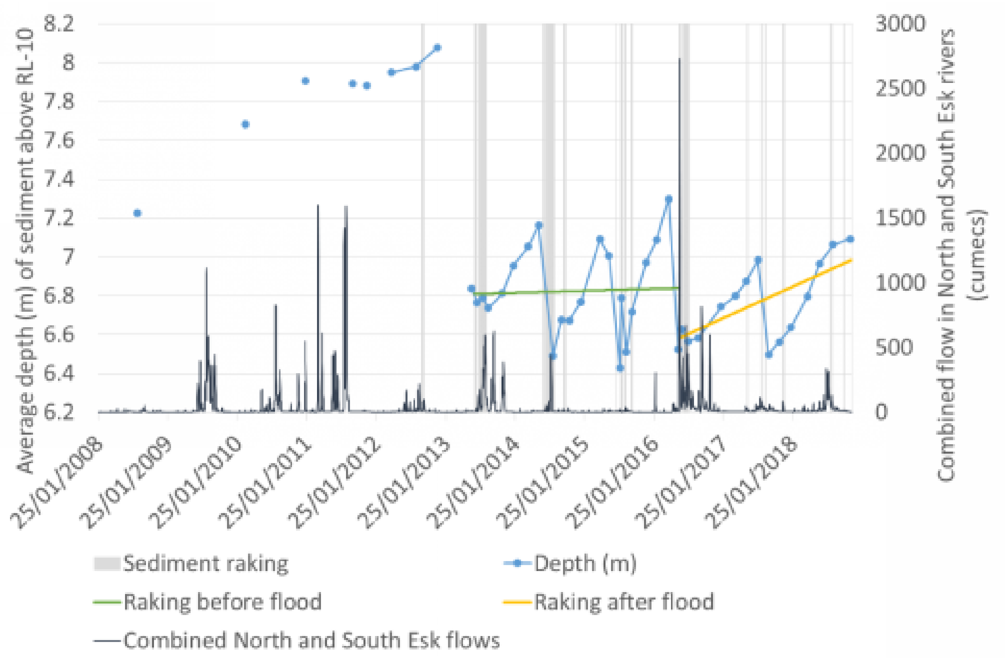



*Figure 23. Section 9 – Seaport: Trends in average sediment depth above RL-10 (m) during the raking period before the 2016 floods and after the 2016 floods. Line before the commencement of raking is the median of \available data. Plotted against combined daily flow from North and South Esk and sediment raking*

*Table 10. Trend regression parameters for Section 9 – Seaport*

| | Raking before flood | Raking after flood |
|---|---|---|
| $R^2$ | 0.002 | 0.398 |
| F significance | 0.859 | 0.016 |
| Intercept | 6.81 | 6.58 |
| Trend (m per day) | 2.93E-05 | 0.00044 |
| *p*-value intercept | 5.17E-24 | 6.82E-18 |
| *p*-value Days | 0.859 | 0.016 |

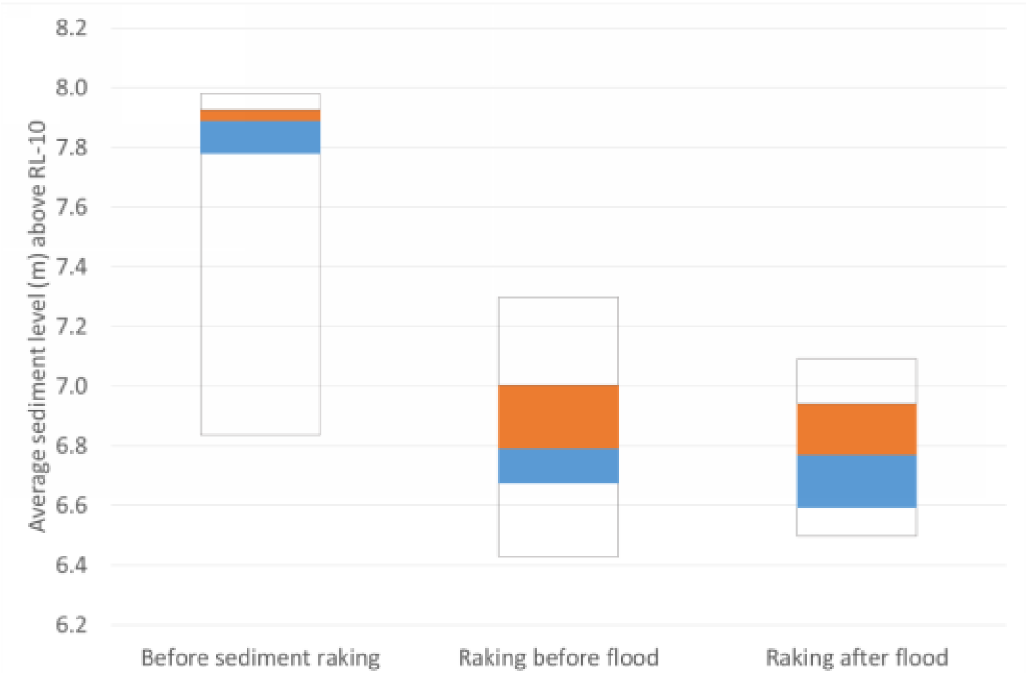



*Figure 24. Section 9 –Seaport: Box plot comparison for three periods. Clear boxes indicate range (max and min value), blue is the 1st quartile to median value, orange is median value to 3rd quartile.*

## 2.3 Discussion of impacts on bathymetry

These results show clearly that there are trade-offs between the objectives of sediment raking being met and in fact, sediment raking has already negatively impacted on some objectives. There is also evidence that without significant flood events, sediment raking does not lead to sustained decreases in sediment volumes in the upper estuary (ie Sections 1 to 4), with sediment levels across Sections 1 to 4 of the upper estuary immediately before the 2016 flood returning to levels that were 1600$m^3$ higher than the maximum levels before sediment raking commenced and 30,000$m^3$ higher than the median level from before sediment raking commenced.

### 2.3.1 Aesthetics

Sediment raking alone appears to have led to significant decreases in sediment levels in the Upper West Bank, key to achieving aesthetic objectives relating to the visibility of sediment banks in the estuary around Launceston. Results for the Lower West Bank are similar to those for the Upper West Bank. In general, North Bank also appears to have reduced sediment levels with the advent of sediment raking though these are not sustained, with sediment levels increasing through the period before and then again after the 2016 flood to levels similar to before raking commenced (noting that sparse data makes this result less certain than was the case for the West Bank). The minimum levels in the North Bank in the pre-raking period are below levels in both raking periods, though this observation is well below the other measured data pre-raking for reasons that aren't clear due to the sparseness of the data for this section in the pre-raking period. During periods without a combination of significant flow and sediment raking, sediment returns rapidly to the West Bank. Sediment raking alone (with low flows) does not appear to lead to a sustained lower sediment levels in the West Bank (upper or lower). The major flood event in 2016 coupled with sediment raking led to a large and rapid decrease in sediment levels in the Upper West Bank section however sediment has been steadily returning to this section of the estuary despite continued sediment raking efforts. Sediment levels also increased in the Lower West Bank but appear to have stabilised at a level well below the period before sediment raking. By contrast sediment levels in the North Bank have increased past values from sediment raking before the flood indicating that any aesthetic benefits of sediment raking in the North Bank have not been sustained.

Sediment levels around Royal Park initially decreased with the commencement of sediment raking but increased to levels higher than pre-sediment raking during the period before the 2016 flood in spite of continued sediment raking efforts. Sediment raking without flows appears to lead to little immediate effect on sediment levels in the Royal Park section, with sediment rapidly returning to levels similar or higher than before the sediment raking took place. The 2016 flood and associated sediment raking led to large decreases in sediment levels around Royal Park, however sediment has been steadily returning to this section of the estuary despite subsequent sediment raking campaigns in the period since.

### 2.3.2 Navigation and the channel

Sediment raking appears to have led to infilling of the channel. In particular, there was a rapid increase in sediment levels in the Mid Channel (near the confluence with the North Esk) following the commencement of sediment raking with well over 1m of additional sediment accumulating in the Mid Channel in the sediment raking period up to the 2016 floods. Likewise in the period before the 2016 flood, the Upper Channel accumulated roughly 1m of sediment more than the median level before sediment raking commenced. While the flood led to an immediate decrease in sediment levels in both the Upper and Mid Channel, in the case of the Mid Channel this decrease was not sufficient to return this section of the estuary to pre-raking sediment levels, with all summary statistics between 0.3m and 0.5m higher than they were pre-sediment raking. The increasing trend for sediment in this section is likely to continue without significant flood events. Data for the Lower Channel is sparser than for the other channel sections but suggest that even immediately after the 2016 flood, sediment levels were higher than after much smaller high flow periods before the commencement of sediment raking. Changes in the channel, particularly in the Mid Channel, are likely to mean that access to the Ship lift is more difficult than it was before sediment raking commenced and that navigation in the channel itself may be compromised. It is not clear whether this process of infilling has finished or the time scale over which this process might cease even if sediment raking were to cease today. It is possible that unconsolidated sediments may continue to be pushed upstream for some time and settle in the channel.

### 2.3.3 North Esk and the Seaport

Data before the commencement of sediment raking is sparse for both the North Esk and the Seaport however results indicate that sediment raking has led to very substantial decreases in sediment in the Seaport area but potentially more sediment in the main channel of the lower North Esk. Decreases in sediment levels in the Seaport are transient and require frequent prop washing to occur as sediment steadily returns to the area.

## 2.4 Sediment movement - Conclusions

While sediment raking clearly has the capacity to reduce visible sediments in the West Bank and, to a lesser extent, areas around Royal Park and the North Bank, this comes at a considerable trade-off in terms of infilling of the channel and impacts on navigation and access to areas such as the Ship lift and Home Point. Sediment raking appears to have changed the response of the channel to large flow events with even very large floods such as the 2016 flood unable to return the Mid Channel to pre-sediment raking levels. Sediment also appears to be accumulating in the channel of the North Esk. Sediment raking without significant flood events has very little impact on sediment levels, with any decrease in sedimentation being rapidly counteracted with increased rates of sedimentation which often fairly rapidly result in sediment levels that are higher than the pre-sediment raking level. It is clear from the data that the sediment raking program is not meeting all its objectives around sediment movement and, in meeting some objectives such as reducing the extent of the West Bank mudflats, has compromised other objectives such as navigation.

# 3 Localised impacts on water quality in and around the sediment rake

One of the licence conditions for sediment raking required a sediment raking monitoring plan to be developed to include *'details of a monitoring strategy to assess potential impact on the receiving environment'*[6] A monitoring plan was developed for water quality which consisted of taking grab samples upstream of the sediment raking boat each day during raking on the ebb tide and downstream of the sediment rake, where 4 samples taken downstream at 15 minute intervals would be composited into a single sample. Parameters to be monitored were: Dissolved oxygen, pH, conductivity, Total Nitrogen, Total Phosphorus, Nitrate and nitrite, ammonia, dissolved nitrogen and metals[7]. Types of metals for which data were to be collected are not specified. Data was collected on 14, 21 and 6 days respectively in 2013, 2014 and 2015 respectively (samples were not collected on all raked days). No data was collected in 2016 and 2017. Data was collected for all raked days in 2018(18 days). As was discussed in Section 2 very limited qualitative information is available on the location where raking occurred and relative sediment raking effort on individual days.

This section analyses data collected by the LFA under this sediment raking monitoring plan. This analysis considers the data from each year separately. There are differences between years in terms of what metals were reported and some differences in the approach to monitoring the plume between years. Data collected in 2014 and 2015 was collected from the sediment raking vessel upstream and downstream of the rake. Data in 2013 was collected at sites at Kings Bridge (upstream) and Kings Wharf (downstream). In 2018 data was also collected in the North Esk River (upstream) and Ti Tree Bend (downstream). Figure 25 shows these key locations. There are also issues with Limits of Reporting (LOR), particularly for metals data, with different LOR used within the same data set at times as well as between data sets. Data with <LOR have been given a value of 0.5xLOR. Where different LOR appear to have been used within the same data set (ie. same metal in a specific year) the same LOR value has been used for all observations <LOR in that year, in general set below data in that data set with a value.

[6] Approval and authority to undertake works associated with sediment raking program within the Tamar Conservation Area, May 2013.
[7] 2013 Sediment Raking Scoping Document submitted to the EPA by the Launceston Flood Authority.


*FIGURE 25. LOCATIONS ASSOCIATED WITH LFA SAMPLING PROGRAM (NOTE EXACT LOCATION OF SAMPLING CHANGED BETWEEN YEARS)*

Data below is presented using a boxplot of values upstream and in the plume or downstream for each year. The blue section on each figure shows the 25th percentile to median of values, orange shows the median to 75th percentile while the clear boxes show the range out to maximum and minimum values.

## 3.1 Total suspended sediments and turbidity

Figure 26 and Figure 27 show the boxplot of data for total suspended sediments (TSS) and turbidity. Note that no turbidity data was available for 2014 or 2015. These figures both show the very large impact sediment raking has on suspended sediments in the water column and subsequently turbidity during the raking event. The water quality objective (WQO) for turbidity used for the TEER Estuary Report Card is 6.4 NTU and the default ANZECC default guideline value is 10 NTU. Sediment raking increases the median turbidity by an order of magnitude from 19-52 (2018 and 2013 respectively) to 138-415 NTU, greatly exceeding both the ANZECC default guideline values and WQO. There is no default guideline value or WQO for TSS but TSS increases in the plume due to sediment raking are between 2 and 173 times higher than upstream with median concentrations increasing from 7.5-19.5 mg/L upstream of the raking to 148.5-805 mg/L downstream. Maximum TSS concentrations under raking are range up to 2300mg/L compared to 68mg/L upstream.

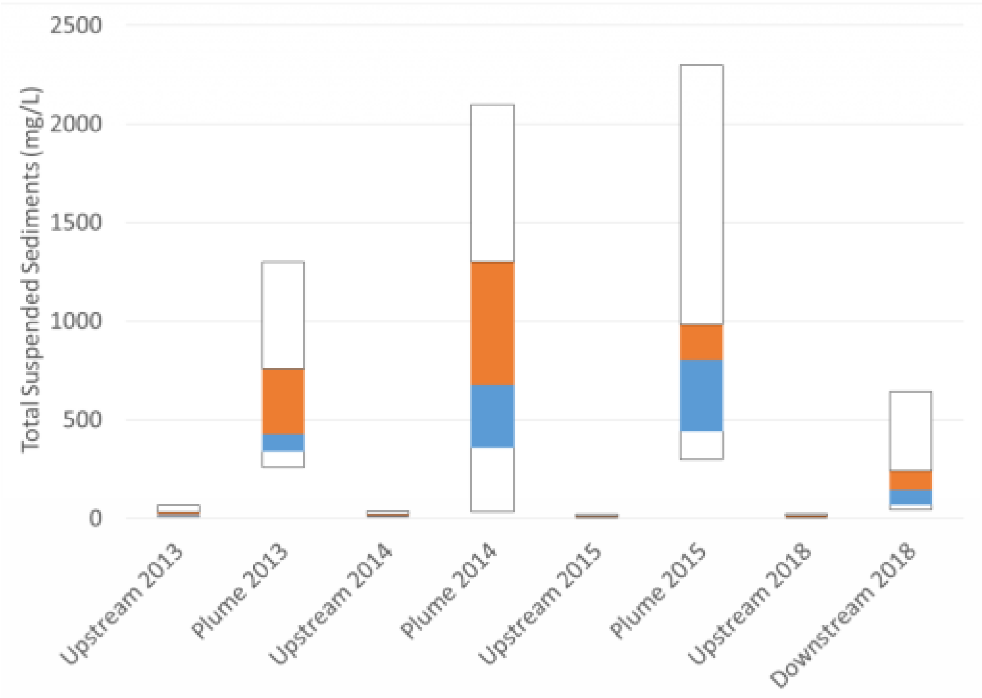



*FIGURE 26. TOTAL SUSPENDED SEDIMENT: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014, 2015 AND 2018. NO DEFAULT GUIDELINE VALUES OR TEER WQO ARE AVAILABLE FOR TSS*

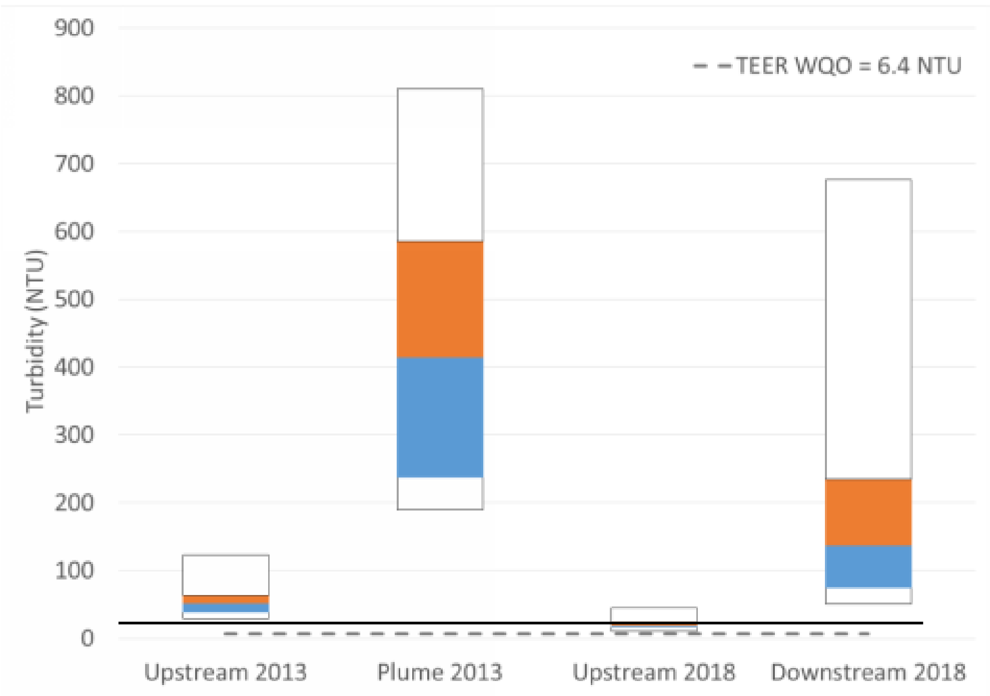



*FIGURE 27. TURBIDITY: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013 AND 2018. NOTE NO TURBIDITY DATA WAS AVAILABLE FOR 2014 OR 2015. TEER WQO OF 6.4 NTU. ANZECC DEFAULT GUIDELINE VALUE IS 10 NTU*

### 3.2 Nutrients

Figure 28 to Figure 32 show the impacts of raking on nutrients – Total Nitrogen, Nitrate+Nitrite (NOx), ammonia, Total Kjeldahl Nitrogen (TKN), and Total Phosphorus (TP). These figures show sediment raking leads to large increases in TN, ammonia, TKN and TP. Impacts on NOx are less apparent with concentrations in the plume frequently being less than those upstream.

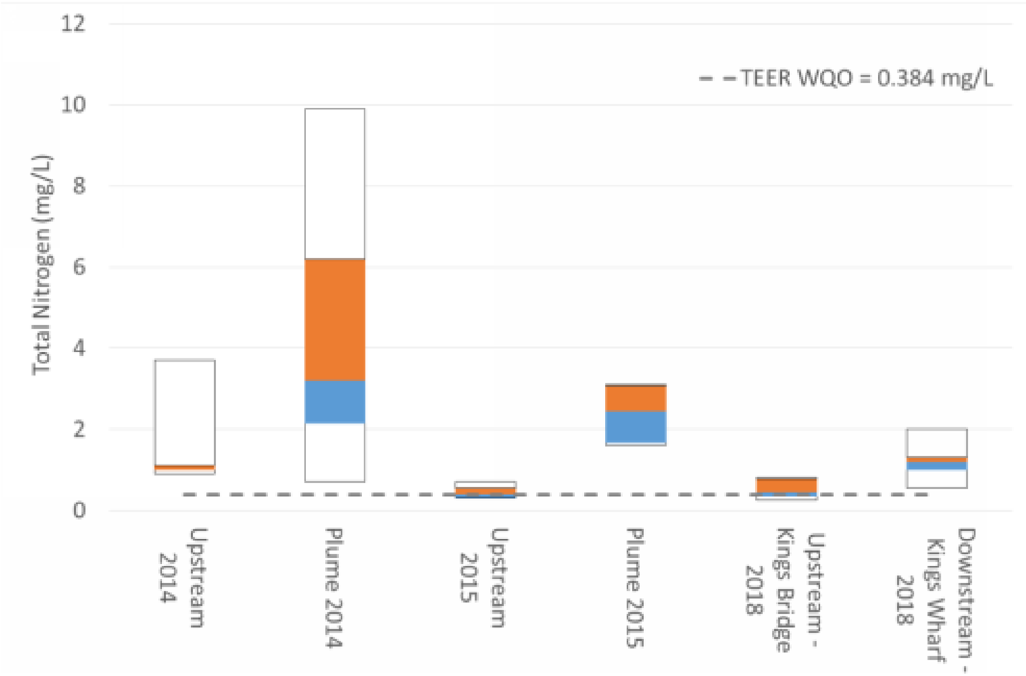



*FIGURE 28. TN: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2014, 2015 AND 2018. NOTE NO TN DATA WAS AVAILABLE FOR 2013. THE TEER WQO OF 0.384 MG/L IS SHOWN. THE ANZECC DEFAULT GUIDELINE VALUE IS 0.3 MG/L*

The WQO for TN is 0.384 and ANZECC default guideline value is 0.3. Values upstream vary from 0.3 to a high of 3.7 in 2014 (Figure 28). 20% of upstream concentrations fall below the WQO. The 90$^{th}$ percentile of all upstream concentrations of TN is 1.1 mg/L. By comparison the lowest concentration measured downstream of the raking is in 2018 at 0.56mg/L, with maximum values in 2014 nearly 10mg/L. While 90% of concentrations measured upstream are below 1.1mg/L, 17% are below this threshold downstream of the plume.

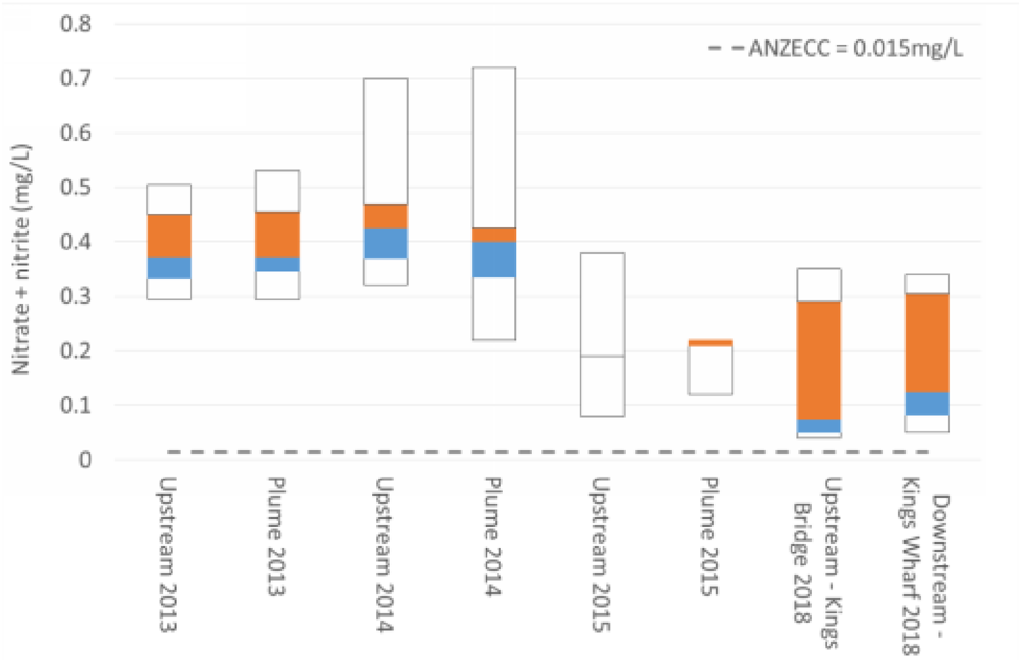



*FIGURE 29. NOX: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014, 2015 AND 2018. MAXIMUM VALUE OF 2.7MG/L FOR UPSTREAM VALUES IN 2014 IS NOT SHOWN ON FIGURE SO AS TO ALLOW OTHER RESULTS TO BE SHOWN MORE CLEARLY. THE ANZECC DEFAULT GUIDELINE VALUE OF 0.015MG/L IS MARKED. THERE IS NO TEER WQO FOR NOX.*

The ANZECC guideline for NOx is 0.015mg/L. All observations of NOx are above this threshold values for upstream and downstream of the raking (Figure 29). While there are differences between years, there is very little difference between upstream and downstream of the rake within a year. In 2013 and 2018 comparison of observations taken on each day show that for most days NOx increased slightly in the plume or downstream of the raking, though this wasn't the case for every day. By contrast in 2014 most values were higher upstream than in the plume. There was very little variation in observations in 2015, with the same higher value recorded in the plume as for upstream for all but one observation (the maximum shown in the upstream for this year). This single observation gives the appearance that NOx concentrations decreased in 2015 in the plume though this is not generally the case. It is possible that the different approach used to take samples in 2014 (collecting them immediately downstream of the sediment rake from the boat) may have affected the results.

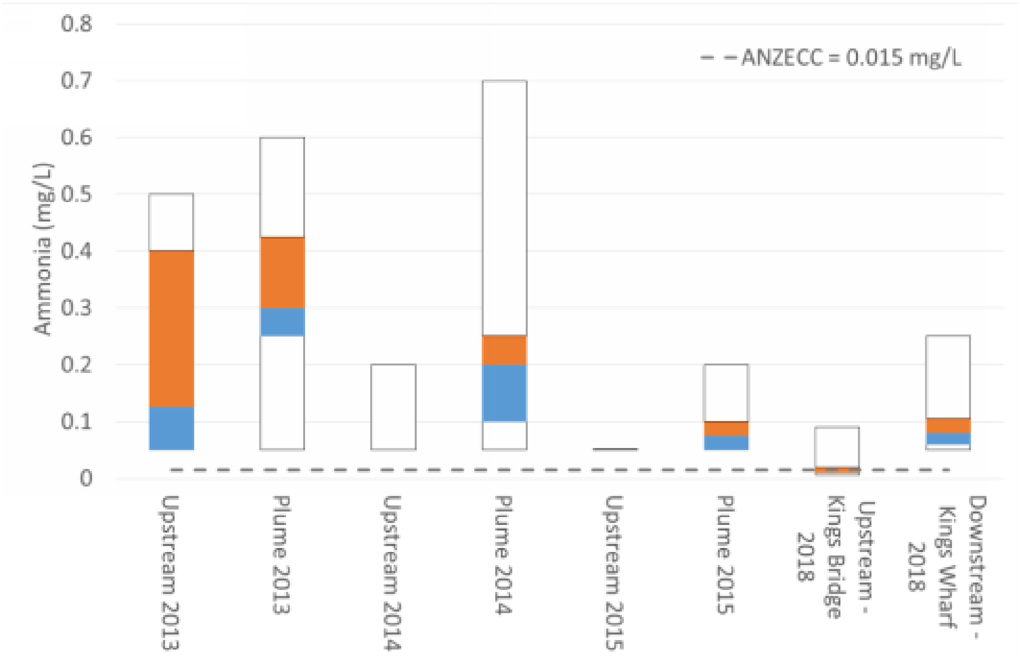



*Figure 30. Ammonia: Comparison between observations upstream and in plume for 2013, 2014, 2015 and 2018. ANZECC default guideline value of 0.015 mg/L is shown. There is no TEER WQO for Ammonia*

As was the case for TN, ammonia increased as a response to sediment raking in all years (Figure 30). The ANZECC default guideline value for ammonia is 0.015mg/L. The limits of reporting change within the data set from 0.1mg/L (above this default guideline level) in 2013 to 2015 to below the lowest recorded measurement of 0.006mg/L (likely 0.005mg/L) in 2018. This has the effect of making minimum values appear to be above the ANZECC default guideline value in some years, which may not be the case. In 2018 the median of upstream values is below this default guideline value (0.01mg/L) with the 75$^{th}$ percentile falling above at 0.02mg/L. The downstream ammonia concentrations for percentiles in this year are 5 to 8 times higher than the upstream value with the exception of the maximum, which is just less than three times higher than the maximum upstream concentration. Most of the upstream data in other years is at the limits of reporting, with maximum and 75$^{th}$ percentile values well below the concentration in the plume.

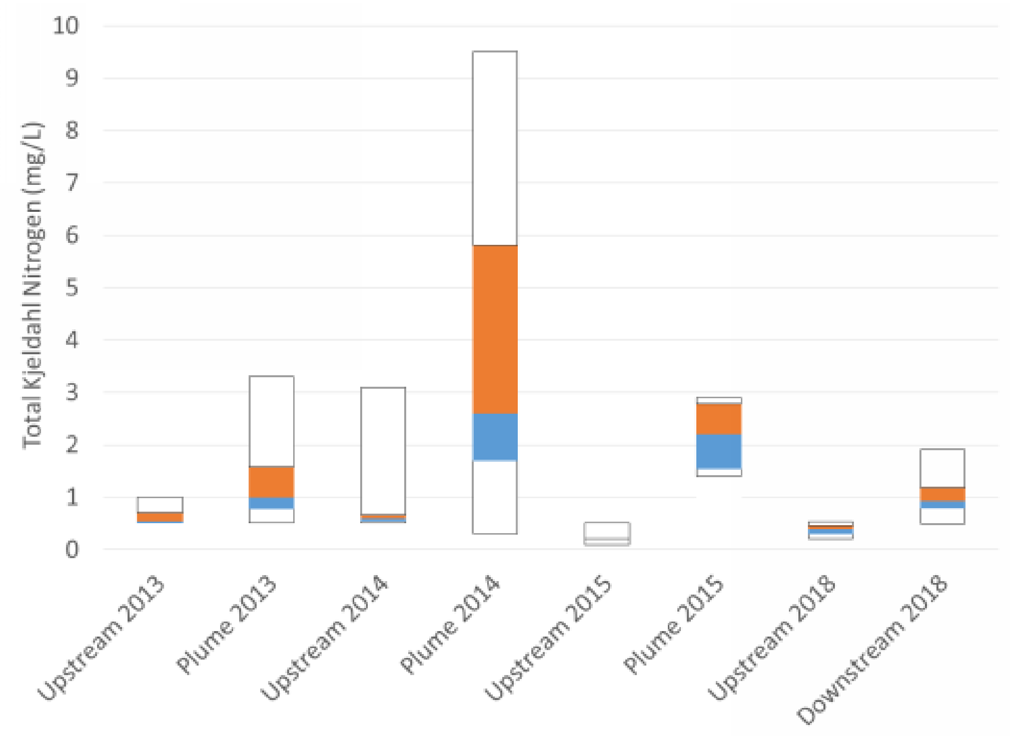



*FIGURE 31. TOTAL KJELDAHL NITROGEN: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014, 2015 AND 2018. THERE IS NOT ANZECC DGV OR TEER WQO FOR TKN*

There is no ANZECC default guideline value for TKN, but considering the default guideline value for TN is 0.3, relatively few values fall below this level (Figure 31). Minimum values of TKN upstream of the rake in 2015 and 2018 are below this TN default guideline value with the median in 2018 just above this (0.394mg/L). No concentrations in the plume are below 0.3 mg/L (the minimum in 2014 is on the threshold). Maximum values in the plume are very large, ranging from 1.9mg/L in 2018 to 9.5mg/L in 2014. The differences between these maximums between years is possibly due to the differences in collection method with higher concentrations likely to be experienced in the plume directly behind the sediment raking boat than at a fixed downstream site.

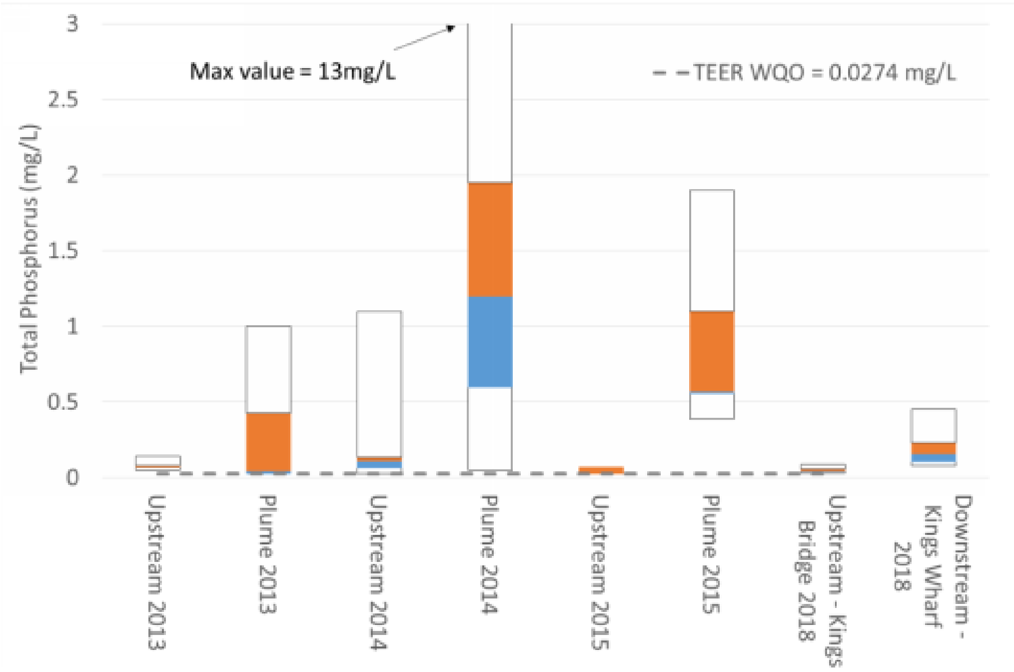



*FIGURE 32. TOTAL PHOSPHORUS: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014, 2015 AND 2018. NOTE MAXIMUM VALUE FOR PLUME IN 2014 WAS 13 AND IS OFF THE CHART TO ALLOW MAJOR DIFFERENCES IN DATA TO BE SEEN. THE TEER WQO OF 0.0274 MG/L IS SHOWN. THE ANZECC DEFAULT GUIDELINE VALUE IS 0.03MG/L*

As was the case with most other nutrients, concentrations of TP increase substantially in the plume relative to upstream concentrations (Figure 32). The ANZECC default guideline value for TP is 0.03mg/L and WQO used in the TEER Report card is 0.0274mg/L however the limit of reporting for TP for most of the series is 0.05mg/L. The LOR in 2018 is 0.003 mg/L. There are large increases in TP in the plume in all years, with maximum values increasing from upstream concentrations by between 12 and 400 times the ANZECC default guideline value.

## 3.3 Heavy metals

Figure 33 to Figure 45 show the impact of sediment raking on total concentrations of a range of heavy metals. Note that as was the case for nutrients, limits of reporting frequently vary for the same metal between years. The metals tested for also varied by year. Table 11 summarises the range and median of all total metal concentrations of upstream and in the plume, with ANZECC default guideline values provided for comparison where available.

*Table 11. Summary of range and median heavy metals concentrations upstream and in the plume across all years (mg/L)*

| Heavy metal | ANZECC default guideline value (mg/L) | Median | | Range | |
|---|---|---|---|---|---|
| | | Upstream | Plume | Upstream | Plume |
| Aluminium | 0.055 | 0.7 | 9.82 | 0.128 - 5 | 0.2 - 53 |
| Arsenic | 0.013 | 0.005 | 0.01 | 0.0005 - 0.01 | 0.002 - 0.04 |
| Barium | N | 0.01 | 0.03 | 0.0025 - 0.04 | 0.005 - 0.13 |
| Chromium | 0.001 | 0.003 | 0.02 | 0.0005 - 0.01 | 0.005 - 0.11 |
| Copper | 0.0014 | 0.003 | 0.02 | 0.0005 - 0.005 | 0.004 - 0.12 |
| Iron | N | 0.9 | 15 | 0.297 - 4.3 | 0.3 - 82 |
| Lead | 0.0034 | 0.005 | 0.01 | 0.0005 - 0.006 | 0.004 - 0.07 |
| Manganese | 1.9 | 0.04 | 0.488 | 0.005 - 0.16 | 0.03 - 3.1 |
| Nickel | 0.011 | 0.005 | 0.009 | 0.001 - 0.005 | 0.005 - 0.1 |
| Strontium | N | 0.02 | 0.06 | 0.02 - 0.04 | 0.02 - 0.12 |
| Titanium | N | 0.01 | 0.27 | 0.005 - 0.2 | 0.005 - 0.58 |
| Vanadium | 0.1 | 0.005 | 0.05 | 0.0005 - 0.02 | 0.005 - 0.16 |
| Zinc | 0.008 | 0.01 | 0.1 | 0.003 - 0.072 | 0.005 - 0.5 |

These figures and table show very large increases in total metals under sediment raking for all metals and all years. These increases are substantial, generally being at least one, and in many cases, more orders of magnitude greater than the ANZECC default guideline value.

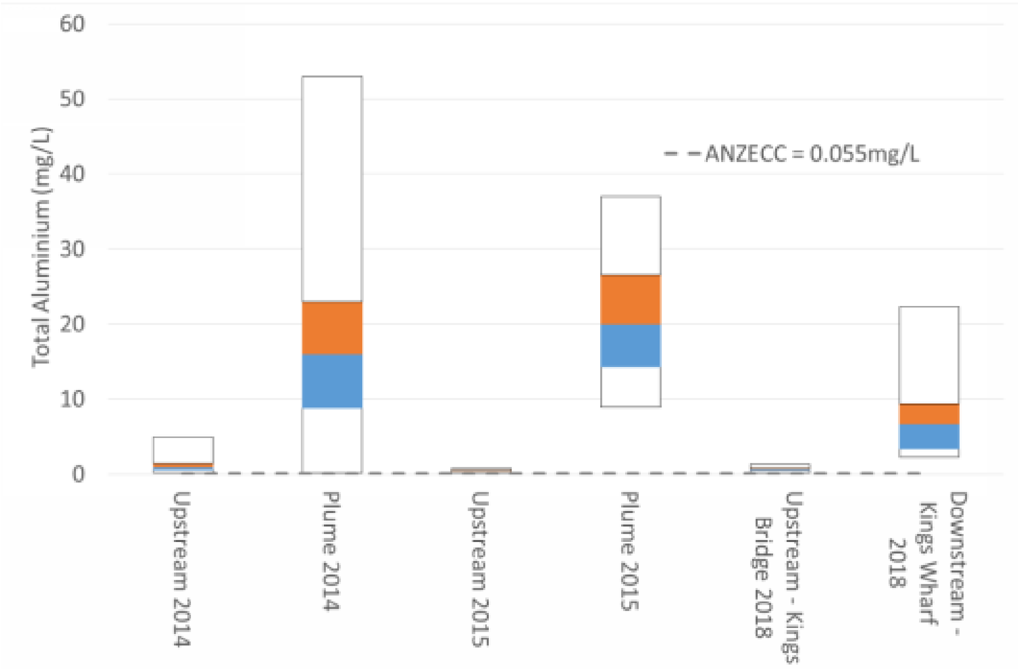



*FIGURE 33. TOTAL ALUMINIUM: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2014, 2015 AND 2018. NOTE NO TOTAL ALUMINIUM DATA WAS AVAILABLE FOR 2013. ANZECC DGV IS 0.055MG/L*

The ANZECC default guideline value for aluminium is 0.055mg/L with most observations of aluminium well above this level (Figure 33). Increases of aluminium concentration in the plume are very high with a median of 9.82 mg/L versus 0.7mg/L upstream and maximum of 53mg/L versus 5mg/L upstream.

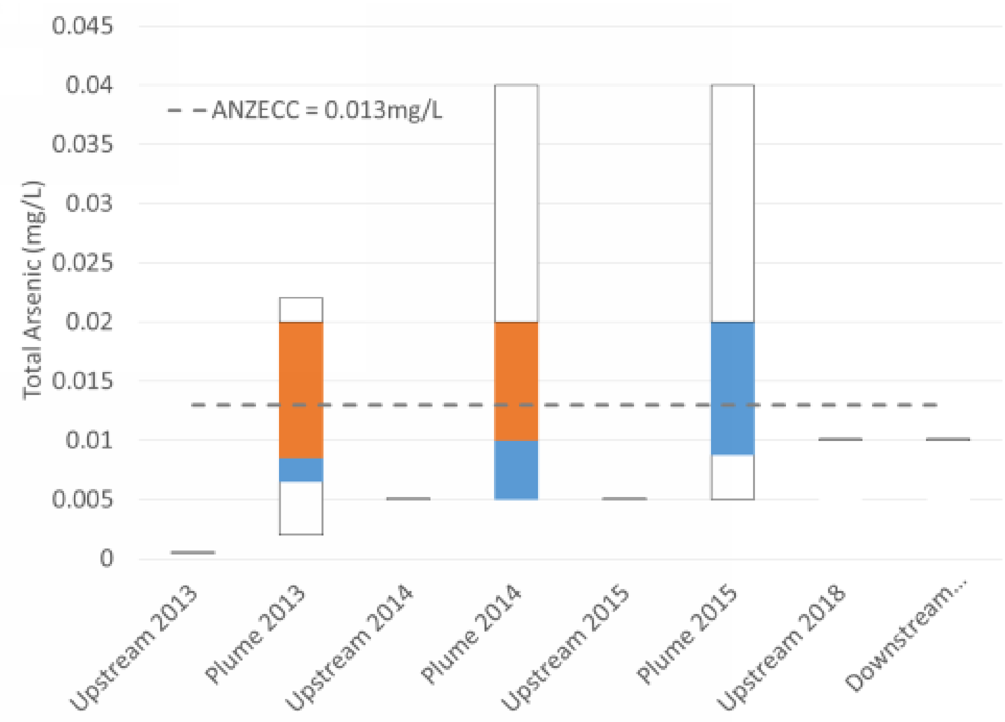



*FIGURE 34. TOTAL ARSENIC: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014, 2015 AND 2018. ANZECC IS DGV 0.013MG/L*

The limits of reporting for arsenic varies between years (Figure 34). Concentrations in 2018 are below the limits of reporting of 0.02mg/L for all observations both upstream and in the plume. The LOR in 2018 is higher than the ANZECC default guideline value of 0.013mg/L. LOR in other years are 0.001 mg/L in 2013 and 0.01mg/L in 2014 and 2015. All upstream data is below the relevant LOR in each year. Concentrations of arsenic in the plume is greater than the relevant LOR for the majority of observations, with maximum values between 0.02 mg/L and 0.04mg/L. Compared with the default guideline value of 0.013mg/L for arsenic these increases are substantial.

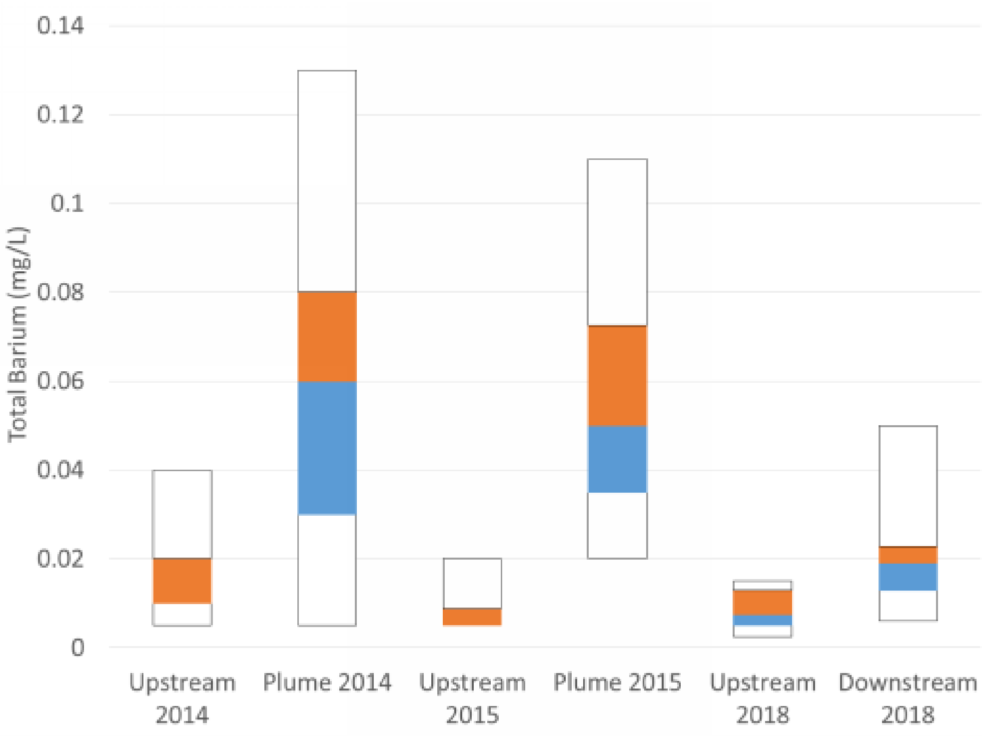



*FIGURE 35. TOTAL BARIUM: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2014, 2015 AND 2018. NOTE NO TOTAL BARIUM DATA WAS AVAILABLE FOR 2013*

There is no ANZECC default guideline value for barium. It does however follow the same general pattern of large increases in concentration in the plume relative to upstream (Figure 35). Maximum concentrations are between 2 and 6 times higher in the plume than they were upstream. There are also large increases in median concentrations with the overall median of plume concentrations 3 times higher than the upstream concentrations.

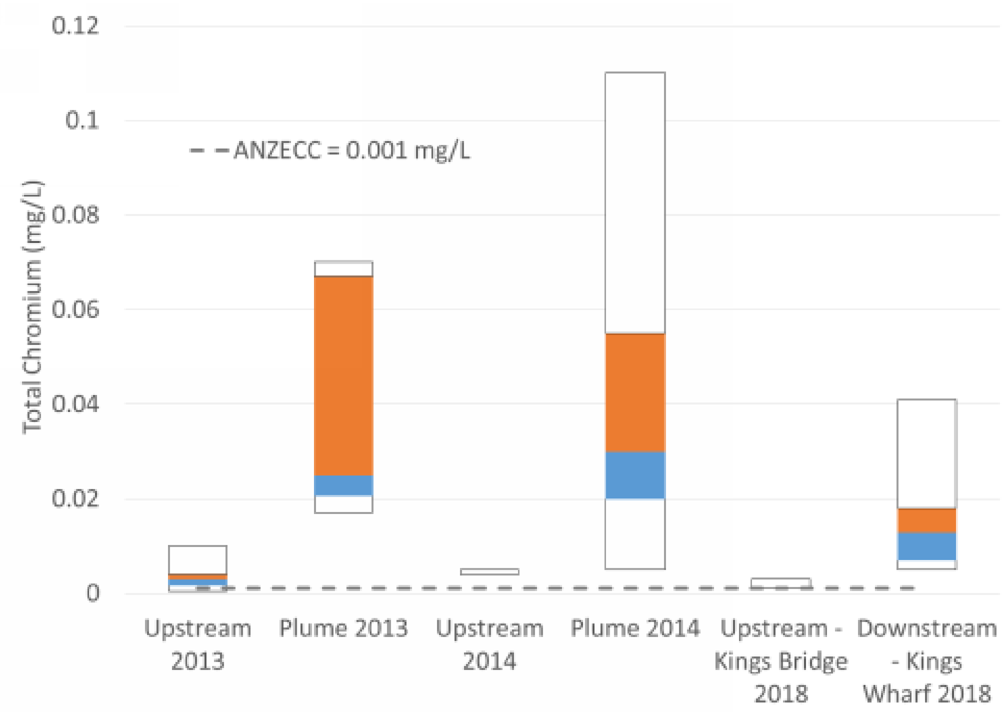



*FIGURE 36. TOTAL CHROMIUM: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014 AND 2018. ANZECC DGV IS 0.001MG/L*

Chromium concentrations also increase by an order of magnitude in the plume to a maximum of 100 times the ANZECC default guideline value of 0.001mg/L (Figure 36). Different LOR are used in each year and even within data sets for the year. In some years such as 2018 the LOR is 0.002mg/L, whereas in 2013 data is reported both <0.01mg/L and <0.001mg/L. There is very little variation in upstream values of chromium, with most observations at or just over the LOR. By comparison the plume concentrations of chromium are very high and vary between one and two orders of magnitude greater than the ANZECC default guideline value. These increases associated with sediment raking are thus substantial.

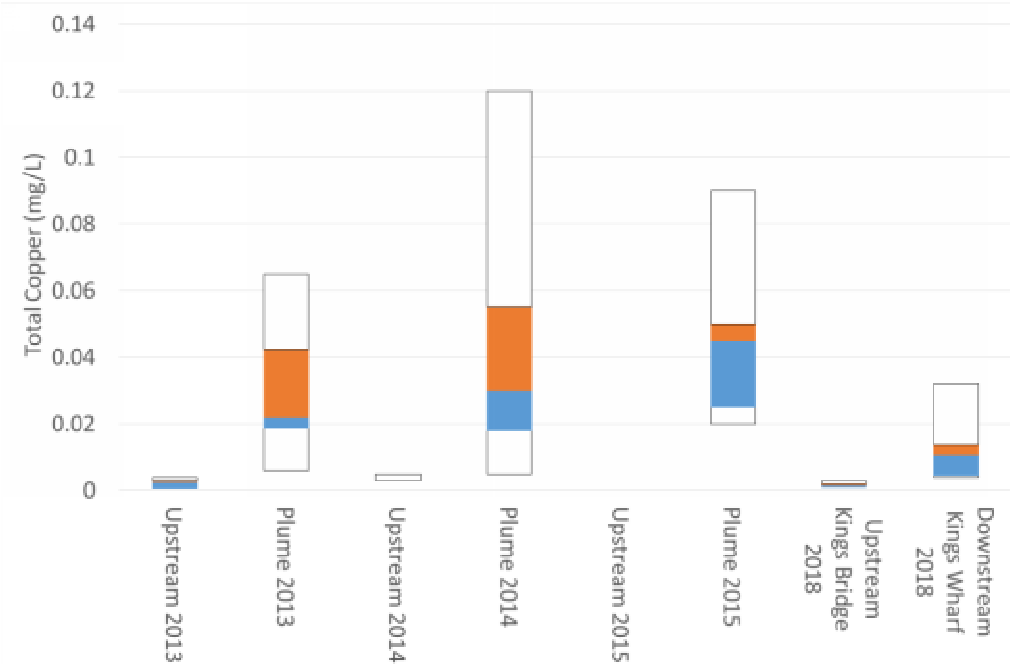



*Figure 37. Total Copper: Comparison between observations upstream and in plume for 2013, 2014, 2015 and 2018. ANZECC DGV is 0.0014mg/L*

The default guideline value for copper is 0.0014mg/L. This compares with limits of reporting of 0.001mg/L in some years and 0.01mg/L in others (both values are used in the 2013 data set). All upstream copper concentrations fall between these limits of reporting, with observations where a concentration was recorded generally less than 0.005mg/L (Figure 37). Concentrations in the plume are an order of magnitude larger than upstream samples and are in all cases greater than the default guideline value.

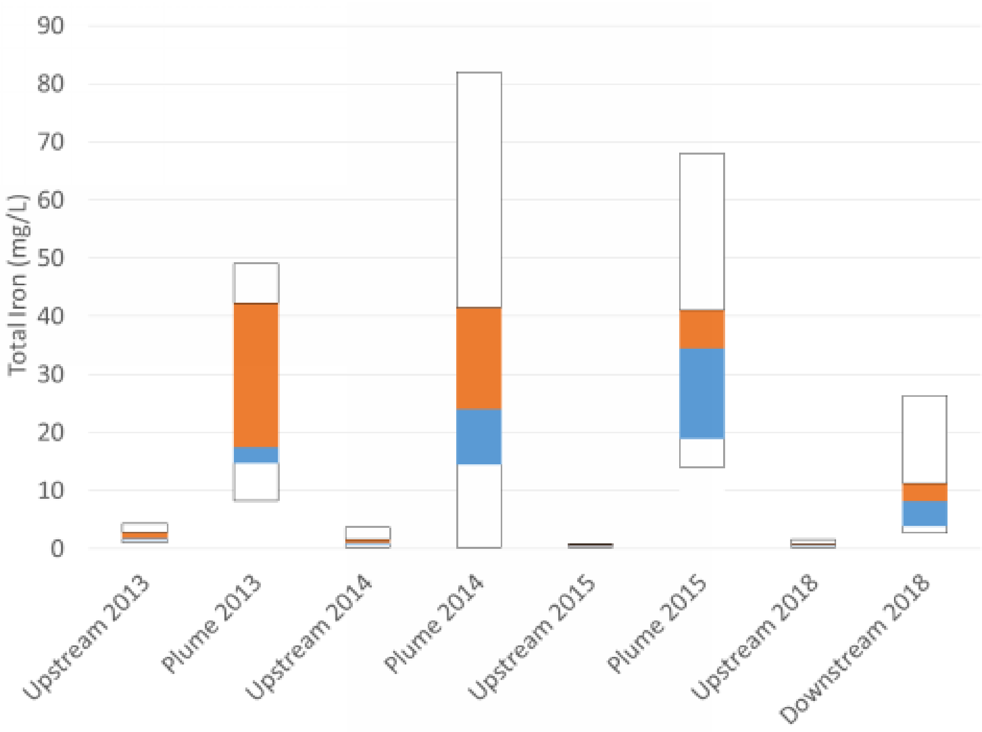



*Figure 38. Total Iron: Comparison between observations upstream and in plume for 2013, 2014, 2015 and 2018. There is no ANZECC DGV for Iron*

There is no default guideline value for iron. As was the case with other metals, concentrations in the plume are an order of magnitude greater than those measured upstream (Figure 38).

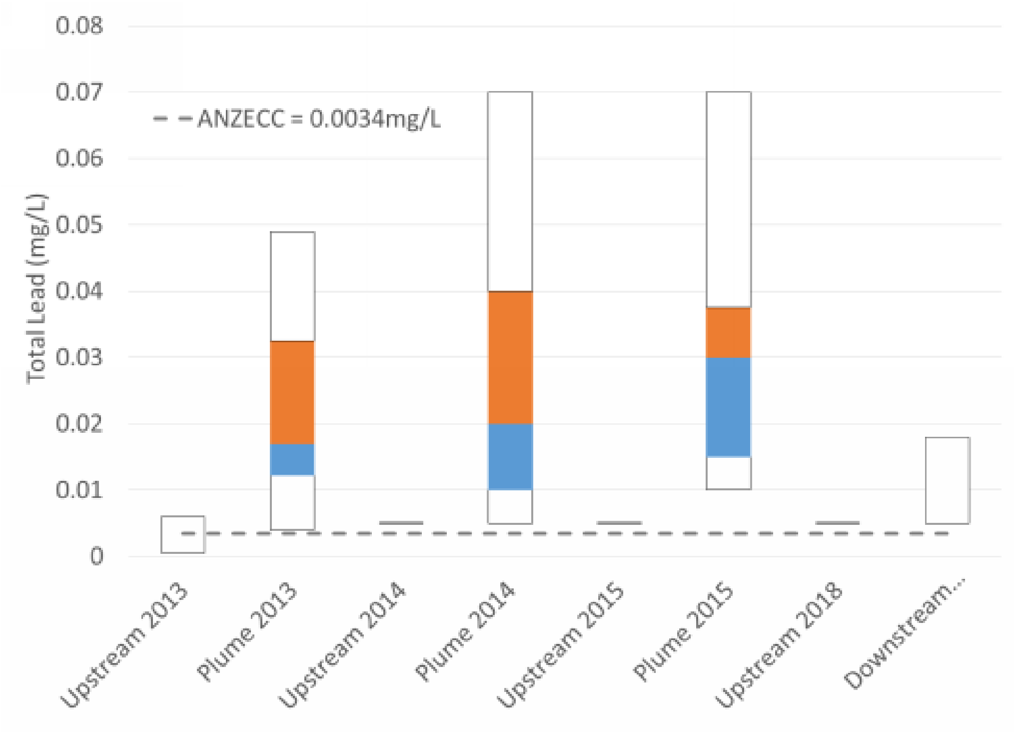



*FIGURE 39. TOTAL LEAD: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014, 2015 AND 2018. ANZECC DGV IS 0.0034MG/L*

The default guideline value for lead is 0.0034mg/L. Limits of reporting for lead vary between 0.01 and 0.001mg/L. Figure 39 shows there is a single upstream observation greater than the limit of reporting (in 2013). All other values fall below the LOR. Concentrations in the plume are an order of magnitude greater than the default guideline value and substantially greater than the concentrations upstream of raking.

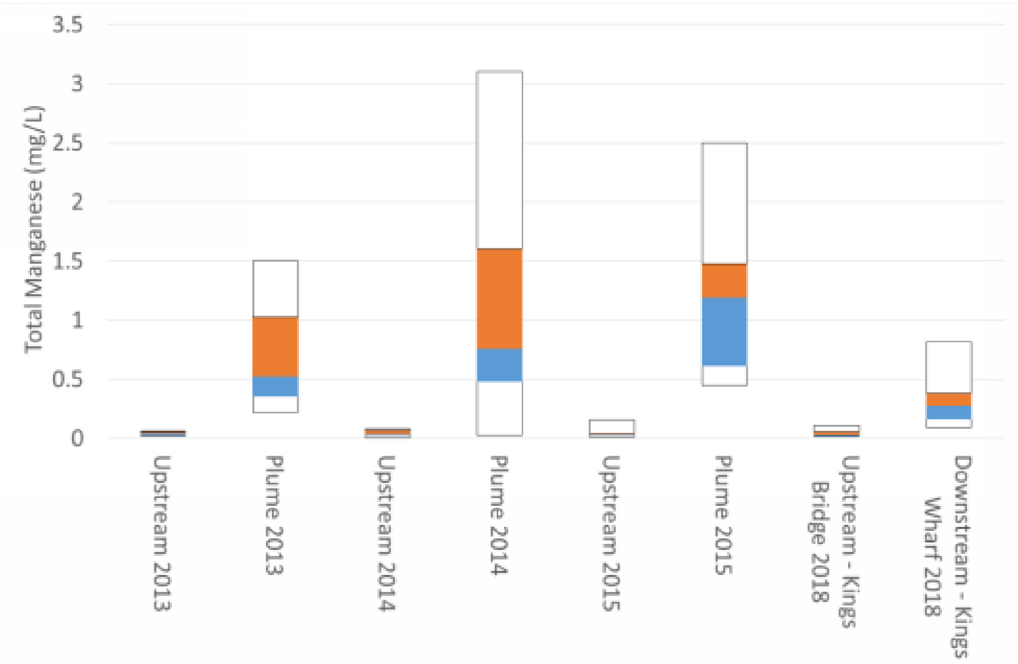



*FIGURE 40. TOTAL MANGANESE: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014, 2015 AND 2018. THE ANZECC DGV IS 1.9MG/L*

The default guideline value for manganese is 1.9mg/L. Upstream concentrations are below 0.1mg/L for all years, except a single observation in 2015 (0.16mg/L) (Figure 40). Concentrations in the plume are much higher with the overall median concentration in the plume 0.488mg/L, which is still below the default guideline value. Maximum concentrations in the plume in 2014 and 2015 are greater than the default guideline value but 75th percentiles fall below.

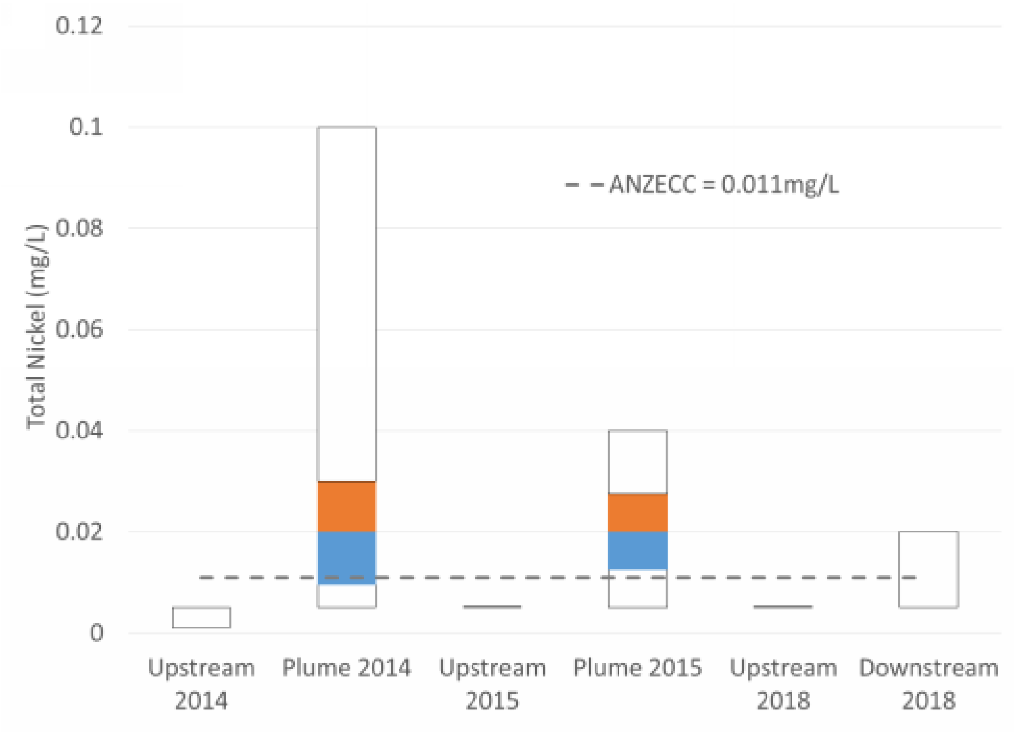



*Figure 41. Total Nickel: Comparison between observations upstream and in plume for 2014, 2015 and 2018. Note there is no Nickel Data for 2013. ANZECC DGV is 0.011mg/L*

Upstream concentrations of nickel are generally below the limits of reporting which varies between 0.01mg/L and 0.001mg/L (Figure 41). Concentrations of nickel in the plume are generally much higher in 2014 and 2015. Concentrations in the plume in 2018 are often below the LOR but maximums are above the default guideline value of 0.011mg/L. Maximum concentrations in the plume in 2014 and 2015 reach 0.1mg/L and 0.04mg/L respectively.

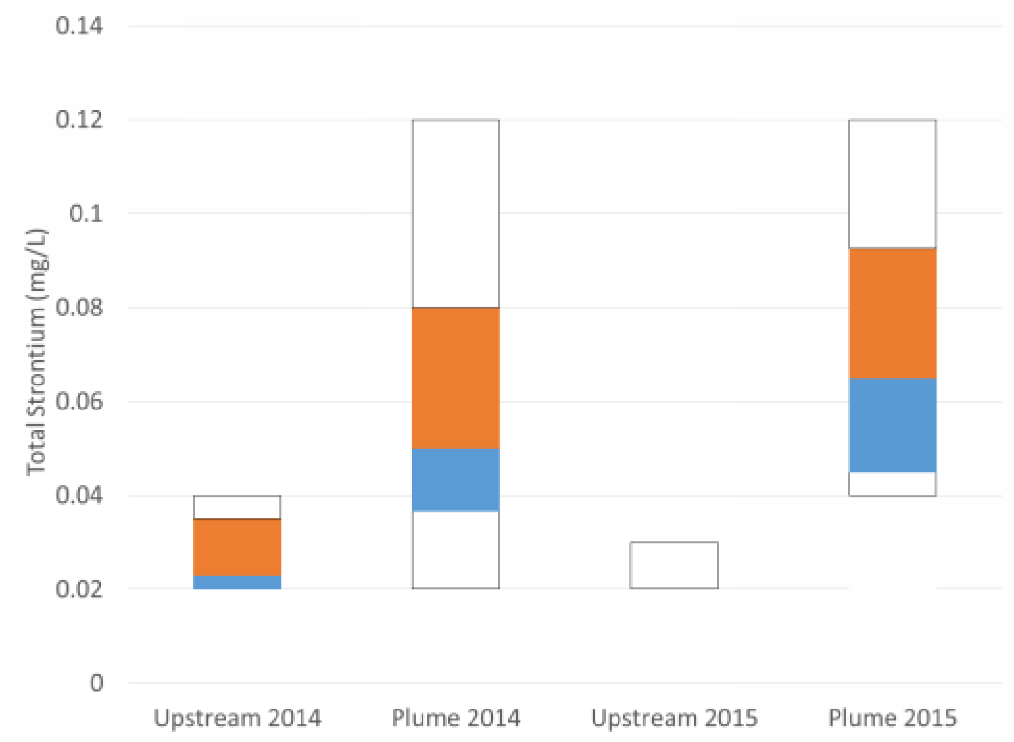



*FIGURE 42. TOTAL STRONTIUM: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2014 AND 2015. NOTE THERE IS NO STRONTIUM DATA FOR 2013 OR 2018. THERE IS NO ANZECC DGV FOR STRONTIUM*

Strontium concentrations are also increased substantially in the plume compared to upstream (Figure 42). There is no ANZECC default guideline value for strontium. Upstream concentrations vary between 0.02mg/L and 0.04mg/L with concentrations in the plume reaching 0.12mg/L and median values of greater than 0.05mg/L.

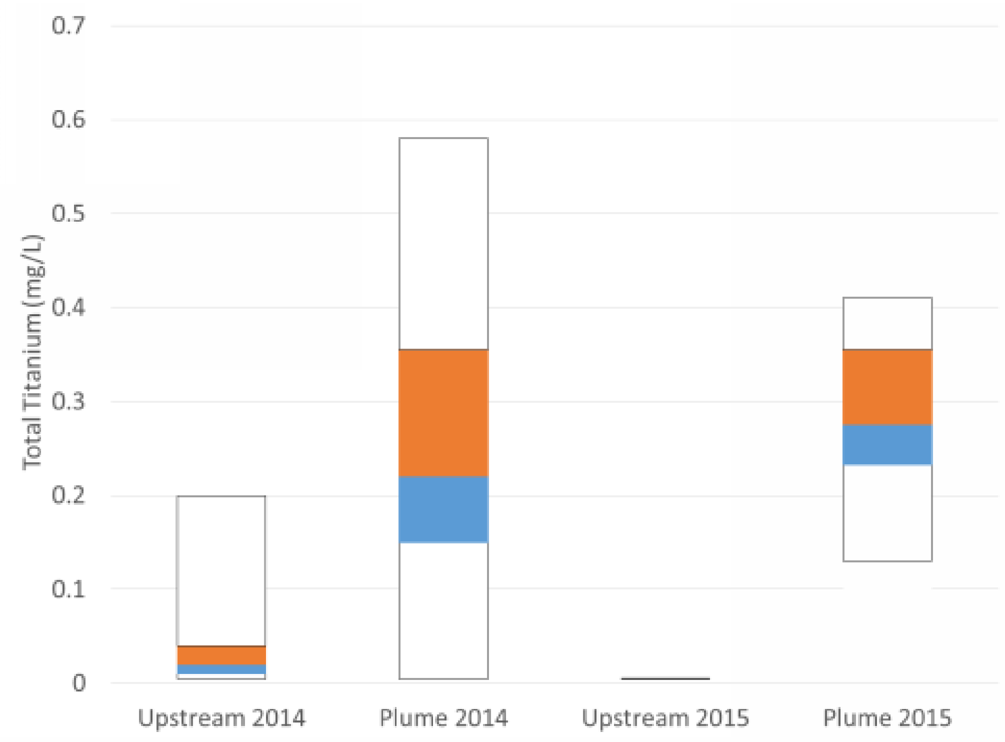



*FIGURE 43. TOTAL TITANIUM: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2014 AND 2015. NOTE THERE IS NO TITANIUM DATA FOR 2013 OR 2018. THERE IS NOT ANZECC DGV FOR TITANIUM*

Total titanium also increases significantly in the plume compared to downstream (Figure 43). Like strontium, there is no ANZECC default guideline value for titanium. All upstream concentrations in 2015 are below the limits of reporting (0.01 mg/L), while concentrations in 2014 vary up to 0.2 mg/L with most concentrations below 0.04 mg/L (75$^{th}$ percentile). Maximum concentrations in the plume are an order of magnitude higher, ranging up to 0.4 mg/L in 2015 and nearly 0.6 mg/L in 2014.

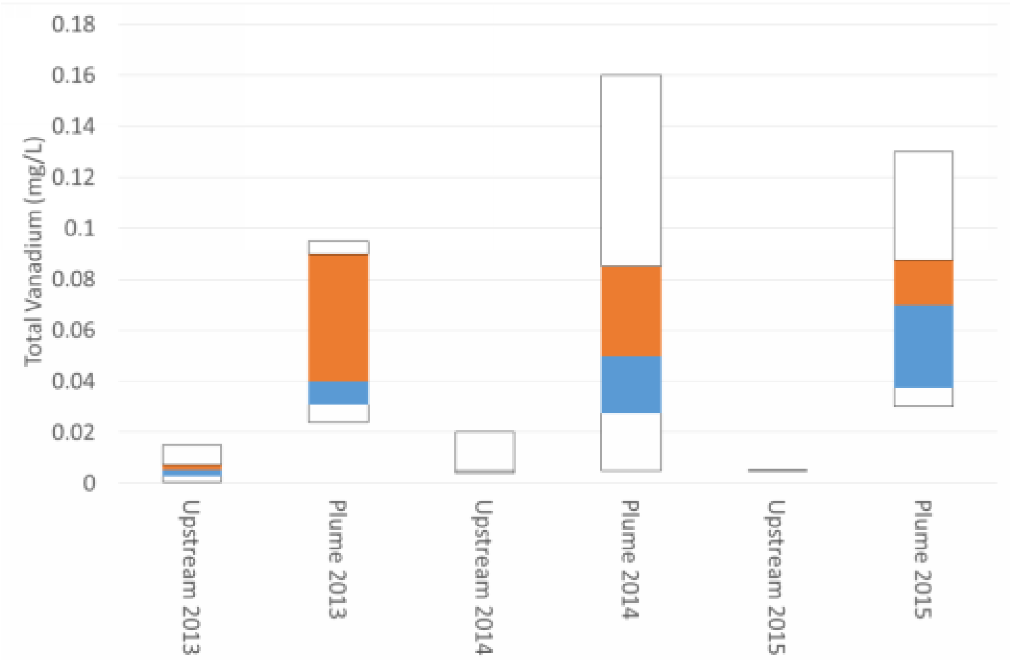



*Figure 44. Total Vanadium: Comparison between observations upstream and in plume for 2013, 2014 and 2015. Note there is no Vanadium Data for 2018. The ANZECC Default guideline value for marine waters of 0.1mg/L is plotted. A low Reliability value of 0.006mg/L is the only available default guideline value for Vanadium*

There is no ANZECC default guideline value for vanadium in freshwater systems (there is a low reliability value of 0.006mg/L). The ANZECC default guideline value in marine waters for vanadium is 0.1mg/L. Maximum upstream concentrations in 2013 and 2014 are well below this default guideline value at 0.015mg/L and 0.02mg/L respectively (Figure 44). Upstream concentrations in 2015 are below the limits of reporting (0.01mg/L). Sediment raking increases concentrations substantially above upstream values but these remain within the default guideline with the exception of two observations in 2014 and 1 observation in 2015. Concentrations in the plume in 2013 are below the ANZECC default guideline though 3 observations are within 10% of the default guideline.

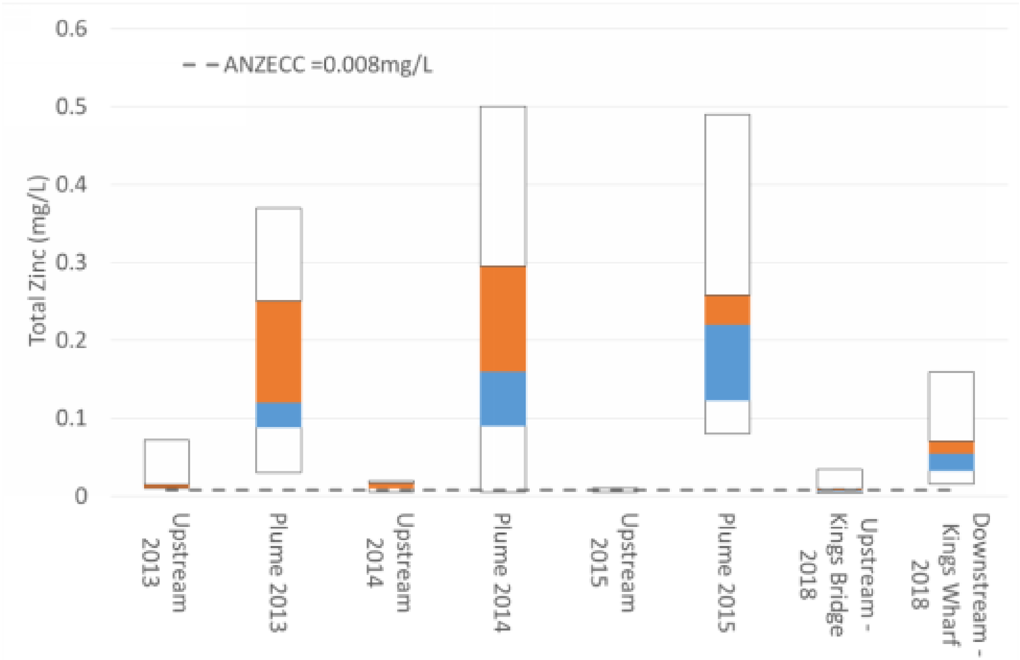



*FIGURE 45. TOTAL ZINC: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014, 2015 AND 2018. ANZECC DEFAULT GUIDELINE VALUE IS 0.008MG/L*

ANZECC default guideline values for zinc are 0.008 mg/L. Maximum upstream concentrations are above this DGV in all years, though in 2015 only a single observation is above the DGV (Figure 45). Increases in the plume are substantial, an order of magnitude higher than upstream concentrations. Maximum concentrations in the plume are two orders of magnitude greater than the DGV.

Data on dissolved metals was also collected. In most cases dissolved metal concentrations were below the limits of reporting both upstream and in the plume. Three metals – aluminium, iron and manganese, had concentrations greater than LOR. Concentrations of these dissolved metals are shown in Figure 46 to Figure 48.

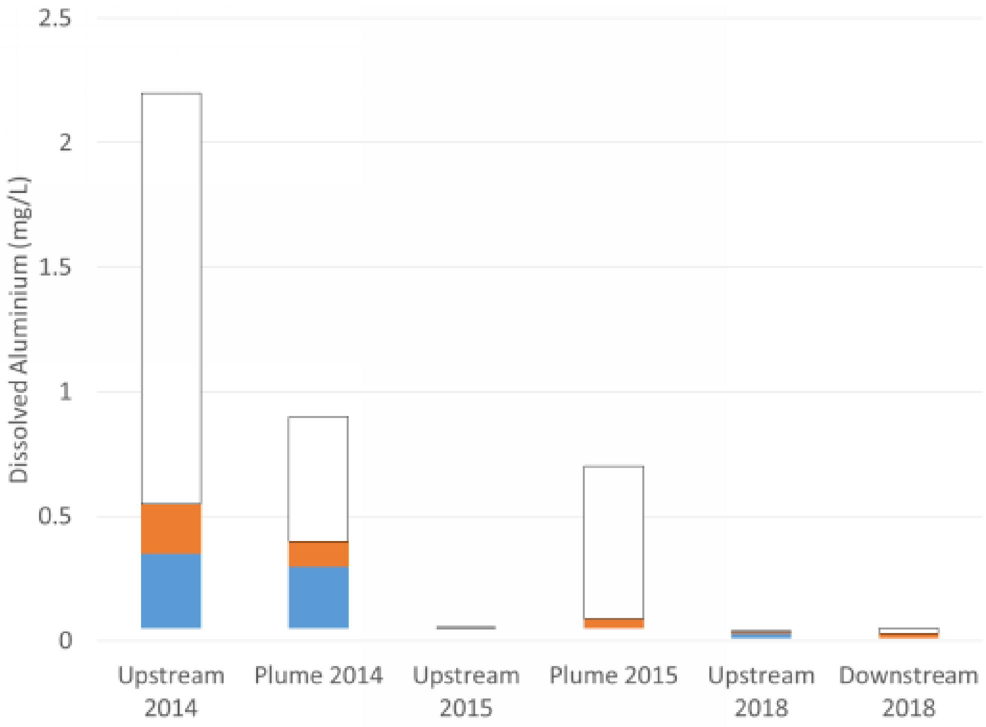



*Figure 46. Dissolved Aluminium: Comparison between observations upstream and in plume for 2014, 2015 and 2018. Note no Total Aluminium data was available for 2013*

Impacts of raking on dissolved aluminium are shown in Figure 46. This figure shows mixed results. Concentrations in the plume in 2014 and 2018 are generally lower than upstream concentrations although the maximum concentrations in 2018 are higher in the plume than upstream. Concentrations in 2015 reflect the two large concentrations observed in the plume while all other concentrations remain below the limits of reporting (0.1 mg/L) in that year. The limits of reporting are lower in 2018, at 0.02mg/L.

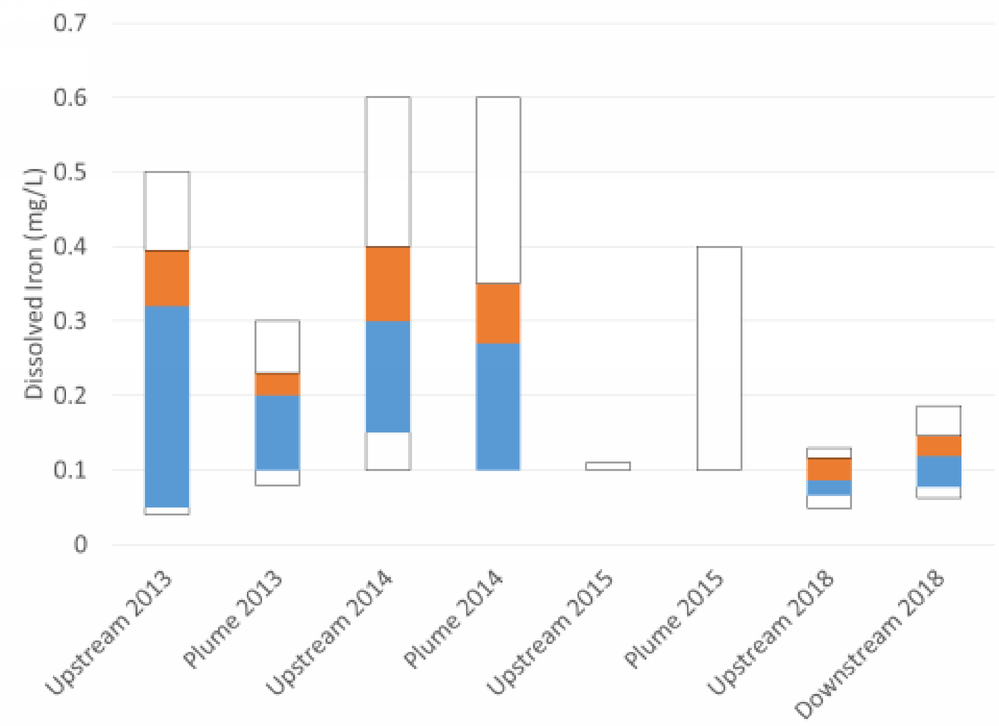



*FIGURE 47. DISSOLVED IRON: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2013, 2014, 2015 AND 2018*

Concentrations of dissolved iron in the plume decrease in 2013 and 2014 but increase relative to upstream values in 2018 (Figure 47). The maximum concentration in the plume in 2015 is greater downstream but all other observations are slightly lower than upstream concentrations (0.1mg/L in the plume compared to 0.11mg/L). It is likely that the differences in collection method between years is affecting results with concentrations in earlier years measured in the sediment stirred into the water column from the boat more likely to be attached to sediment than metals which have had slightly longer to detach in the water column using the method of collection in 2018.

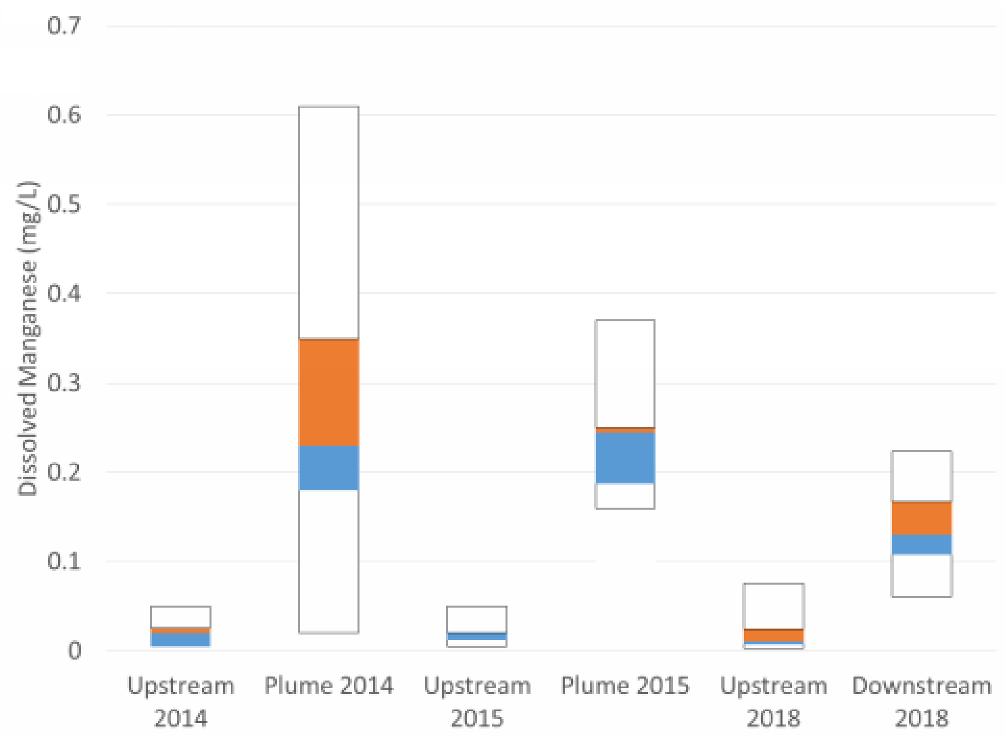



*FIGURE 48. DISSOLVED MANGANESE: COMPARISON BETWEEN OBSERVATIONS UPSTREAM AND IN PLUME FOR 2014, 2015 AND 2018. NOTE NO MANGANESE DATA WAS AVAILABLE FOR 2013*

Concentrations of dissolved manganese increase significantly in the plume compared to upstream (Figure 48). Concentrations are generally an order of magnitude higher in the plume than upstream.

## 3.4 Discussion

These results show that sediment raking has an immediate impact on most pollutants, including nutrients, sediment, turbidity and heavy metals. Increases in the case of metals are generally very high, up to two orders of magnitude greater than upstream values. In most cases these increases are also substantial when considered against ANZECC default guideline values. The exceptions to this are NOx and dissolved aluminium. Differences between the behaviour of these pollutants in different years are likely to reflect the different collection methods and may be demonstrating that totals of these pollutants (nitrogen and aluminium) increase substantially immediately but dissolved forms are impacted by the very high sediment concentrations immediately behind the boat. It is possible that the slightly greater time and distance between raking and collection in 2018 meant these dissolved pollutants had a greater chance to detach from sediments, explaining the general increase in the plume seen in data from this year, whereas decreases were experienced in years where samples were collected directly behind the rake boat. Regardless it is clear that sediment raking has large localised impacts on water quality. The monitoring plan for sediment raking was not capable of assessing whether these impacts extended downstream, either immediately in the upper estuary or over longer time scales in the lower estuary. The next section analyses ambient data collected for the Tamar Estuary and Esk Rivers program to assess whether these types of longer-term and large scale impacts can be observed.

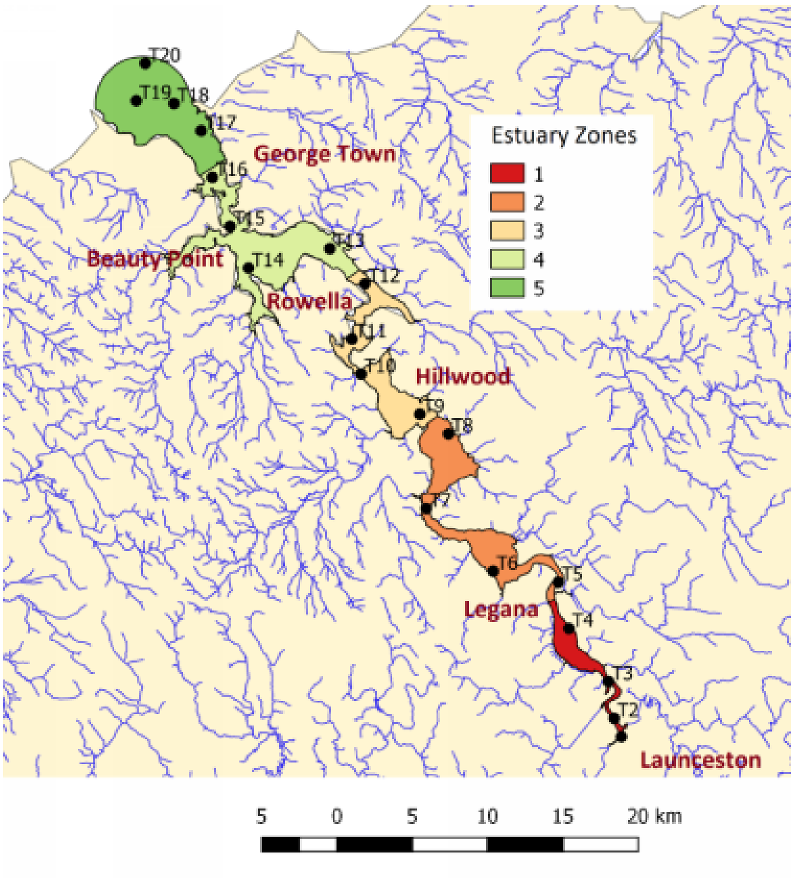
# 4 Longer-term impacts on water quality across the estuary

In order to assess the potential impacts sediment raking may be having on water quality at a whole of estuary scale, a long-term monitoring data set covering the length of the estuary is required. The sediment raking program had water quality monitoring requirements that focused on the immediate and localised impacts of raking (in front of and behind the raking boat). This monitoring regime did not produce data that could answer key questions:

- What is the cumulative effect of raking campaigns and for how long do water quality impacts persist?
- What is the spatial extent of impacts?
- How does this vary by pollutant?

The Tamar Estuary and Esk Rivers (TEER) Ecological Health Assessment Program (EHAP) has collected monthly grab sample data for 18 sites in the estuary between October 2009 and July 2018 with data collected 2 years on, 2 years off (see Figure 49 - note Sites 8 and 11 are no longer used for monitoring so data is not available for these sites). This data includes nutrients (TP, DRP, TN, NOX, Ammonia), enterococci, Chlorophyll-a (ChlA) and dissolved oxygen. A limited set of data on metals has also been collected quarterly at sites in Zone 1 and Zone 4 across the period. A more comprehensive set of metals data was collected from 2014 onwards at all monitoring sites.

This section focuses on analysis to identify what impacts, if any, sediment raking may be having on water quality across the estuary. It needs to be acknowledged that the EHAP data was never collected for this purpose and so the monitoring program has not been designed in a way to most clearly estimate any impacts of sediment raking. This section looks instead for evidence of impacts using the data that is available. This means that the data analysis can provide evidence of impact but cannot rule out possible impacts that may have occurred but were not adequately measured.




| SITE | Location |
|---|---|
| T1 | Kings Bridge |
| T2 | Ship Lift |
| T3 | Hunters Cut |
| T4 | Tamar Island |
| T5 | Fresh Water Point |
| T6 | Lone Pine |
| T7 | Blackwall |
| T8 | Swan Point |
| T9 | Egg Island |
| T10 | Batman Bridge |
| T11 | Bonnie Beach |
| T12 | Rowella |
| T13 | Long Reach |
| T14 | Beauty Point |
| T15 | Clarence Point |
| T16 | Windmill Point |
| T17 | Lagoon Bay |
| T18 | Low Head |
| T19 | Hebe Reef |
| T20 | Bass Strait |

*Figure 49. Location of TEER EHAP monitoring sites and Estuary Zones used for TEER Report Card*

The analysis in this section uses a simple estimate of sediment raking effort – with days where sediment raking occurred given a value of 1 and other days a value of 0. This treatment ignores the very real differences between impacts that may occur based on the location of raking efforts or the intensity with which this occurred. For example an hour of raking around Royal Park is treated identically to 6 hours of raking on the Western Shoal. This is an obvious simplification and is likely to be a source of error and uncertainty in the analysis.

## 4.1 Impacts on nutrients, sediments, turbidity and enterococci

The TEER EHAP data set includes:

- Total Suspended sediments
- Turbidity

- Total nitrogen (TN), nitrate and nitrite (NOx) and ammonia
- Total phosphorus (TP) and dissolved reactive phosphorus (DRP)
- Enterococci.

Figure 50 shows the days on which monitoring data for these constituents were measured (in black) against the days when sediment raking occurred. This shows clearly the gaps in the EHAP monitoring data set which coincide with the commencement of sediment raking. There are however significant overlaps between sediment raking campaigns in 2014, 2015, 2017 and 2018 which allow for impacts to be analysed, particularly given that a 'pre-raking' data set is available from 2009 to 2011 for most constituents.

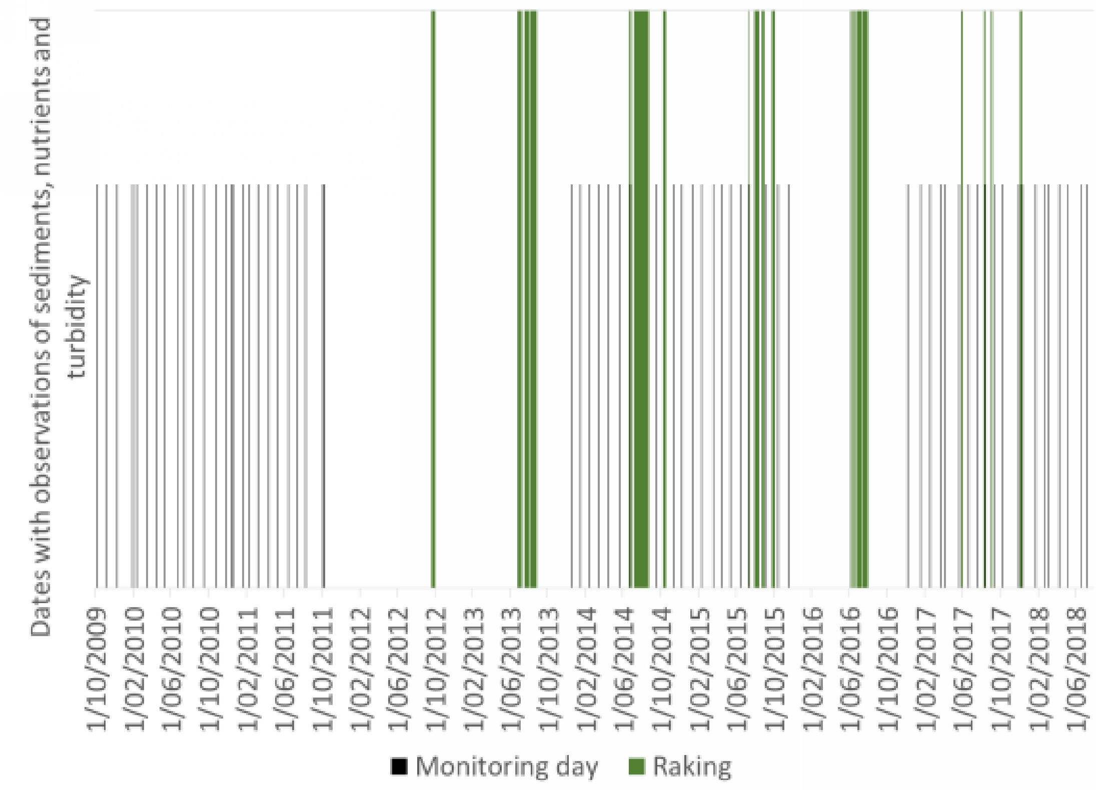



*FIGURE 50. DAYS ON WHICH NUTRIENT, SEDIMENT, TURBIDITY AND ENTEROCOCCI DATA WERE COLLECTED WITH SEDIMENT RAKING DAYS*

Two types of impacts have been investigated:

- Immediate impacts (within a week) of sediment raking looking at a simple comparison of differences between days where raking has occurred in the previous week versus days with no raking in the preceding week.
- The effects of raking over longer time periods and how this is affected by the intensity of raking and how recent it was.

### 4.1.1 Immediate impacts on water quality

The immediate impacts (within a week) of sediment raking have been investigated using a paired sample to minimise differences in water quality caused by other factors such as inflows from the North Esk and South Esk Rivers. Paired samples have been developed from within the period where raking occurred (ie. after Jun 2013) and matched based on observations of the average daily flow in the preceding week. Note given the small data set available pairs were based entirely on antecedent flow conditions and did not attempt to control for other variables such as season. Given that these data are unlikely to be normally distributed a non-parametric test – the Wilcox signed rank test – is used to test for differences between the paired samples at sites T1 to T7. This test produces a *p*-value indicating the statistical significance of differences in the median of the two samples. Figure 51 to Figure 58 show the median value for paired samples at each monitoring location for days with and without raking during the raking period for each pollutant. In this section of analysis:

- 'raking days' refers to those where raking occurred in the previous week
- 'non-raking days' refer to those where no raking occurred at any time in the preceding week.

The *p*-value indicating the statistical significance of the differences between these median values is shown. The dotted line indicates the 95% confidence level with *p*-values below this line indicating a statistically significant difference in medians. Medians are based on 7 paired data points for each site and parameter.

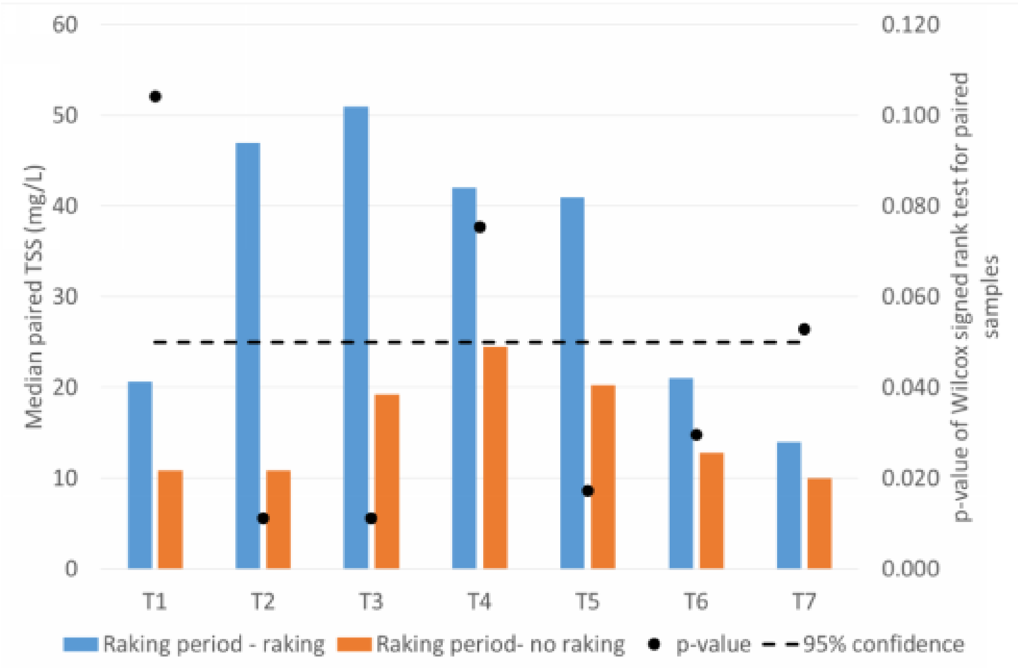



*FIGURE 51. TSS – MEDIAN OF PAIRED VALUES DURING THE RAKING PERIOD WITH AND WITHOUT RAKING IN THE PREVIOUS WEEK. P-VALUE INDICATING SIGNIFICANCE OF DIFFERENCE IN MEDIAN VALUES PLOTTED ON THE SECONDARY AXIS WITH 95% CONFIDENCE LEVEL INDICATING THE STATISTICAL DIFFERENCE IN MEDIAN VALUE NOTED*

Figure 51 shows the median of TSS values for raking (ie when raking occurred in the previous week) and non-raking days in the period when raking occurred. This shows substantial and statistically significant differences in the median TSS at T2, T3 and T5 (concentrations in raking periods are between 2 and 5 times concentrations in non-raking periods). Differences at T6 are also statistically significant but smaller in magnitude.

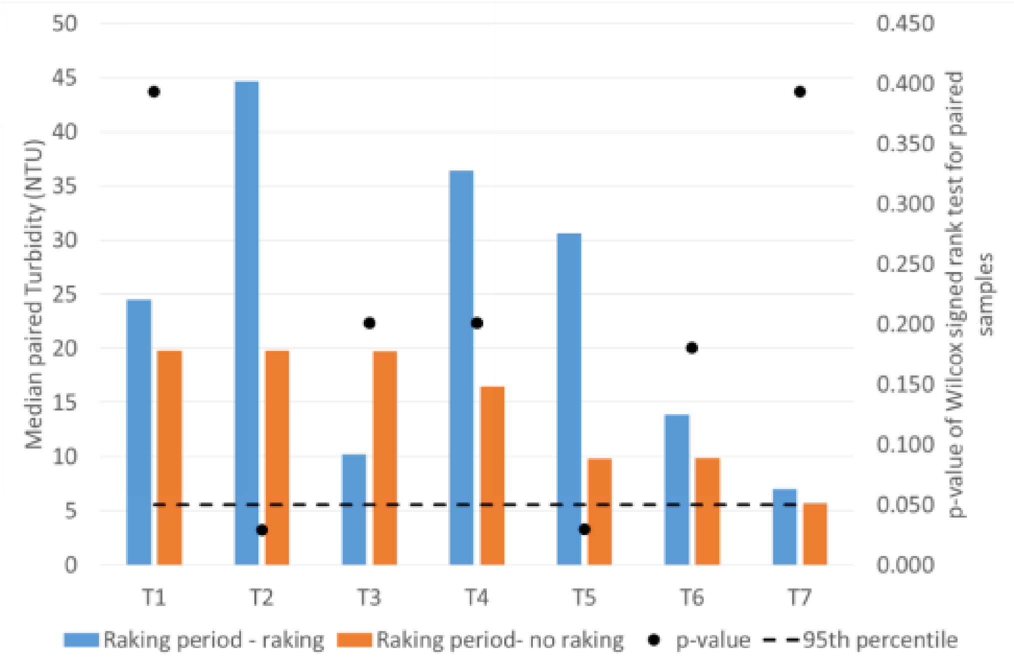



*Figure 52. Turbidity – Median of paired values during the raking period with and without raking in the previous week. P-value indicating significance of difference in median values plotted on the secondary axis with 95% confidence level noted*

Figure 52 shows the median of paired values of turbidity data and *p*-values showing the statistical significances of differences in these medians. In this case only T2 and T5 have statistically different turbidity values in raking and non-raking periods. The magnitude of differences at T2 and T5 is large, with raking periods having turbidity 2 to 2.5 times that of non-raking periods at these sites. The ANZECC default guideline value for turbidity is 10 NTU. This is exceeded at sites T1 to T4 on non-raking and raking days. At T5 and T6 the DGV is met on raking days but turbidity is 3 times higher on raking days at T5 and nearly 1.5 times this value at T6. Both non-raking and raking days are within the ANZECC DGV at T7.

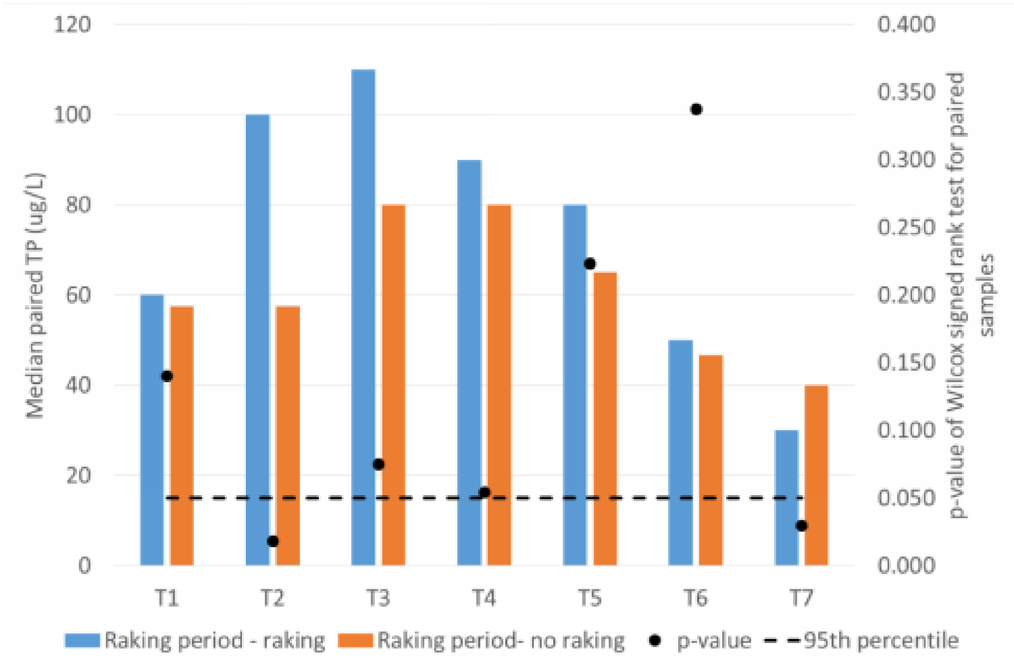



*FIGURE 53. TP – MEDIAN OF PAIRED VALUES DURING THE RAKING PERIOD WITH AND WITHOUT RAKING IN THE PREVIOUS WEEK. P-VALUE INDICATING SIGNIFICANCE OF DIFFERENCE IN MEDIAN VALUES PLOTTED ON THE SECONDARY AXIS WITH 95% CONFIDENCE LEVEL NOTED*

Figure 53 shows the median of paired values of TP concentrations on raking and non-raking days in the raking period. This figure shows significant differences at sites T2 and T7 with the *p*-value at site T4 just outside the 0.05 threshold. While median values at T7 are statistically significantly different, the magnitude of these differences is less than was the case for other sites and pollutants (33%) with raking days being lower than non-raking days. TP concentrations are over 70% higher at T2 for raking days compared to non-raking days. Note that the ANZECC default guideline value is 30µg/L and EPA guideline used for the TEER report card is 27.4µg/L. All median values are above these levels. The increase between non-raking and raking days at T2 is greater than the guideline values.

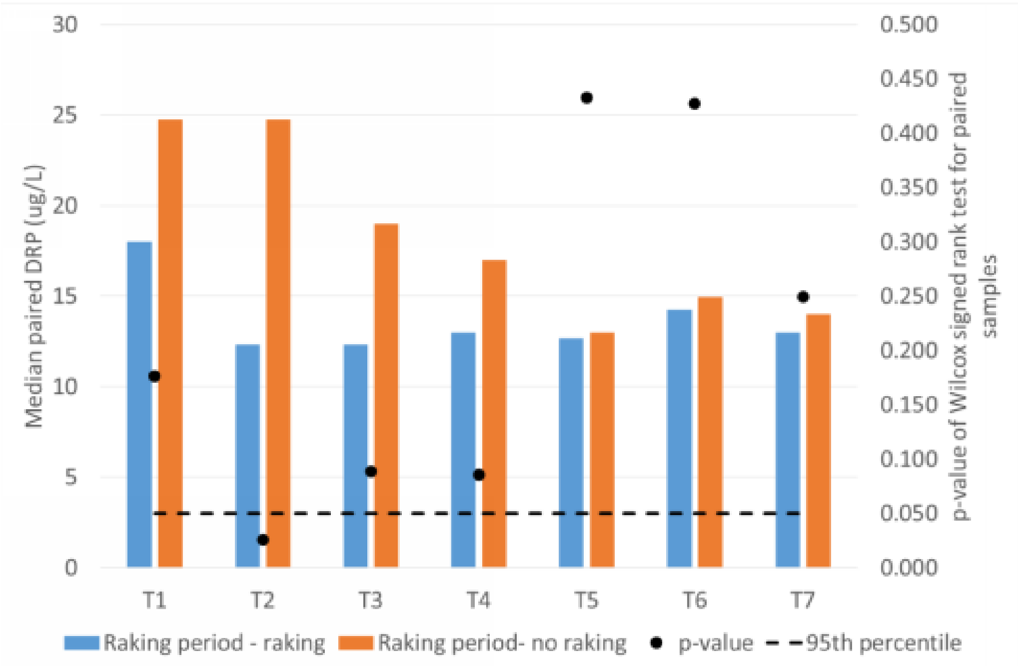



*FIGURE 54. DRP – MEDIAN OF PAIRED VALUES DURING THE RAKING PERIOD WITH AND WITHOUT RAKING IN THE PREVIOUS WEEK. P-VALUE INDICATING SIGNIFICANCE OF DIFFERENCE IN MEDIAN VALUES PLOTTED ON THE SECONDARY AXIS WITH 95% CONFIDENCE LEVEL NOTED*

Figure 54 shows the median of paired values of DRP between raking and non-raking days and the significance of differences between these. This figure shows significant differences between DRP at T2. The median of raking days is less than that of non-raking days for all sites from T1 to T4 although T2 is the only site at which this difference is statistically significant. This is the opposite of what was seen for TP with raked days having a statistically significantly higher median than non-raked days at T2. This result is likely to reflect the initial response of phosphorus attaching to sediments suspended through sediment raking. The ANZECC default guideline value for DRP is 5 µg/L. Median values at all sites for both raking and non-raking days are above this value.

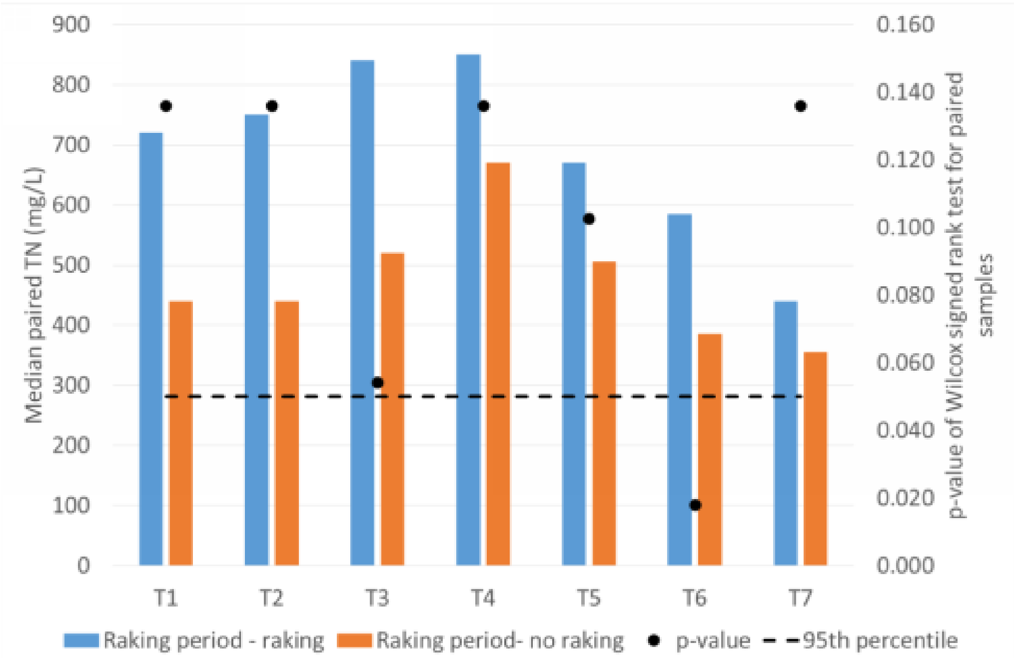



*FIGURE 55. TN – MEDIAN OF PAIRED VALUES DURING THE RAKING PERIOD WITH AND WITHOUT RAKING IN THE PREVIOUS WEEK. P-VALUE INDICATING SIGNIFICANCE OF DIFFERENCE IN MEDIAN VALUES PLOTTED ON THE SECONDARY AXIS WITH 95% CONFIDENCE LEVEL NOTED*

Figure 55 shows the median of paired values of TN. This shows that while median values of sediment raking days are higher than non-sediment raking days at all sites, these differences are only statistically significantly different at T6 with the *p*-value at site T3 falling just outside the 0.05 thresholds for statistical significant at the 95% level. Other *p*-values are weakly significant falling within the 0.15 threshold. Median values of TN increase moving downstream from T1 and peak at T4 before falling below T1 levels by T7. The ANZECC DGV for TN is 300µg/L (TEER WQO is 384µg/L). Median values for all sites for both raking and non-raking days are above this value with increases at T3 and T6 taking TN to nearly 2 to 3 times the DGV.

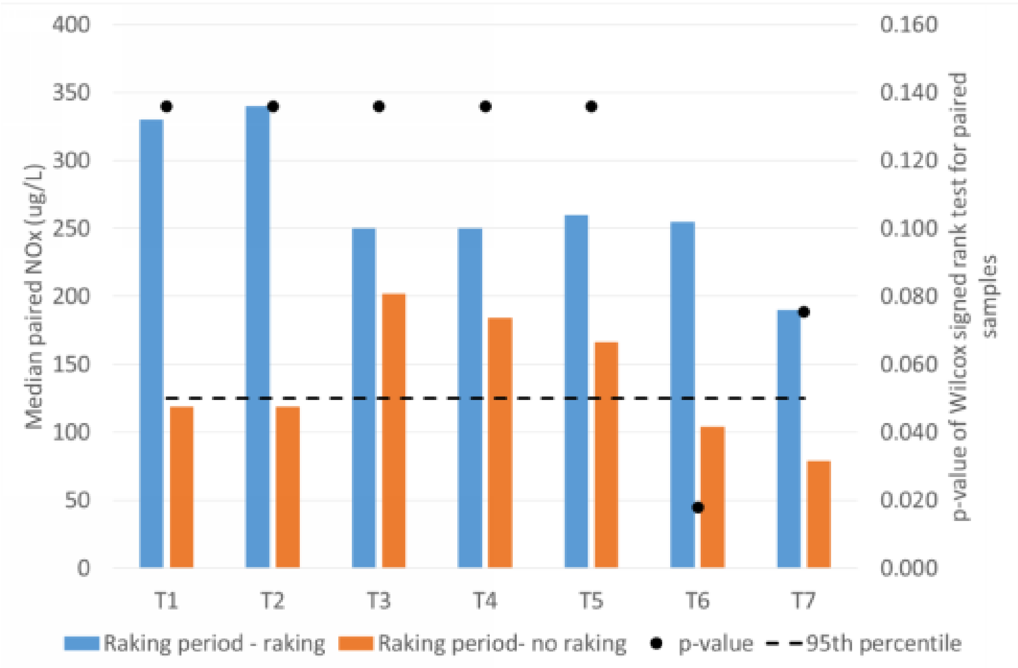



*FIGURE 56. NOX – MEDIAN OF PAIRED VALUES DURING THE RAKING PERIOD WITH AND WITHOUT RAKING IN THE PREVIOUS WEEK. P-VALUE INDICATING SIGNIFICANCE OF DIFFERENCE IN MEDIAN VALUES PLOTTED ON THE SECONDARY AXIS WITH 95% CONFIDENCE LEVEL NOTED*

Figure 56 shows the median of paired values of NOx at sites T1 to T7. This shows that median values for days associated with sediment raking are higher than non-raking days at all sites. As was the case for TN these differences are only statistically significant at Site T6, with *p*-values at other sites being less than 0.15 (indicating they are weakly significant). The ANZECC DGV for NOx is 15µg/L. Median values at all sites are substantially larger than this DGV with raking days at T1 and T2 being more than 20 times this value. All increases are large relative to the DGV.

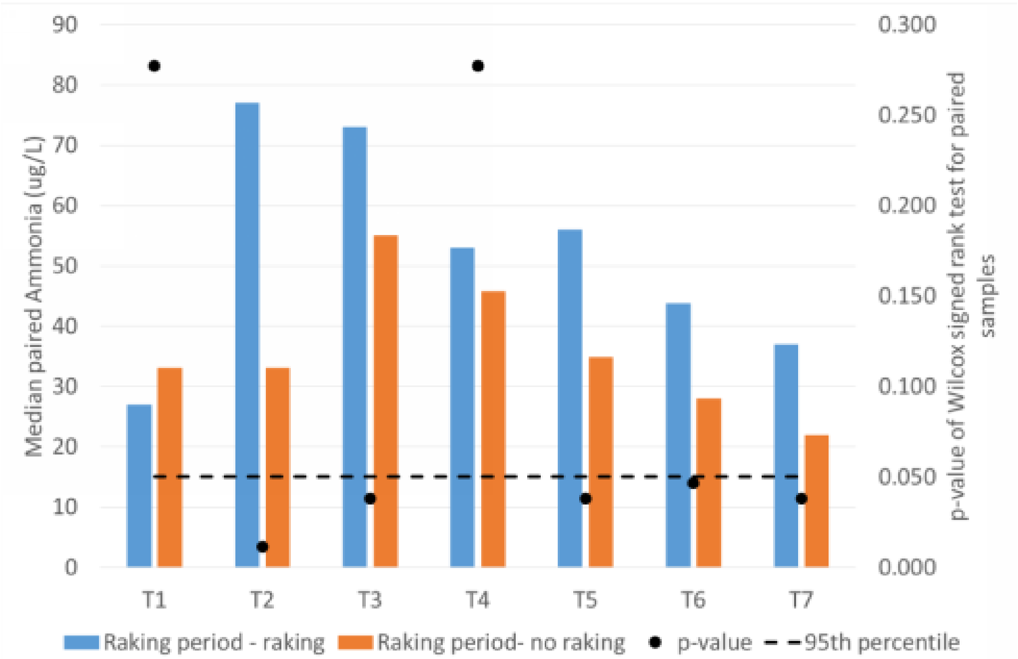



*FIGURE 57. AMMONIA – MEDIAN OF PAIRED VALUES DURING THE RAKING PERIOD WITH AND WITHOUT RAKING IN THE PREVIOUS WEEK. P-VALUE INDICATING SIGNIFICANCE OF DIFFERENCE IN MEDIAN VALUES PLOTTED ON THE SECONDARY AXIS WITH 95% CONFIDENCE LEVEL NOTED*

Figure 57 shows the median of paired values of ammonia and their *p*-values. This figure shows that median vales are higher on days associated with sediment raking at all sites except T1. Differences at T1 are small and not statistically significant. Small differences at T4 are also not statistically significant. Differences at other sites are generally larger and statistically significant. The ANZECC DGV for ammonia is 15µg/L. Median values at all sites for both raking and non-raking days are above this value. Statistically significant increases in ammonia at T2, T3, T5, T6 and T7 are all at or greater than this DGV.

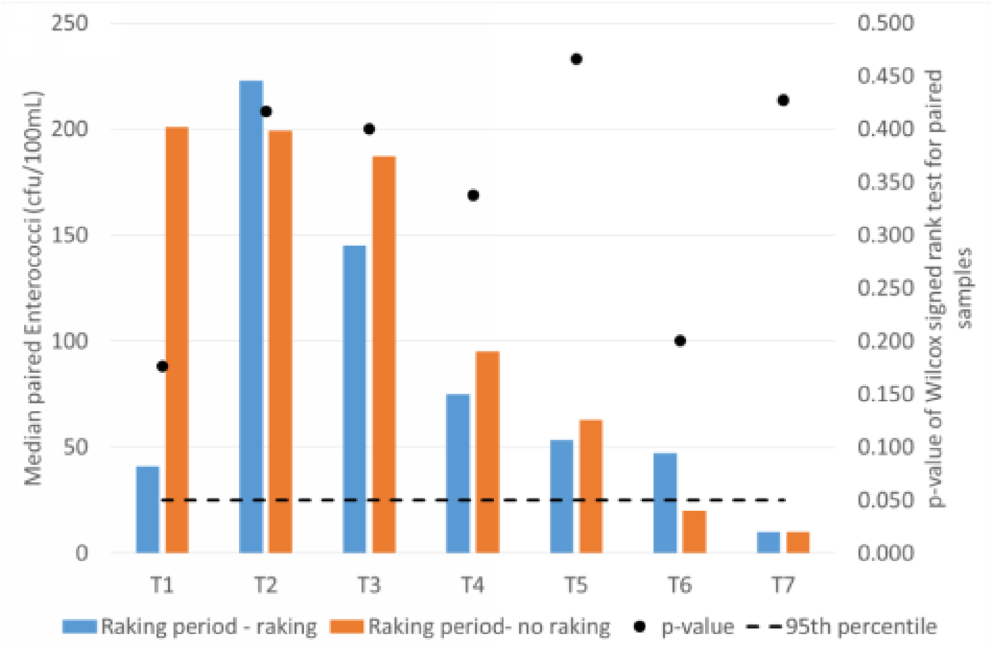



*FIGURE 58. ENTEROCOCCI – MEDIAN OF PAIRED VALUES DURING THE RAKING PERIOD WITH AND WITHOUT RAKING IN THE PREVIOUS WEEK. P-VALUE INDICATING SIGNIFICANCE OF DIFFERENCE IN MEDIAN VALUES PLOTTED ON THE SECONDARY AXIS WITH 95% CONFIDENCE LEVEL NOTED*

Figure 58 shows the median of paired values of enterococci concentrations and their *p*-values. This figure shows there are no statistically significant differences in these median values. *P*-values are higher than 0.3 at most sites and greater than 0.15 at all sites.

Table 12 summarises the difference in median values for each constituent of water quality evaluated in relation to sediment raking relative to non-sediment raking days. Note that as described previously 'raking' days are those for which raking occurred in the preceding week while 'non-raking' days had no raking in the preceding week. Cells are coloured to indicate the statistical significance of these differences – green cells are those where the *p*-value of differences between the medians is <0.05 (highly significant), orange cells are where the *p*-value is less than 0.15 but greater than 0.05 (weakly significant), and red cells are not statistically significant.

*TABLE 12. SUMMARY OF DIFFERENCES IN MEDIAN VALUES FOR EACH CONSTITUENT (RELATIVE TO NON-RAKING DAYS - NOTE 0% MEANS MEDIAN VALUES ARE THE SAME). GREEN CELLS ARE SIGNIFICANTLY DIFFERENT AT 95% LEVEL. ORANGE CELLS ARE WEAKLY SIGNIFICANT (85%). RED CELLS ARE INSIGNIFICANT.*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|
| TSS | 90% | 333% | 165% | 71% | 102% | 64% | 40% |
| Turbidity | 24% | 125% | -48% | 121% | 213% | 41% | 23% |
| TP | 4% | 74% | 38% | 13% | 23% | 7% | -25% |
| DRP | -27% | -50% | -35% | -24% | -3% | -5% | -7% |
| TN | 64% | 70% | 62% | 27% | 32% | 52% | 24% |
| NOx | 177% | 185% | 24% | 36% | 56% | 145% | 141% |
| Ammonia | -19% | 132% | 33% | 16% | 61% | 56% | 68% |
| Enterococci | -80% | 12% | -22% | -21% | -15% | 135% | 0% |

This analysis shows there are statistically significant differences in paired data sets at many sites in Zones 1 and 2.

- Large and significant differences are seen at T2 for TSS, turbidity, TP and ammonia.
- Differences in TSS extend to T3, T5 and T6, with weakly significant differences also at T1, T4 and T7.
- Ammonia has a similar pattern of impacts to TSS, although increases at T7 are statistically significant for ammonia.
- Turbidity experiences statistically significant increases at T5 as well as T2.
- Increases in TN and NOx are statistically significant at T6 only but weakly significant increases are also seen at all other sites.

In contrast to all other results DRP decreases at all sites (significant at T2 and weakly significant at T3 and T4). This is possibly due to phosphorus attaching to the additional sediment that is mobilised and elevated immediately after raking (the rate of attachment to sediment is also affected by other factors such as pH and iron in the water column)[8].

Enterococci shows no difference between days where raking has occurred in the previous week and those with no raking in the preceding week.

#### 4.1.2 Persistence and spatial extent of water quality impacts

The effects of sediment raking on water quality on all sites to Clarence Point (T15) and the period over which water quality is impacted after sediment raking ceases is explored in this section using linear regression. Three periods (7, 10 and 14 days) for sediment raking were considered using a weighted sediment raking effort measure. This measure was calculated as the weighted sum of days of sediment raking during the preceding period:

$$WSRE = \frac{1}{T}\sum_{n=1}^{T} n \times s_n$$

where n=1 is the first day of the period and T is the final day of the period (ie. the day on which the water quality observation was taken). This measure weights raking today more strongly than yesterday and also accounts not just for the number of days of raking within the period but also the number of days since raking ceased.

##### *4.1.2.1 Effects of sediment raking effort on pollutant concentrations*

Table 13 summarises the significance of the coefficient of WSRE in regression models for each of the pollutants and sediment raking periods. Note “N” indicates a model wasn’t fitted due to the expectation of no relationship (ie. where any impact has clearly receded at upstream monitoring points). Colours indicate the statistical significance of estimated coefficient on WSRE (ie. the strength

[8] See for example Khalil and Rifaat (2013) for a description of factors affecting phosphorus cycling with sediments in an estuarine system.

of the correlation). Full details of the model fit for these regression models can be found in Appendix 1.

*Table 13. Summary of statistical significance of regression models between pollutant concentration and weighted sediment raking effort (WSRE) in the preceding period given. 'N' is used to indicate where a model was not fit. As above Green cells are significantly different at 95% level. Orange cells are weakly significant (85%). Red cells are insignificant. NOTE: full details of regression models are provided in Appendix 1.*

| Regression | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TSS** | | | | | | | | | | | | | |
| 7 days | Red | Orange | Red | Green | Green | Green | Red | N | N | N | N | N | N |
| 10 days | Red | Red | Red | Orange | Orange | Green | Red | Red | Red | N | N | N | N |
| 14 days | Red | Red | Orange | Red | Orange | Green | Green | Red | Red | N | N | N | N |
| **Turbidity** | | | | | | | | | | | | | |
| 7 days | Red | Orange | Red | Orange | Red | Red | Red | | | | | | |
| 10 days | Red | Orange | Red | Green | Orange | Green | Orange | Orange | Orange | | | | |
| 14 days | Red | Orange | Red | Red | Red | Green | Green | Green | Green | Green | Green | Red | Orange |
| **TP** | | | | | | | | | | | | | |
| 7 days | Red | Orange | Red | Orange | Orange | Red | Red | N | N | N | N | N | N |
| 10 days | Red | Red | Red | Orange | Orange | Red | Red | Red | N | N | N | N | N |
| 14 days | Red | Red | Red | Orange | Red | Green | Orange | Orange | Red | Orange | Red | Red | Red |
| **DRP** | | | | | | | | | | | | | |
| 7 days | Red | Red | Red | Red | Red | Red | Red | N | N | N | N | N | N |
| 10 days | Red | Red | Red | Red | Red | Red | Red | Red | Red | N | N | N | N |
| 14 days | Red | Red | Red | Red | Red | Red | Green | Green | Green | Green | Green | Green | Green |
| **TN** | | | | | | | | | | | | | |
| 7 days | Red | Red | Red | Orange | Green | Red | Red | N | N | N | N | N | N |
| 10 days | Green | Red | Orange | Green | Green | Green | Orange | Red | N | N | N | N | N |
| 14 days | Green | Red | Green | Green | Green | Green | Green | Orange | Orange | Orange | Red | N | N |
| **NOX** | | | | | | | | | | | | | |
| 7 days | Red | Red | Red | Red | Orange | Orange | Red | N | N | N | N | N | N |
| 10 days | Green | Orange | Orange | Orange | Green | Green | Orange | Red | Red | N | N | N | N |
| 14 days | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green | Green |
| **Ammonia** | | | | | | | | | | | | | |
| 7 days | Red | Orange | Orange | Red | Green | Orange | Red | N | N | N | N | N | N |
| 10 days | Red | Red | Orange | Red | Orange | Orange | Red | Red | Red | N | N | N | N |
| 14 days | Red | Orange | Orange | Red | Red | Green | Green | Green | Green | Green | Green | Green | Green |
| **Enterococci** | | | | | | | | | | | | | |
| 7 days | Red | Red | Red | Red | Red | Red | Red | N | N | N | N | N | N |
| 10 days | Red | Red | Red | Red | Red | Red | N | N | N | N | N | N | N |
| 14 days | Red | Red | Red | Red | Red | Orange | Red | N | N | N | N | N | N |

This table shows that there are clear differences between the behaviour of different pollutants in response to sediment raking:

- For most pollutants there is a 'pulse' effect evident where the impact of sediment raking effort within the preceding 7 days is stronger at upstream sites but that as the period lengthens these impacts spread downstream. As the period lengthens stronger correlations are generally found further downstream and in some cases upstream impacts become weaker or statistically insignificant.
- Impacts on TSS appear to be limited in extent to T7 for the periods considered once the window extends to 2 weeks. The strongest impacts are seen from sites T4 to T6 when sediment raking has occurred within the preceding week.
- Impacts on turbidity extend much further than those on TSS. When a two week period is considered there is a statistically significant correlation with WSRE and turbidity to T13.
- In the case of dissolved nutrients (DRP, NOX and ammonia) impacts extend at least until T15 if a two week window is considered (note that this means that sediment raking that ended 13 days earlier is still expected to have a small impact on concentrations of these nutrients). The impacts of WSRE on NOx remain strong in the upper estuary (T1 to T6) for the 2 week period but are insignificant for ammonia to T5 and DRP to T6.
- Enterococci concentrations appear to be unimpacted by sediment raking activities in these periods.

#### *4.1.2.2 Effects of sediment raking relative to flow*

Given that sediment raking activities often occur during periods of persistent higher flows a second analysis was undertaken considering WSRE for the 2 week period. This analysis included average daily flow over the period as a second independent variable. Table 14 provides the *p*-values of the coefficients for WSRE and flow for these regression models. As before colours indicate the strength of the correlation.

*TABLE 14. P-VALUE ON COEFFICIENTS FOR WEIGHTED SEDIMENT RAKING EFFORT (WSRE) AND FLOW IN PREVIOUS 2 WEEKS FOR REGRESSION MODELS. GREEN CELLS ARE STATISTICALLY SIGNIFICANT (P-VALUE <0.05), ORANGE CELLS ARE WEAKLY SIGNIFICANT (0.05<=P-VALUE<0.15) AND RED CELLS ARE INSIGNIFICANT. NOTE FULL REGRESSION COEFFICIENTS AND MEASURES OF FIT ARE PROVIDED IN APPENDIX 1.*

| Coefficient | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TSS** | | | | | | | | | | | | | |
| WSRE | 0.47 | 0.17 | 0.06 | 0.21 | 0.18 | 0.01 | 0 | 0.54 | 0.33 | N | N | N | N |
| Flow | 0.63 | 0.73 | 0.13 | 0.23 | 0.96 | 0.81 | 0.06 | 0.89 | 0.23 | N | N | N | N |
| **Turbidity** | | | | | | | | | | | | | |
| WSRE | 0.94 | 0.09 | 0.48 | 0.48 | 0.48 | 0.01 | 0.01 | 0.04 | 0 | 0.01 | 0.01 | 0.8 | 0.21 |
| Flow | 0.73 | 0.89 | 0.85 | 0.93 | 0.8 | 0.27 | 0.01 | 0 | 0 | 0.02 | 0 | 0.96 | 0 |
| **TP** | | | | | | | | | | | | | |
| WSRE | 0.23 | 0.17 | 0.83 | 0.1 | 0.21 | 0.03 | 0.26 | 0.13 | 0.94 | 0.05 | 0.28 | 0.2 | 0.26 |
| Flow | 0.79 | 0.58 | 0.19 | 0.27 | 0.86 | 1 | 0.07 | 0 | 0.34 | 0.34 | 0.59 | 0.45 | 0.48 |
| **DRP** | | | | | | | | | | | | | |
| WSRE | 0.31 | 0.5 | 0.41 | 0.2 | 0.26 | 0.5 | 0.03 | 0.03 | 0.03 | 0 | 0 | 0.04 | 0.05 |
| Flow | 0.74 | 0.81 | 0.67 | 0.98 | 0.3 | 0.54 | 0.21 | 0.26 | 0.19 | 0.11 | 0.17 | 0.08 | 0.32 |
| **TN** | | | | | | | | | | | | | |
| WSRE | 0 | 0.44 | 0.02 | 0.01 | 0.04 | 0 | 0 | 0.1 | 0.18 | 0.09 | 0.38 | 0.24 | 0.38 |
| Flow | 0.29 | 0.51 | 0.54 | 0.62 | 0.37 | 0.09 | 0 | 0 | 0 | 0.01 | 0.04 | 0.02 | 0.16 |
| **NOX** | | | | | | | | | | | | | |
| WSRE | 0 | 0.02 | 0.02 | 0.02 | 0.01 | 0 | 0 | 0.01 | 0 | 0.01 | 0 | 0.01 | 0.03 |
| Flow | 0.26 | 0.07 | 0.04 | 0.07 | 0.07 | 0.03 | 0.01 | 0.01 | 0 | 0.01 | 0.01 | 0 | 0.01 |
| **Ammonia** | | | | | | | | | | | | | |
| WSRE | 0.95 | 0.14 | 0.15 | 0.34 | 0.28 | 0.03 | 0.04 | 0.03 | 0.02 | 0.01 | 0 | 0.02 | 0.07 |
| Flow | 0.62 | 0.46 | 0.36 | 0.65 | 0.65 | 0.51 | 0.15 | 0.03 | 0.01 | 0.01 | 0.01 | 0 | 0.06 |
| **Enterococci** | | | | | | | | | | | | | |
| WSRE | 0.81 | 0.84 | 0.94 | 0.49 | 0.28 | 0.06 | 0.54 | N | N | N | N | N | N |
| Flow | 0.67 | 0.59 | 0.58 | 0.42 | 0.27 | 0.47 | 0.87 | N | N | N | N | N | N |

This table shows:

- The effects of sediment raking on water quality persist for at least 2 weeks in areas of the lower estuary. In most cases where there are statistically significant relationships, pollutant concentrations have a more significant correlation with sediment raking effort than they do flow.

- Of all the pollutants, nitrogen is most strongly affected by sediment raking effort for the greatest extent of the estuary. In particular, relationships between the concentration of NOx and weighted sediment raking effort in the previous two weeks remain very strong for the entire length of the estuary. The *p*-value of the coefficient for WSRE is stronger than for flow until T14 but even at T14 and T15 it remains well below 0.05. For TN, WSRE has a significant correlation in the upper estuary with a transition at T6 to T7 of flow becoming the dominant influence.
- For turbidity and DRP the persistent effects of sediment raking after 2 weeks are only seen downstream of T6. The transition between fresh and saline water occurs between T5 and T6 with flocculation known to occur in this part of the estuary. It is likely that these effects are due to heavy sediments settling out from the water column at this point while dissolved pollutants and very small particles of sediment remain suspended and continue to be carried by tides downstream of this point.
- TSS and TP are not correlated with WSRE at as many sites as other nutrients and turbidity are. Flow is also not correlated with these pollutants at most sites. TSS at T6 and T7 is strongly correlated with WSRE but not flow.
- Enterococci is not statistically significantly correlated with either flow or sediment raking effort.

#### *4.1.2.3 Magnitude of effects of sediment raking on pollutant concentrations*

While a relationship can be statistically significant this does not give an indication of the magnitude of the change in concentration that can be expected as a result of sediment raking. This depends on the scale of the coefficient of WRSE relative to the intercept term. Statistically significant (green) models considering WSRE only have been simulated for a series of sediment raking scenarios to estimate the relative increase in pollutant concentration 'all other things being equal' (ie. not considering other factors which may be impacting on concentration). This simulation is undertaken to allow the relative magnitude of estimated differences due to sediment raking to be considered to explore how substantial these are in addition to being statistically significant, and is not intended to be a predictive model. The simulation below use the 2 week period models from Section 4.1.2.1. Note in the text below, references to the days since raking ceased or no raking refer to the number of days within the 14 day period since raking was undertaken assuming the raking begins at the beginning of the 14 day period (ie. 5 days of no raking or since raking ceased is equivalent to 14-5=9 days of raking commencing at the beginning of the two week period).

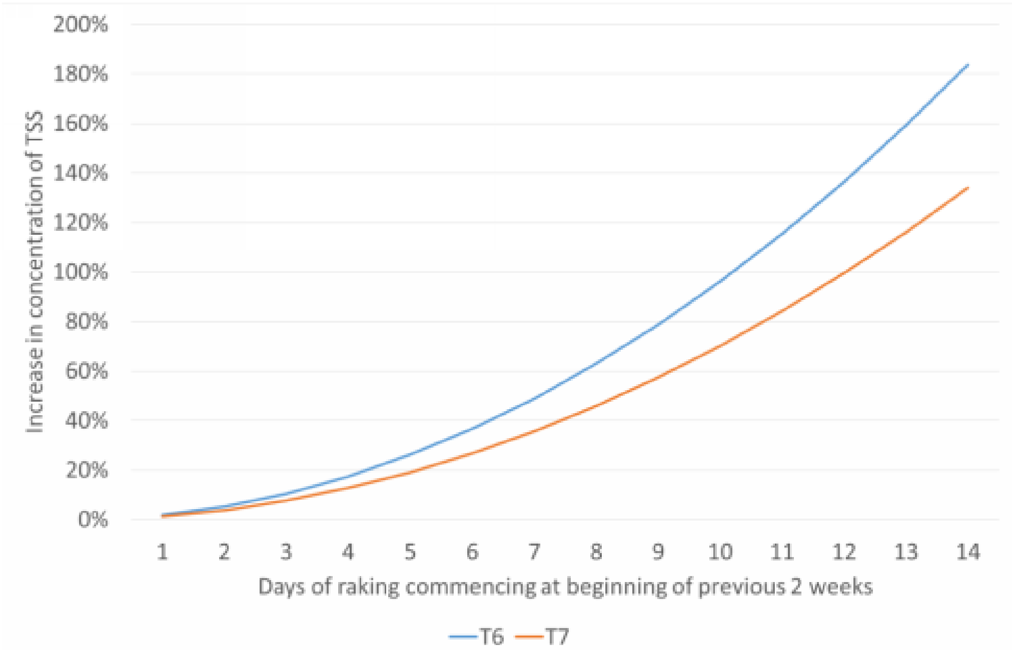



*FIGURE 59. SIMULATED INCREASE IN TSS CONCENTRATION AS A RESULT OF DIFFERENT PERIODS OF RAKING COMMENCING 2 WEEKS EARLIER*

Figure 59 shows the simulated impact on TSS concentrations at sites T6 and T7. Note that the x-axis is the days of raking assumed to begin at the beginning of the preceding fortnight – so 1 indicates a single day of raking at the beginning of the fortnight followed by 13 days of no raking. This figure shows that an extended period of raking can be expected to more than double TSS concentrations at both sites (occurs at 10 days and 12 days for T6 and T7 respectively) with the peak after 2 weeks of continuous raking at approximately 180% and 130% increases respectively. It takes 6 to 7 days of no raking (ie. 7 to 8 days of raking commencing at the beginning of the previous week on the figure) for concentrations to fall below a 50% increase.

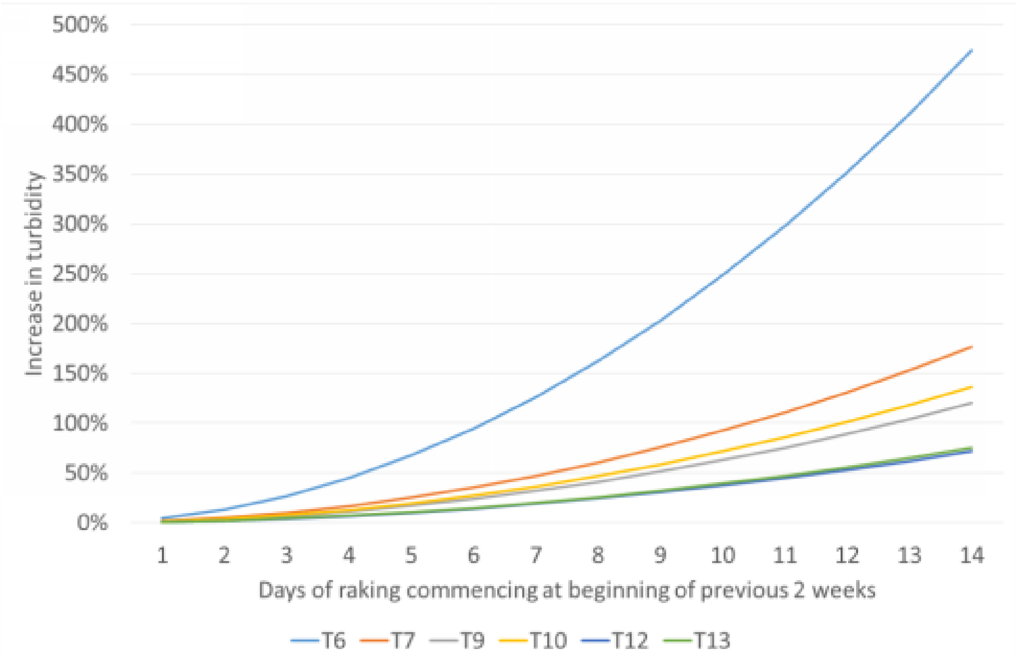



*Figure 60. Simulated increase in Turbidity as a result of different periods of raking commencing 2 weeks earlier*

Figure 60 shows the simulated impacts on turbidity of different periods of sediment raking in the preceding two weeks. In this case statistically significant models were available for sites T6 to T13 (note that there are no sites T8 or T11). This shows a large increase in turbidity at Site 6 with a two week campaign expected to increase turbidity close to 6 times the base level. It takes 8 days after the cessation of raking for turbidity levels at T6 to fall back to a doubling (100% increase). A single day of raking at the beginning of the two week period corresponds to a 5% increase in turbidity. Relative impacts on turbidity decrease downstream. Sites T7 to T10 experience more than doubling of turbidity (120% to 176% increase) after a 2 week raking campaign. It takes between 5 and 7 days of no raking for this increase to fall to 50% of the base value. Turbidity at sites T12 and T13 increase by over 70% after 14 days of continuous raking. It takes 3 days of no raking for this to fall below 50% with increases down to 10% 10 days after sediment raking ceases.

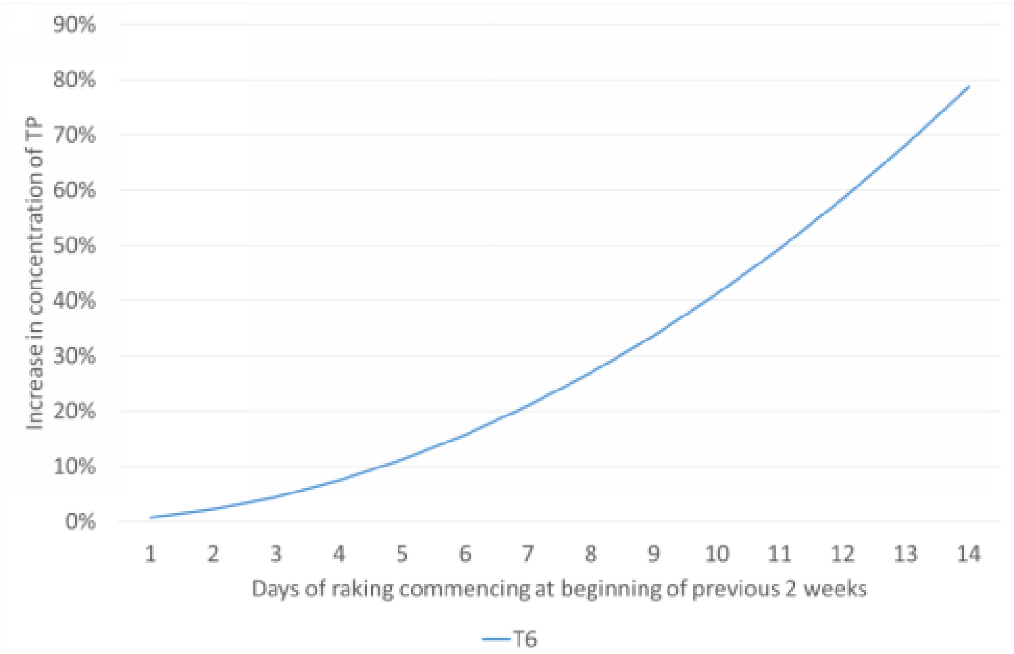



*FIGURE 61. SIMULATED INCREASE IN TP CONCENTRATION AS A RESULT OF DIFFERENT PERIODS OF RAKING COMMENCING 2 WEEKS EARLIER*

Figure 61 shows the simulated impacts of sediment raking in the preceding 2 weeks on TP. There was a single statistically significant model for the 2 week period for TP (T6). This figure shows that after an extended 2 week sediment raking campaign, TP can be expected to increase at T6 by roughly 80%. It takes 3 days of no sediment raking for the increase to fall below 50% and 10 days for it to fall below 10%.

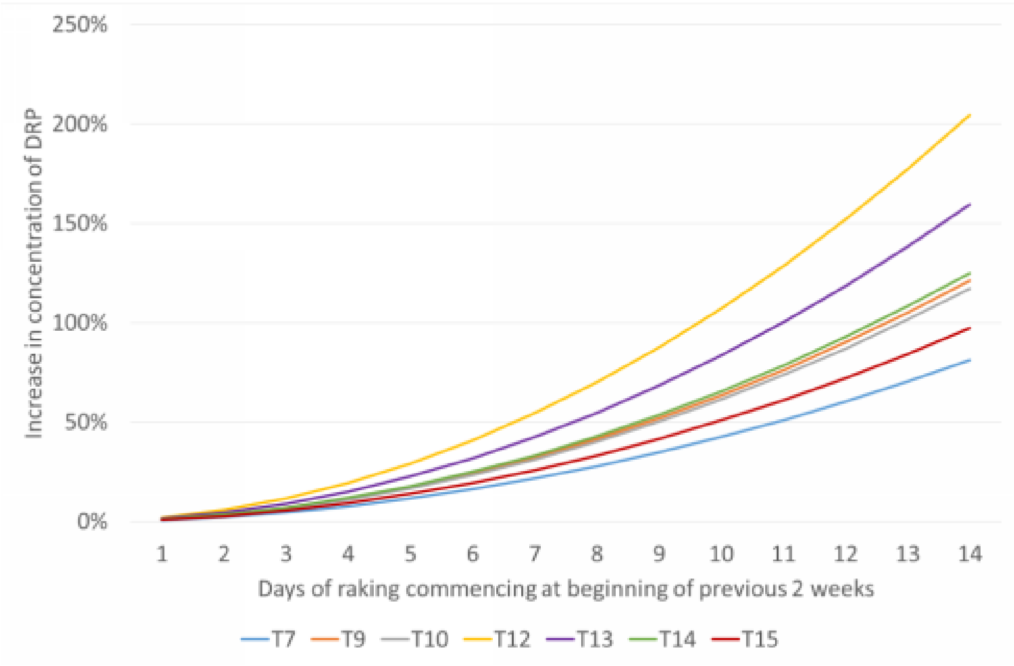



*FIGURE 62. SIMULATED INCREASE IN DRP CONCENTRATION AS A RESULT OF DIFFERENT PERIODS OF RAKING COMMENCING 2 WEEKS EARLIER*

Figure 62 shows the simulated impact of sediment raking in the preceding 2 weeks on DRP concentrations. There are statistically significant models for DRP at 7 sites (from T7 to T15). This figure shows that the greatest relative impacts are expected at sites T12 and T13 with increases of 205% and 160% respectively. At these sites it takes 3 to 4 days of no sediment raking for increases to fall below 100% (ie. DRP is double the base level). Sites T9, T10 and T14 are very similar with little difference between simulated impacts at these sites. At these sites an extended 2 week raking campaign could be expected to more than double DRP concentrations (~120% increase). It takes 2 days without raking for levels to fall below 100% increase, 6 days without raking to fall to a 50% decrease, and 11 days of no raking to fall below a 10% increase level.

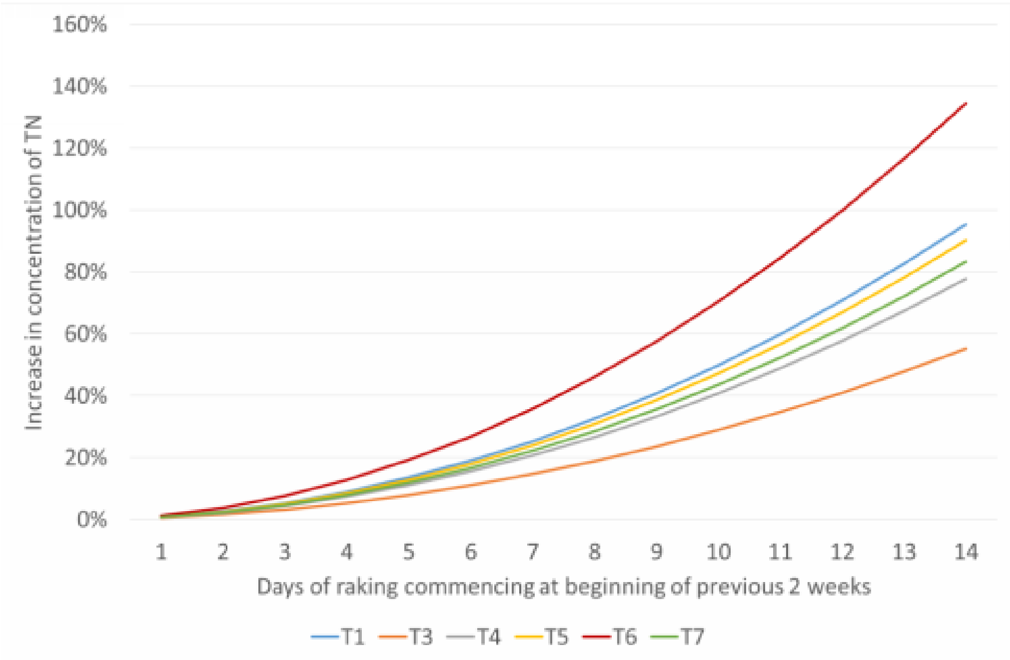
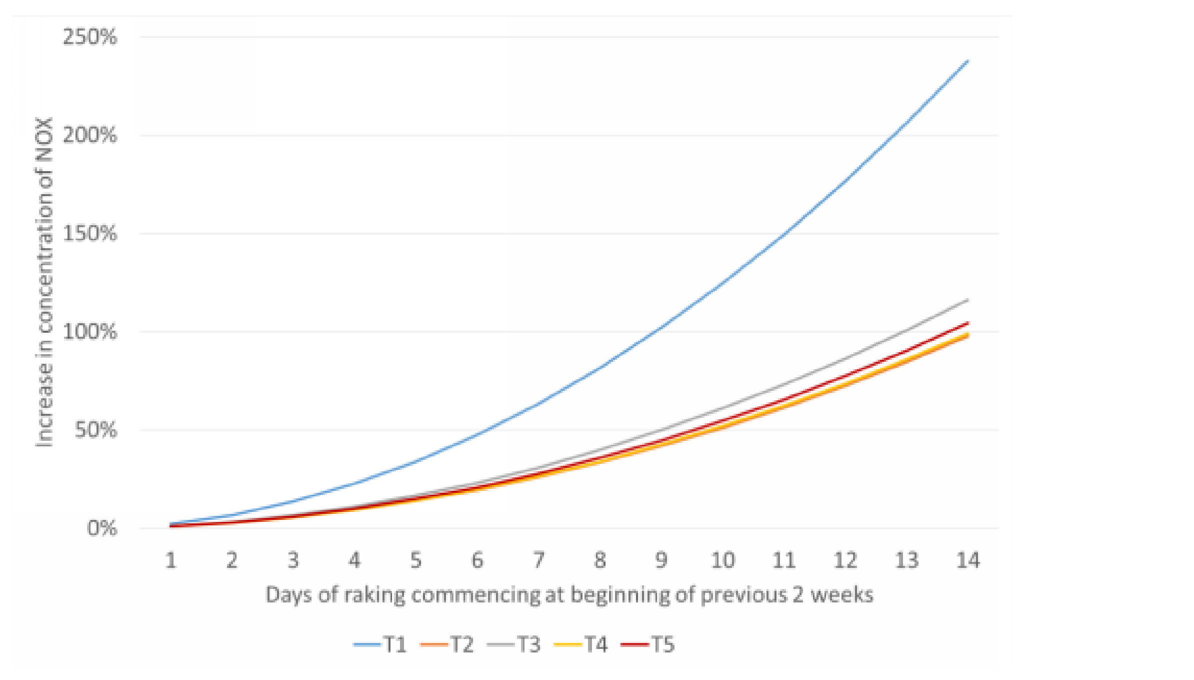



*FIGURE 63. SIMULATED INCREASE IN TN CONCENTRATION AS A RESULT OF DIFFERENT PERIODS OF RAKING COMMENCING 2 WEEKS EARLIER*

Figure 63 shows the simulated increases in TN concentrations in response to sediment raking in the preceding 2 weeks. There are 6 statistically significant regression models for TN. The largest simulated increase is at T6 where TN increases by over 130% after an extended 2 week sediment raking campaign. It takes 6 days of no raking for this increase to fall below 50% and 11 days to fall below 10%. Sites T1, T4, T5 and T7 are similar with the range of maximum increases being 78% to 95% across these sites. It takes 3 to 4 days of no raking for this increase to fall below 50% at these sites and 10 to 11 days to fall below a 10% increase. Site T3 experiences the smallest increase in TN concentrations, peaking at a 55% increase after a 2-week raking campaign. The increase at T3 falls below 10% after 9 days of not raking.



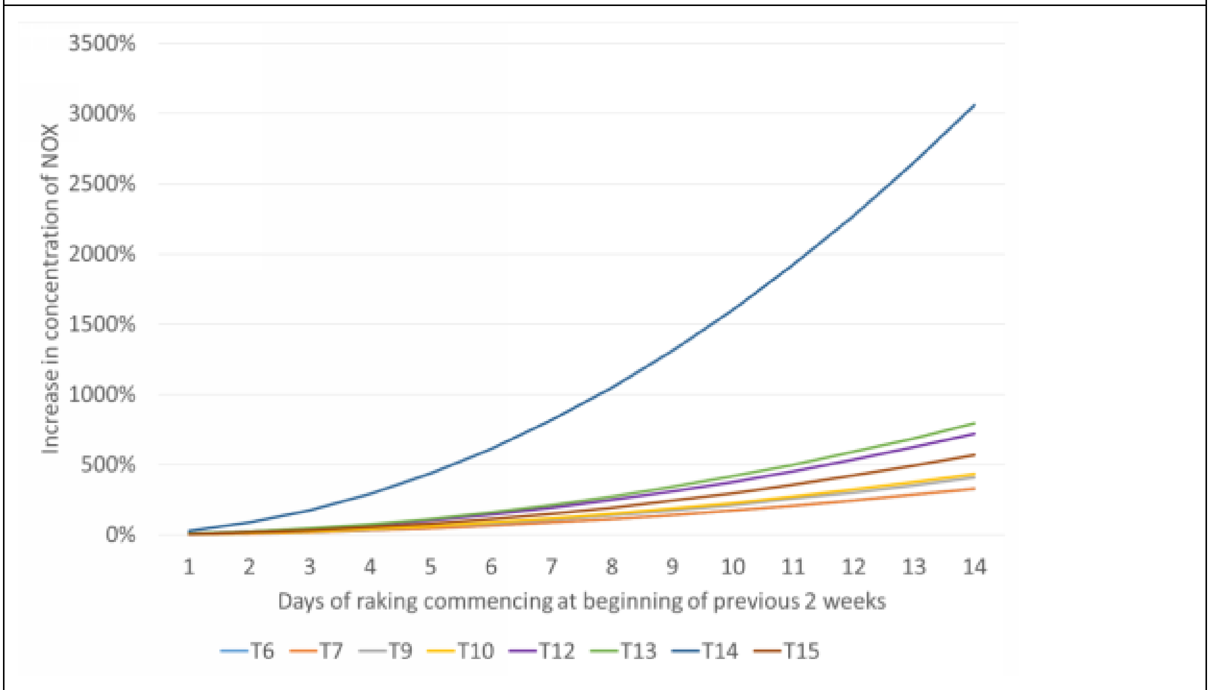




*Figure 64. Simulated increase in NOX concentration as a result of different periods of raking effort commencing 2 weeks earlier*

Figure 64 shows the simulated impact of sediment raking in the preceding 2 week period on NOx concentrations. Note that there are statistically significant regression models for all sites for NOx for the 2 week period. Given the number of sites and the differences in the magnitude of impacts at different sites these have been plotted onto two separate charts (T1-T5 and T6-T15). This figure shows:

- Simulated increases at sites T2 to T5 are very similar with a 2 week sediment raking campaign roughly doubling NOx concentrations at these sites. It takes 5 to 6 days after the cessation of sediment raking for the concentration of NOx to fall below 50% higher than baseline levels, and approximately 11 days to fall below a 10% increase.
- Simulated increases at T1 are larger than for the other upper estuary sites. At this site simulated NOx is over 3 times higher after a 2 week raking campaign and takes 5 days of no raking to fall to a 100% increase in concentration. It takes 8 days and 12 days with no raking respectively to fall below the 50% and 10% increase levels.
- Simulated increases in the mid to lower estuary are substantially larger than in the upper estuary. This is likely to be in part because of the lower base level of NOx in downstream areas of the estuary. The intercept terms for models downstream of T7 are statistically insignificant indicating a high degree of uncertainty in these values.
- The largest increase is seen at site T14 corresponding to over a 30 times increase. Base levels of NOx are very low at this site with the intercept term statistically insignificantly different from zero. The very large magnitude of relative impacts at this site is likely to be to some extent an artefact of this uncertainty around baseline levels of NOx in the lower estuary. The coefficient on WRSE at T14 and T15 is several times larger than the intercept terms (note that this is more pronounced at T14). While there is a degree of uncertainty about the specific magnitude of increase in NOx at these sites it is likely that sediment raking raises NOx levels well above baseline levels after a 2 week campaign and that this effect is sustained for a relatively long period after sediment raking ceases.
- Impacts at sites T6 to T10 are very similar with maximum NOx concentrations 4 to 5 times higher than the base level. These high concentration levels are sustained with it taking a week of no sediment raking for levels to return to less than double the baseline concentration.
- Sites T12 and T13 are similar with increases of over 700% with it taking 10 days of no raking for this to fall to a doubling of NOx. As with other lower estuary results there is a large degree of uncertainty in the magnitude of these changes given that the intercept term is statistically insignificant however it can be expected that NOx at these sites will increase substantially and persist for an extended period after sediment raking occurs.

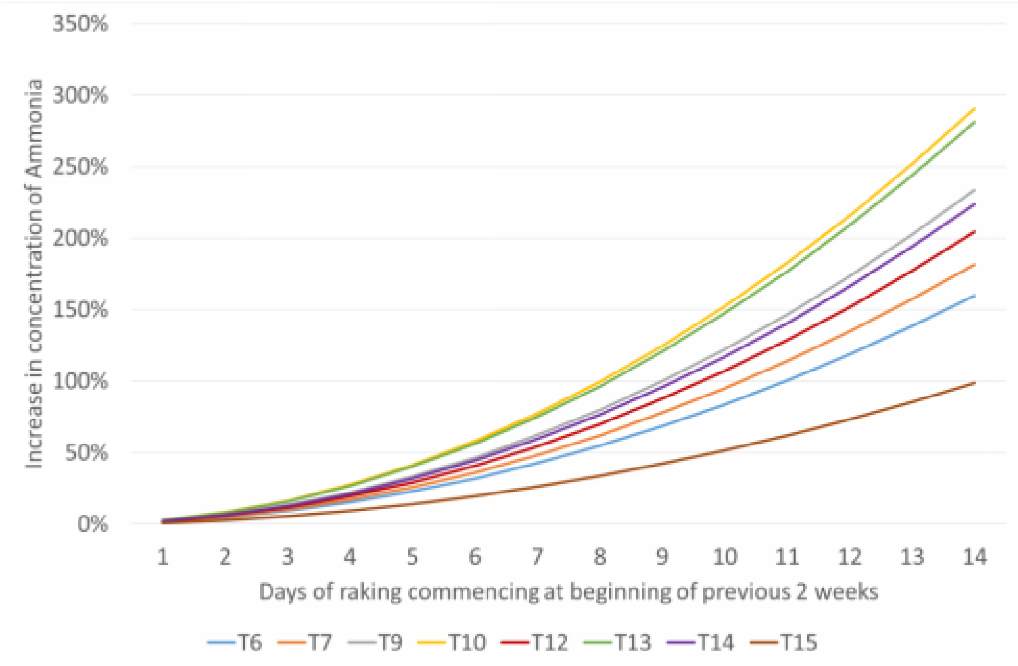



*FIGURE 65. SIMULATED INCREASE IN AMMONIA CONCENTRATION AS A RESULT OF DIFFERENT PERIODS OF RAKING COMMENCING 2 WEEKS EARLIER*

Figure 65 shows the simulated increase in ammonia concentrations as a result of sediment raking in the preceding fortnight. There are statistically significant models for sites T6 to T15. This figure shows that all sites are expected to at least double ammonia concentrations after an extended 2 week sediment raking campaign. The largest relative increases are expected at sites T10 and T13 (280% to 290% increase). Site T15 has the smallest relative increase but still is expected to have double the ammonia concentration after 2 weeks of sediment raking compared to base levels. It takes between 4 to 7 days for other sites to fall below the 100% increase level.

Another way to consider impacts on pollutants is relative to water quality objectives or ANZECC default guideline values (DGV). The TEER Estuary report card uses WQO derived by EPA staff to create grades based on an ecological health index. Not all pollutants considered here have WQOs. WQOs are available for turbidity, TN and TP. Generic ANZECC default guideline values (2000) are also available for DRP, NOx and ammonia. No value is available against which to assess TSS. Table 15 summarises the WQOs/DGVs used in the comparison and their source.

*TABLE 15. WATER QUALITY OBJECTIVE/ANZECC DGV USED FOR COMPARISON WITH SEDIMENT RAKING IMPACT*

| Pollutant | Estuary | Marine | Source |
|---|---|---|---|
| Turbidity (NTU) | 6.4 | 1.9 | EPA Guideline used for TEER report card |
| TP (µg/L) | 27.4 | 36 | EPA Guideline used for TEER report card |
| DRP (µg/L) | 5 | 10 | ANZECC Guideline 2000 |
| TN (µg/L) | 384 | 340 | EPA Guideline used for TEER report card |
| NOx (µg/L) | 15 | 5 | ANZECC Guideline 2000 |
| Ammonia (µg/L) | 15 | 15 | ANZECC Guideline 2000 |

Table 16 provides a summary of the simulated increase in concentration resulting from sediment raking effort relative to these water quality objectives/DGVs. The increase is provided for two scenarios – 1) the maximum increase resulting from 2 weeks of sustained sediment raking, and 2) the increase associated with 7 days of raking followed by 7 days of no raking. Note that pollutant concentrations would be expected to be higher than this given this is an increase on a base not the total concentration.

*TABLE 16. INCREASE IN POLLUTANT CONCENTRATION AS A PERCENTAGE OF WATER QUALITY OBJECTIVE/DGV FROM SEDIMENT RAKING OPTION*

| | Freshwater | | | | | | | | | | Marine | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
| **Turbidity** | | | | | | | | | | | | | |
| After 14 days of raking | N | N | N | N | N | 281% | 94% | 47% | 47% | 23% | 79% | N | N |
| 7 days after cessation of raking | N | N | N | N | N | 75% | 25% | 13% | 13% | 6% | 21% | N | N |
| **TP** | | | | | | | | | | | | | |
| After 14 days of raking | N | N | N | N | N | 93% | N | N | N | N | N | N | N |
| 7 days after cessation of raking | N | N | N | N | N | 25% | N | N | N | N | N | N | N |
| **DRP** | | | | | | | | | | | | | |
| After 14 days of raking | N | N | N | N | N | N | 135% | 165% | 150% | 180% | 75% | 60% | 53% |
| 7 days after cessation of raking | N | N | N | N | N | N | 36% | 44% | 40% | 48% | 20% | 16% | 14% |
| **TN** | | | | | | | | | | | | | |
| After 14 days of raking | 101% | N | 90% | 105% | 103% | 102% | 63% | N | N | N | N | N | N |
| 7 days after cessation of raking | 27% | N | 24% | 28% | 27% | 27% | 17% | N | N | N | N | N | N |
| **NOX** | | | | | | | | | | | | | |
| After 14 days of raking | 1725% | 1080% | 1055% | 1025% | 1055% | 1490% | 1170% | 1000% | 880% | 705% | 1635% | 1590% | 975% |
| 7 days after cessation of raking | 460% | 288% | 281% | 273% | 281% | 397% | 312% | 267% | 235% | 188% | 436% | 424% | 260% |
| **Ammonia** | | | | | | | | | | | | | |
| After 14 days of raking | N | N | N | N | N | 210% | 185% | 165% | 155% | 120% | 315% | 255% | 150% |
| 7 days after cessation of raking | N | N | N | N | N | 56% | 49% | 44% | 41% | 32% | 84% | 68% | 40% |

This table shows that the increases in pollutant concentrations estimated from the regression models is substantial relative to water quality/default guideline values:

- Increases in turbidity 23% to 281% of the WQO immediately after 2 weeks of sediment raking. The highest increase is experienced at T6. The increase in turbidity at site T6 falls to 75% of the WQO a week after sediment raking ceases. Relative increases are less moving downstream until T13 where the lower, marine WQO applies.
- There is only one statistically significant regression model for TP, at site T6. The increase in TP at this site immediately after the 2 week sediment raking campaign is 93% of the WQO value. This falls to 25% of the WQO a week after sediment raking ceases.
- The increase in DRP for sites T7 to T12 after a 2 week sediment raking campaign is well over the default guideline value – 135% to 180%. This falls to between 36% and 48% 7 days after sediment raking ceases. Increases in DRP at sites T13 to T15 range from 53% to 75% of the default guideline value. These increases fall to 14% to 20% a week after sediment raking ceases.
- Increases in TN concentration are approximately equal to the WQO for TN at T1, T4, T5 and T6 and less at T3 (90%) and T7 (63%). These increases fall to between 24% and 28% for sites from T1 to T6 and to 17% of the WQO at site 7.
- Increases in the concentration of NOx are expected to be many times higher than the default guideline values after a sustained 2 week sediment raking campaign (705% to 1725% of the default guideline value) and to remain very high for a week after sediment raking ceases (~190% to 460% of the default guideline value). These large increases are expected at all sites from T1 to T15.
- Increases in ammonia for all sites from T6 to T15 resulting from a 2 week sediment raking campaign are well above the default guideline values (120% to 315%). These drop to between 32% and 84% of the default guideline value a week after sediment raking ceases. Impacts decrease moving downstream from site T6 and then again from T13 where the transition to the marine default guideline value occurs.

## 4.2 Impacts on heavy metals

Monitoring data on heavy metals in the Tamar Estuary is much more limited than for other physico-chemical parameters:

- Metals have generally been collected quarterly as part of the TEER EHAP program.
- Before 2014, observations of dissolved metals only were collected 6-monthly at sites T1 to T4 and T13 to T16.
- Total and dissolved metals have been collected approximately every 3 months during EHAP monitoring periods (ie. two years on-two years off) from 2014.
- The limits of reporting for some metals are above the water quality objective/ANZECC guideline level for the estuary (see Table 17). For some metals, particularly dissolved

aluminium and dissolved zinc, a large proportion of the data set is below the limits of reporting which means changes in concentrations which correlate to sediment raking are impossible to assess.

- For dissolved zinc between 67% and 94% of observations at a site were assigned a value "<2" by the laboratory and up to a further 20% assigned a value of "<1" at all sites.
- For dissolved aluminium between 50% and 95% of observations were assigned a value of "<20".

*TABLE 17. LIMITS OF REPORTING VERSUS WATER QUALITY OBJECTIVES/ANZECC DEFAULT GUIDELINE VALUES FOR HEAVY METALS IN THE KANAMALUKA/TAMAR RIVER ESTUARY*

| Indicator | Limits of Reporting | Estuary | Marine |
|---|---|---|---|
| Aluminium (µg/L) | <20 | 6 | 6 |
| Arsenic (µg/L) | <5 | 2.3 | 2.3 |
| Cadmium (µg/L) | <1 | 5.5 | 5.5 |
| Copper (µg/L) | <2 | 1.3 | 1.3 |
| Mercury (µg/L) | <0.05 | 0.1 | 0.1 |
| Lead (µg/L) | <0.5 | 4.4 | 4.4 |
| Zinc (µg/L) | <2 | 15 | 15 |

These data limitations mean that a full assessment of the potential impacts of sediment raking on metals concentrations is not possible. It has been possible to conduct a less comprehensive analysis of some metals data for correlations between sediment raking effort and heavy metals concentrations.

Two types of analysis have been conducted:

1. A regression analysis looking at the relationship between metals concentration and sediment raking effort in the preceding 3, 7, 10, 14 and 21 days which includes observations with zero sediment raking effort. This analysis allows for the differences between 'non-raking' and 'raking' days under these criteria to be assessed. The level of certainty around the effects of raking effort on raking days is much less due to the large part of the data set that consists of 'non-raking' days – ie. this analysis tends to pick up where there are significant differences in raking versus non-raking days but is not as accurate in its estimate of the effect of specific raking effort on metals concentrations. It will be weighted towards picking up the immediate impacts of raking on metals concentrations.
2. A regression analysis looking at the relationship between sediment raking effort in the previous 21 days with non-raking days removed. This analysis provides a clearer indication of how persistent the impacts of raking are and the impacts of longer versus shorter raking periods on metals concentrations. Less data is available (7 to 8 observations versus 16 to 17 observations for the previous analysis). The 21 day period was chosen to maximise the number of points in the data set available for analysis.

Metals analysed are:

- Total aluminium.
- Total zinc.
- Total and dissolved manganese.
- Total and dissolved iron.

These metals were chosen as they had enough data above the limits of reporting to allow for regression analysis.

#### 4.2.1 Impacts on heavy metals concentrations of raking versus no raking in the preceding period

Table 18 to Table 23 provide the regression parameters and measures of fit for the models including non-sediment raking days for all metals which were analysed (1 above). Note analysis was limited to sites T1 to T7 due to the large number of observations below the limits of reporting for non-raking days in the lower estuary.

*Table 18. Total aluminium (µg/L): Regression parameters for concentration versus sediment raking effort in preceding period. Note this includes days where no raking occurred in the previous period*

| | | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|---|
| **3 Days** | $R^2$ | 0.126 | 0.257 | 0.338 | 0.248 | 0.254 | 0.508 | 0.004 |
| | Significance F | 0.162 | 0.038 | 0.014 | 0.042 | 0.046 | 0.002 | 0.818 |
| | Intercept | 627.6 | 1370.9 | 1269.9 | 1503.9 | 1206 | 561.5 | 376.8 |
| | Coefficient | 209.19 | 635.91 | 735.87 | 621.4 | 515.08 | 504.69 | 14.99 |
| | *p*-value intercept | 0.001 | 0 | 0 | 0 | 0 | 0.001 | 0 |
| | *p*-value coefficient | 0.162 | 0.038 | 0.014 | 0.042 | 0.046 | 0.002 | 0.818 |
| | N | 17 | 17 | 17 | 17 | 16 | 16 | 15 |
| **7 Days** | $R^2$ | 0.113 | 0.245 | 0.363 | 0.254 | 0.239 | 0.495 | 0.001 |
| | Significance F | 0.186 | 0.044 | 0.01 | 0.039 | 0.055 | 0.002 | 0.932 |
| | Intercept | 631.4 | 1372.5 | 1245.6 | 1492.5 | 1209 | 558.7 | 382.8 |
| | Coefficient | 103.08 | 322.15 | 396.13 | 326.41 | 259.51 | 258.57 | 2.91 |
| | *p*-value intercept | 0.001 | 0 | 0 | 0 | 0 | 0.001 | 0 |
| | *p*-value coefficient | 0.186 | 0.044 | 0.01 | 0.039 | 0.055 | 0.002 | 0.932 |
| | N | 17 | 17 | 17 | 17 | 16 | 16 | 15 |
| **10 Days** | $R^2$ | 0.1 | 0.22 | 0.35 | 0.25 | 0.247 | 0.483 | 0.002 |
| | Significance F | 0.217 | 0.058 | 0.012 | 0.041 | 0.05 | 0.003 | 0.863 |
| | Intercept | 637.9 | 1389.5 | 1250.8 | 1492.8 | 1201.9 | 559.9 | 379 |
| | Coefficient | 74.19 | 234.23 | 298.66 | 248.86 | 202.58 | 190.94 | 4.48 |
| | *p*-value intercept | 0.001 | 0 | 0 | 0 | 0 | 0.001 | 0 |
| | *p*-value coefficient | 0.217 | 0.058 | 0.012 | 0.041 | 0.05 | 0.003 | 0.863 |
| | N | 17 | 17 | 17 | 17 | 16 | 16 | 15 |
| **14 Days** | $R^2$ | 0.095 | 0.227 | 0.359 | 0.266 | 0.277 | 0.494 | 0.009 |
| | Significance F | 0.228 | 0.053 | 0.011 | 0.034 | 0.036 | 0.002 | 0.739 |
| | Intercept | 636.6 | 1371.3 | 1229.6 | 1468.1 | 1172.1 | 546.3 | 371.5 |
| | Coefficient | 60.31 | 198.09 | 251.56 | 213.41 | 178.53 | 157.77 | 7.24 |
| | *p*-value intercept | 0.001 | 0 | 0.001 | 0 | 0 | 0.001 | 0 |
| | *p*-value coefficient | 0.228 | 0.053 | 0.011 | 0.034 | 0.036 | 0.002 | 0.739 |
| | N | 17 | 17 | 17 | 17 | 16 | 16 | 15 |
| **21 Days** | $R^2$ | 0.096 | 0.272 | 0.375 | 0.277 | 0.33 | 0.478 | 0.021 |
| | Significance F | 0.226 | 0.032 | 0.009 | 0.03 | 0.02 | 0.003 | 0.604 |
| | Intercept | 625.4 | 1298.8 | 1174.2 | 1422 | 1124.8 | 521.1 | 360.9 |
| | Coefficient | 49.32 | 176.55 | 209.29 | 177.19 | 156.59 | 123.81 | 9.2 |
| | *p*-value intercept | 0.001 | 0.001 | 0.001 | 0 | 0.001 | 0.002 | 0 |
| | *p*-value coefficient | 0.226 | 0.032 | 0.009 | 0.03 | 0.02 | 0.003 | 0.604 |
| | N | 17 | 17 | 17 | 17 | 16 | 16 | 15 |

Table 18 shows the regression parameters and goodness of fit for models of total aluminium. This table shows highly significant models for T2 to T6 for most periods (note 7 day and 14 day models at T2 fall just outside the highly significant threshold of 0.05). Models at T1 and T7 are insignificant indicating no significant difference between raking and non-raking days was observed at these sites. $R^2$ values are generally relatively low indicating substantial unexplained scatter around the fitted model. This is in part because of the large proportion of data points associated with non-raking days.

*Table 19. Total zinc (µg/L): Regression parameters for concentration versus sediment raking effort in preceding period. Note this includes days where no raking occurred in the previous period*

| | | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|---|
| **3 Days** | $R^2$ | 0.23 | 0.373 | 0.342 | 0.289 | 0.37 | 0.531 | 0.193 |
| | Significance F | 0.052 | 0.009 | 0.014 | 0.026 | 0.012 | 0.002 | 0.101 |
| | Intercept | 5.4 | 8.8 | 9.2 | 10.7 | 7.8 | 4.7 | 3.1 |
| | Coefficient | 1.44 | 4.65 | 4.24 | 3.44 | 3.66 | 2.43 | 1.08 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 |
| | *p*-value coefficient | 0.052 | 0.009 | 0.014 | 0.026 | 0.012 | 0.002 | 0.101 |
| | N | 17 | 17 | 17 | 17 | 16 | 15 | 15 |
| **7 Days** | $R^2$ | 0.224 | 0.371 | 0.382 | 0.307 | 0.374 | 0.532 | 0.145 |
| | Significance F | 0.055 | 0.01 | 0.008 | 0.021 | 0.012 | 0.002 | 0.162 |
| | Intercept | 5.4 | 8.8 | 9 | 10.6 | 7.7 | 4.6 | 3.2 |
| | Coefficient | 0.74 | 2.41 | 2.33 | 1.85 | 1.91 | 1.27 | 0.49 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 |
| | *p*-value coefficient | 0.055 | 0.01 | 0.008 | 0.021 | 0.012 | 0.002 | 0.162 |
| | N | 17 | 17 | 17 | 17 | 16 | 15 | 15 |
| **10 Days** | $R^2$ | 0.183 | 0.339 | 0.37 | 0.303 | 0.374 | 0.546 | 0.2 |
| | Significance F | 0.087 | 0.014 | 0.01 | 0.022 | 0.012 | 0.002 | 0.095 |
| | Intercept | 5.5 | 8.9 | 9 | 10.6 | 7.7 | 4.6 | 3.1 |
| | Coefficient | 0.42 | 1.77 | 1.76 | 1.41 | 1.47 | 0.96 | 0.44 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 |
| | *p*-value coefficient | 0.087 | 0.014 | 0.01 | 0.022 | 0.012 | 0.002 | 0.095 |
| | N | 17 | 17 | 17 | 17 | 16 | 15 | 15 |
| **14 Days** | $R^2$ | 0.183 | 0.336 | 0.303 | 0.313 | 0.389 | 0.571 | 0.292 |
| | Significance F | 0.087 | 0.015 | 0.022 | 0.02 | 0.01 | 0.001 | 0.037 |
| | Intercept | 5.5 | 8.8 | 10.6 | 10.5 | 7.6 | 4.5 | 2.9 |
| | Coefficient | 0.42 | 1.46 | 1.41 | 1.19 | 1.24 | 0.8 | 0.44 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 |
| | *p*-value coefficient | 0.087 | 0.015 | 0.022 | 0.02 | 0.01 | 0.001 | 0.037 |
| | N | 17 | 17 | 17 | 17 | 16 | 15 | 15 |
| **21 Days** | $R^2$ | 0.154 | 0.363 | 0.378 | 0.314 | 0.409 | 0.552 | 0.426 |
| | Significance F | 0.119 | 0.011 | 0.009 | 0.019 | 0.008 | 0.002 | 0.008 |
| | Intercept | 5.5 | 8.4 | 8.6 | 10.3 | 7.4 | 4.4 | 2.6 |
| | Coefficient | 0.32 | 1.24 | 1.2 | 0.97 | 1.03 | 0.63 | 0.44 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 |
| | *p*-value coefficient | 0.119 | 0.011 | 0.009 | 0.019 | 0.008 | 0.002 | 0.008 |
| | N | 17 | 17 | 17 | 17 | 16 | 15 | 15 |

Table 19 shows the regression parameters and goodness of fit for total zinc. This table shows highly significant models for T2 to T6 for all periods. T7 also has highly significant models for 14 day and 21 day periods with weakly significant models for the 3 day and 14 day period and an insignificant result for the 10 day period (noting that this falls just outside the *p*-value threshold for weakly significant of 0.15). T1 has weakly significant models for all periods. The *p*-value for shorter periods is close to the threshold of 0.05 with *p*-values increasing as the period increases. This suggests that any impacts at T1 occur in the immediate period after sediment raking and are less likely to extend into the period after raking (up to 3 weeks). By contrast the *p*-value at site T7 decreases as the period lengthens indicating the models become more significant as the period of possible influence is extended.

*TABLE 20. TOTAL MANGANESE (µG/L): REGRESSION PARAMETERS FOR CONCENTRATION VERSUS SEDIMENT RAKING EFFORT IN PRECEDING PERIOD. NOTE THIS INCLUDES DAYS WHERE NO RAKING OCCURRED IN THE PREVIOUS PERIOD*

| | | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|---|
| **3 Days** | $R^2$ | 0.016 | 0.253 | 0.397 | 0.377 | 0.464 | 0.228 | 0.077 |
| | Significance F | 0.645 | 0.047 | 0.009 | 0.011 | 0.005 | 0.072 | 0.317 |
| | Intercept | 53.3 | 80.6 | 64.2 | 53.6 | 44.7 | 28.9 | 22 |
| | Coefficient | -4.54 | 23.91 | 22.21 | 19.96 | 13.86 | 7.9 | 2.27 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.645 | 0.047 | 0.009 | 0.011 | 0.005 | 0.072 | 0.317 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **7 Days** | $R^2$ | 0.018 | 0.233 | 0.43 | 0.396 | 0.455 | 0.218 | 0.048 |
| | Significance F | 0.624 | 0.058 | 0.006 | 0.009 | 0.006 | 0.079 | 0.434 |
| | Intercept | 53.5 | 80.8 | 63.4 | 53 | 44.6 | 28.9 | 22.3 |
| | Coefficient | -2.51 | 11.92 | 12.01 | 10.64 | 7.14 | 4.01 | 0.93 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.624 | 0.058 | 0.006 | 0.009 | 0.006 | 0.079 | 0.434 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **10 Days** | $R^2$ | 0.027 | 0.2 | 0.412 | 0.364 | 0.438 | 0.214 | 0.059 |
| | Significance F | 0.542 | 0.082 | 0.007 | 0.013 | 0.007 | 0.082 | 0.384 |
| | Intercept | 54.3 | 81.8 | 63.6 | 53.4 | 44.7 | 28.9 | 22.2 |
| | Coefficient | -2.39 | 8.48 | 9.03 | 7.83 | 5.38 | 2.97 | 0.79 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.542 | 0.082 | 0.007 | 0.013 | 0.007 | 0.082 | 0.384 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **14 Days** | $R^2$ | 0.038 | 0.196 | 0.415 | 0.346 | 0.438 | 0.22 | 0.089 |
| | Significance F | 0.471 | 0.086 | 0.007 | 0.017 | 0.007 | 0.078 | 0.281 |
| | Intercept | 55.1 | 81.4 | 63 | 53.3 | 44.4 | 28.6 | 21.8 |
| | Coefficient | -2.34 | 7 | 7.54 | 6.36 | 4.48 | 2.46 | 0.81 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.471 | 0.086 | 0.007 | 0.017 | 0.007 | 0.078 | 0.281 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **21 Days** | $R^2$ | 0.045 | 0.22 | 0.418 | 0.294 | 0.431 | 0.213 | 0.144 |
| | Significance F | 0.429 | 0.067 | 0.007 | 0.03 | 0.008 | 0.083 | 0.164 |
| | Intercept | 56 | 79.2 | 61.5 | 53.1 | 44.1 | 28.2 | 21.1 |
| | Coefficient | -2.09 | 6.04 | 6.18 | 4.78 | 3.58 | 1.94 | 0.85 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.429 | 0.067 | 0.007 | 0.03 | 0.008 | 0.083 | 0.164 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |

Table 20 shows the results for total manganese. These results show that highly significant models are only found at sites T2 to T5 with models for short periods at T2 (ie 3 days) highly significant, 7 days falling just outside the threshold of 0.05 and longer periods having larger *p*-values. This is consistent with impacts at T2 being more immediate in the days after raking. Weakly significant models are found at T6 with all *p*-values falling outside the 0.05 threshold but under 0.1. Models at T1 and T7 are all insignificant though the *p*-value for 21 days at T7 falls just outside the weakly significant threshold of 0.15.

*TABLE 21. DISSOLVED MANGANESE (μG/L): REGRESSION PARAMETERS FOR CONCENTRATION VERSUS SEDIMENT RAKING EFFORT IN PRECEDING PERIOD. NOTE THIS INCLUDES DAYS WHERE NO RAKING OCCURRED IN THE PREVIOUS PERIOD*

| | | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|---|
| **3 Days** | $R^2$ | 0.001 | 0.071 | 0.024 | 0.19 | 0.266 | 0.055 | 0.067 |
| | Significance F | 0.925 | 0.319 | 0.564 | 0.091 | 0.049 | 0.399 | 0.353 |
| | Intercept | 24.4 | 36.9 | 24.7 | 16.8 | 15.8 | 15.6 | 11.5 |
| | Coefficient | -0.94 | 10.37 | 3.14 | 10.85 | 8.62 | 3.01 | 2.31 |
| | *p*-value intercept | 0.037 | 0.004 | 0.001 | 0.022 | 0.004 | 0.001 | 0.001 |
| | *p*-value coefficient | 0.925 | 0.319 | 0.564 | 0.091 | 0.049 | 0.399 | 0.353 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **7 Days** | $R^2$ | 0.001 | 0.054 | 0.013 | 0.189 | 0.266 | 0.049 | 0.044 |
| | Significance F | 0.895 | 0.384 | 0.669 | 0.092 | 0.049 | 0.426 | 0.452 |
| | Intercept | 24.6 | 37.5 | 25.2 | 16.6 | 15.6 | 15.7 | 11.8 |
| | Coefficient | -0.68 | 4.73 | 1.21 | 5.62 | 4.49 | 1.48 | 0.98 |
| | *p*-value intercept | 0.036 | 0.004 | 0.001 | 0.023 | 0.004 | 0.001 | 0.001 |
| | *p*-value coefficient | 0.895 | 0.384 | 0.669 | 0.092 | 0.049 | 0.426 | 0.452 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **10 Days** | $R^2$ | 0.003 | 0.046 | 0.014 | 0.149 | 0.228 | 0.053 | 0.047 |
| | Significance F | 0.833 | 0.427 | 0.667 | 0.14 | 0.072 | 0.411 | 0.44 |
| | Intercept | 25.1 | 38 | 25.2 | 17.4 | 16 | 15.6 | 11.7 |
| | Coefficient | -0.84 | 3.32 | 0.94 | 3.83 | 3.19 | 1.14 | 0.77 |
| | *p*-value intercept | 0.034 | 0.004 | 0.001 | 0.021 | 0.004 | 0.001 | 0.001 |
| | *p*-value coefficient | 0.833 | 0.427 | 0.667 | 0.14 | 0.072 | 0.411 | 0.44 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **14 Days** | $R^2$ | 0.006 | 0.042 | 0.015 | 0.112 | 0.192 | 0.057 | 0.057 |
| | Significance F | 0.774 | 0.446 | 0.655 | 0.205 | 0.102 | 0.391 | 0.39 |
| | Intercept | 25.6 | 38 | 25.1 | 17.9 | 16.3 | 15.5 | 11.5 |
| | Coefficient | -0.95 | 2.66 | 0.81 | 2.77 | 2.44 | 0.97 | 0.71 |
| | *p*-value intercept | 0.032 | 0.005 | 0.001 | 0.021 | 0.005 | 0.001 | 0.001 |
| | *p*-value coefficient | 0.774 | 0.446 | 0.655 | 0.205 | 0.102 | 0.391 | 0.39 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **21 Days** | $R^2$ | 0.012 | 0.03 | 0.014 | 0.061 | 0.134 | 0.058 | 0.077 |
| | Significance F | 0.692 | 0.525 | 0.66 | 0.356 | 0.18 | 0.386 | 0.316 |
| | Intercept | 26.6 | 38.4 | 24.9 | 19 | 17 | 15.3 | 11.1 |
| | Coefficient | -1.07 | 1.82 | 0.65 | 1.67 | 1.64 | 0.79 | 0.68 |
| | *p*-value intercept | 0.031 | 0.006 | 0.001 | 0.022 | 0.005 | 0.001 | 0.002 |
| | *p*-value coefficient | 0.692 | 0.525 | 0.66 | 0.356 | 0.18 | 0.386 | 0.316 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |

Table 21 shows the model parameters and goodness of fit for dissolved manganese. Highly significant models are only found at T5 for 3 and 7 day periods with weakly significant models at T4 for 3 and 7 days and T5 at 10 and 14 days. Models at all other sites are insignificant with *p*-values generally greater than 0.3 and in many cases well above 0.5.

*Table 22. Total iron (μg/L): Regression parameters for concentration versus sediment raking effort in preceding period. Note this includes days where no raking occurred in the previous period*

| | | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|---|
| **3 Days** | $R^2$ | 0.093 | 0.294 | 0.347 | 0.318 | 0.369 | 0.618 | 0.049 |
| | Significance F | 0.25 | 0.03 | 0.016 | 0.023 | 0.016 | 0.001 | 0.426 |
| | Intercept | 808.7 | 1554.1 | 1516.3 | 1612.5 | 1285.1 | 559.5 | 364.2 |
| | Coefficient | 158.49 | 734.39 | 829.65 | 745.34 | 583 | 431.75 | 52.6 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.25 | 0.03 | 0.016 | 0.023 | 0.016 | 0.001 | 0.426 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **7 Days** | $R^2$ | 0.081 | 0.284 | 0.377 | 0.33 | 0.355 | 0.592 | 0.029 |
| | Significance F | 0.284 | 0.034 | 0.011 | 0.02 | 0.019 | 0.001 | 0.543 |
| | Intercept | 813 | 1552.2 | 1483.2 | 1594.2 | 1283.8 | 558.7 | 371.5 |
| | Coefficient | 77.07 | 375.28 | 449.99 | 394.66 | 297.67 | 219.36 | 21.02 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.284 | 0.034 | 0.011 | 0.02 | 0.019 | 0.001 | 0.543 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **10 Days** | $R^2$ | 0.068 | 0.252 | 0.362 | 0.325 | 0.366 | 0.598 | 0.045 |
| | Significance F | 0.327 | 0.048 | 0.014 | 0.021 | 0.017 | 0.001 | 0.447 |
| | Intercept | 820.1 | 1575.3 | 1491.1 | 1595.3 | 1275.8 | 556 | 364.8 |
| | Coefficient | 54.23 | 271.5 | 338.27 | 300.4 | 231.9 | 164.87 | 20.07 |
| | *p*-value intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.327 | 0.048 | 0.014 | 0.021 | 0.017 | 0.001 | 0.447 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **14 Days** | $R^2$ | 0.064 | 0.257 | 0.369 | 0.345 | 0.406 | 0.632 | 0.081 |
| | Significance F | 0.346 | 0.045 | 0.012 | 0.017 | 0.011 | 0 | 0.304 |
| | Intercept | 820.2 | 1555.1 | 1466.1 | 1563.5 | 1241.3 | 539.2 | 351.8 |
| | Coefficient | 43.49 | 228.5 | 284.6 | 257.7 | 203.45 | 138.63 | 22.4 |
| | *p*-value intercept | 0 | 0 | 0.001 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.346 | 0.045 | 0.012 | 0.017 | 0.011 | 0 | 0.304 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **21 Days** | $R^2$ | 0.065 | 0.305 | 0.381 | 0.36 | 0.474 | 0.632 | 0.139 |
| | Significance F | 0.34 | 0.027 | 0.011 | 0.014 | 0.005 | 0 | 0.171 |
| | Intercept | 810.6 | 1468 | 1401.6 | 1502 | 1187.6 | 510.4 | 331.1 |
| | Coefficient | 35.97 | 202.98 | 235.99 | 214.85 | 177.02 | 110.93 | 24.08 |
| | *p*-value intercept | 0 | 0.001 | 0.001 | 0 | 0 | 0 | 0.001 |
| | *p*-value coefficient | 0.34 | 0.027 | 0.011 | 0.014 | 0.005 | 0 | 0.171 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |

Table 22 shows model parameters and goodness of fit for total iron. These results show highly significant relationships between sediment raking effort and total iron concentrations at Sites T2 to T6. Models at T1 and T7 are insignificant though the 21 day model at T7 falls just outside the threshold for weakly significant models.

*TABLE 23. DISSOLVED IRON (µG/L): REGRESSION PARAMETERS FOR CONCENTRATION VERSUS SEDIMENT RAKING EFFORT IN PRECEDING PERIOD. NOTE THIS INCLUDES DAYS WHERE NO RAKING OCCURRED IN THE PREVIOUS PERIOD*

| | | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|---|
| **3 Days** | $R^2$ | 0.101 | 0.133 | 0.225 | 0.217 | 0.369 | 0.618 | 0.049 |
| | Significance F | 0.231 | 0.165 | 0.063 | 0.069 | 0.016 | 0.001 | 0.426 |
| | Intercept | 79.3 | 70.4 | 61.6 | 47 | 1285.1 | 559.5 | 364.2 |
| | Coefficient | 21.7 | 23.17 | 37.96 | 16.52 | 583 | 431.75 | 52.6 |
| | *p*-value intercept | 0.001 | 0.001 | 0.009 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.231 | 0.165 | 0.063 | 0.069 | 0.016 | 0.001 | 0.426 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **7 Days** | $R^2$ | 0.097 | 0.128 | 0.186 | 0.215 | 0.355 | 0.592 | 0.029 |
| | Significance F | 0.239 | 0.173 | 0.095 | 0.07 | 0.019 | 0.001 | 0.543 |
| | Intercept | 79.3 | 70.3 | 63.2 | 46.8 | 1283.8 | 558.7 | 371.5 |
| | Coefficient | 11.1 | 11.84 | 17.97 | 8.56 | 297.67 | 219.36 | 21.02 |
| | *p*-value intercept | 0.001 | 0.001 | 0.01 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.239 | 0.173 | 0.095 | 0.07 | 0.019 | 0.001 | 0.543 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **10 Days** | $R^2$ | 0.111 | 0.147 | 0.225 | 0.254 | 0.366 | 0.598 | 0.045 |
| | Significance F | 0.207 | 0.143 | 0.064 | 0.047 | 0.017 | 0.001 | 0.447 |
| | Intercept | 78.3 | 69.2 | 60.9 | 45.9 | 1275.8 | 556 | 364.8 |
| | Coefficient | 9.09 | 9.72 | 15.14 | 7.13 | 231.9 | 164.87 | 20.07 |
| | *p*-value intercept | 0.001 | 0.001 | 0.01 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.207 | 0.143 | 0.064 | 0.047 | 0.017 | 0.001 | 0.447 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **14 Days** | $R^2$ | 0.12 | 0.166 | 0.283 | 0.279 | 0.406 | 0.632 | 0.081 |
| | Significance F | 0.188 | 0.118 | 0.034 | 0.035 | 0.011 | 0 | 0.304 |
| | Intercept | 77.2 | 67.7 | 57.1 | 44.9 | 1241.3 | 539.2 | 351.8 |
| | Coefficient | 7.89 | 8.6 | 14.15 | 6.23 | 203.45 | 138.63 | 22.4 |
| | *p*-value intercept | 0.001 | 0.001 | 0.013 | 0 | 0 | 0 | 0 |
| | *p*-value coefficient | 0.188 | 0.118 | 0.034 | 0.035 | 0.011 | 0 | 0.304 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |
| **21 Days** | $R^2$ | 0.113 | 0.165 | 0.343 | 0.259 | 0.474 | 0.632 | 0.139 |
| | Significance F | 0.202 | 0.118 | 0.017 | 0.044 | 0.005 | 0 | 0.171 |
| | Intercept | 76.1 | 66.1 | 51.3 | 44.2 | 1187.6 | 510.4 | 331.1 |
| | Coefficient | 6.24 | 7.02 | 12.71 | 4.9 | 177.02 | 110.93 | 24.08 |
| | *p*-value intercept | 0.002 | 0.002 | 0.022 | 0 | 0 | 0 | 0.001 |
| | *p*-value coefficient | 0.202 | 0.118 | 0.017 | 0.044 | 0.005 | 0 | 0.171 |
| | N | 16 | 16 | 16 | 16 | 15 | 15 | 15 |

Table 23 provides model parameters and measure of fit for dissolved iron concentrations.  This table shows highly significant models for T3 to T6 with longer periods being associated with lower *p*-values (shorter periods at T3 and T4 have weakly significant models with highly significant models commencing at 14 days and 10 days respectively). T2 has weakly significant models for all periods from 10 days onwards with *p*-values falling as the period lengthens.  Models at T7 are all insignificant but *p*-values at this site also fall as the period lengthens with the 21 day model falling just outside the weakly significant threshold.

### 4.2.2 Impacts of increased sediment raking effort on heavy metal concentrations

Table 24 summarises 21 day raking period only models (type 2 regression analysis as described above). Note that these models exclude all data from non-raking days and so identify more clearly when there is a relationship between sediment raking effort and concentration as opposed to picking up the impact of raking versus non-raking days. Cells with “N” indicate that insufficient data was available on which to fit a model.

*Table 24. Regression parameters for weighted raking effort in the preceding 21 days with no effort days removed*

| | | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Aluminium (µg/L)** | $R^2$ | 0.021 | 0.037 | 0.041 | 0.195 | 0.256 | 0.618 | 0.502 | 0.502 | 0.441 | 0.331 | 0.384 | 0.716 | 0.668 |
| | Significance F | 0.73 | 0.65 | 0.63 | 0.274 | 0.246 | 0.036 | 0.049 | 0.049 | 0.072 | 0.135 | 0.101 | 0.016 | 0.025 |
| | Intercept | 825.6 | 2042.2 | 2231.7 | 1538.2 | 1225.5 | 380.7 | 163.9 | 58.2 | 32.1 | 59.2 | 50.1 | 25.3 | 15.4 |
| | Coefficient | 19.98 | 67.58 | 54.26 | 160.16 | 142.28 | 143.74 | 38.07 | 26.09 | 26.44 | 8.15 | 8.4 | 8.39 | 8.09 |
| | *p*-value intercept | 0.046 | 0.052 | 0.013 | 0.101 | 0.135 | 0.269 | 0.126 | 0.394 | 0.674 | 0.08 | 0.101 | 0.122 | 0.341 |
| | *p*-value coefficient | 0.73 | 0.65 | 0.63 | 0.274 | 0.246 | 0.036 | 0.049 | 0.049 | 0.072 | 0.135 | 0.101 | 0.016 | 0.025 |
| | N | 8 | 8 | 8 | 8 | 7 | 7 | 8 | 8 | 8 | 8 | 8 | 7 | 7 |
| **Total Zinc (µg/L)** | $R^2$ | 0.043 | 0.045 | 0.007 | 0.142 | 0.127 | 0.5 | 0.456 | 0.474 | N | N | N | N | N |
| | Significance F | 0.621 | 0.615 | 0.841 | 0.358 | 0.432 | 0.076 | 0.066 | 0.059 | N | N | N | N | N |
| | Intercept | 6.6 | 13.7 | 15.9 | 11.5 | 10.4 | 3.5 | 1 | 1.8 | N | N | N | N | N |
| | Coefficient | 0.15 | 0.47 | 0.13 | 0.78 | 0.6 | 0.75 | 0.67 | 0.17 | N | N | N | N | N |
| | *p*-value intercept | 0.009 | 0.041 | 0.006 | 0.049 | 0.069 | 0.146 | 0.596 | 0.006 | N | N | N | N | N |
| | *p*-value coefficient | 0.621 | 0.615 | 0.841 | 0.358 | 0.432 | 0.076 | 0.066 | 0.059 | N | N | N | N | N |
| | N | 8 | 8 | 8 | 8 | 7 | 7 | 8 | 8 | N | N | N | N | N |
| **Total Manganese (µg/L)** | $R^2$ | 0.151 | 0.049 | 0.047 | 0.173 | 0.34 | 0.492 | 0.574 | 0.375 | 0.402 | 0.374 | 0.251 | 0.298 | 0.344 |
| | Significance F | 0.341 | 0.599 | 0.604 | 0.305 | 0.169 | 0.079 | 0.029 | 0.107 | 0.091 | 0.107 | 0.206 | 0.205 | 0.166 |
| | Intercept | 61.5 | 98.8 | 91.9 | 54.3 | 45.5 | 20.5 | 14.6 | 7.6 | 4.8 | 4.7 | 5.7 | 5.1 | 3.4 |
| | Coefficient | -2.89 | 3.18 | 1.72 | 4.61 | 3.38 | 3.03 | 1.8 | 1.6 | 1.7 | 0.83 | 0.49 | 0.7 | 0.39 |
| | *p*-value intercept | 0.01 | 0.028 | 0.003 | 0.069 | 0.019 | 0.058 | 0.008 | 0.181 | 0.382 | 0.127 | 0.032 | 0.122 | 0.06 |
| | *p*-value coefficient | 0.341 | 0.599 | 0.604 | 0.305 | 0.169 | 0.079 | 0.029 | 0.107 | 0.091 | 0.107 | 0.206 | 0.205 | 0.166 |
| | N | 8 | 8 | 8 | 8 | 7 | 7 | 8 | 8 | 8 | 8 | 8 | 7 | 7 |

| | | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dissolved Manganese (µg/L)** | $R^2$ | 0.006 | 0.2 | 0.3 | 0.017 | 0.019 | 0.499 | 0.191 | 0.154 | 0.236 | 0.162 | 0 | 0.18 | 0.021 |
| | Significance F | 0.857 | 0.266 | 0.16 | 0.755 | 0.767 | 0.076 | 0.278 | 0.336 | 0.222 | 0.323 | 0.967 | 0.343 | 0.756 |
| | Intercept | 22.7 | 16.6 | 9.2 | 21.4 | 22.1 | 11.2 | 7.8 | 3.5 | 1.4 | 2.2 | 2.7 | 3.1 | 2.6 |
| | Coefficient | -0.5 | 5.01 | 2.96 | 1.3 | 0.91 | 1.37 | 1.17 | 1.03 | 0.9 | 0.22 | 0.01 | 0.24 | -0.04 |
| | *p*-value intercept | 0.201 | 0.521 | 0.438 | 0.403 | 0.283 | 0.03 | 0.23 | 0.574 | 0.729 | 0.116 | 0.025 | 0.062 | 0.009 |
| | *p*-value coefficient | 0.857 | 0.266 | 0.16 | 0.755 | 0.767 | 0.076 | 0.278 | 0.336 | 0.222 | 0.323 | 0.967 | 0.343 | 0.756 |
| | N | 8 | 8 | 8 | 8 | 7 | 7 | 8 | 8 | 8 | 8 | 8 | 7 | 7 |
| **Total Iron (µg/L)** | $R^2$ | 0.004 | 0.025 | 0.028 | 0.165 | 0.214 | 0.767 | 0.555 | 0.5 | 0.44 | 0.483 | 0.473 | 0.59 | 0.692 |
| | Significance F | 0.883 | 0.706 | 0.691 | 0.318 | 0.296 | 0.01 | 0.034 | 0.05 | 0.073 | 0.056 | 0.059 | 0.044 | 0.02 |
| | Intercept | 1001.7 | 2409.8 | 2648.3 | 1780.1 | 1504.2 | 287.4 | 126.5 | 30 | 1.8 | 46.7 | 30.9 | 25.3 | 5.5 |
| | Coefficient | 7.97 | 64.93 | 53.24 | 174.09 | 132.03 | 142.6 | 54.07 | 33.74 | 33.54 | 9.4 | 11.86 | 8.42 | 9.55 |
| | *p*-value intercept | 0.018 | 0.049 | 0.013 | 0.111 | 0.09 | 0.236 | 0.325 | 0.727 | 0.985 | 0.097 | 0.351 | 0.22 | 0.75 |
| | *p*-value coefficient | 0.883 | 0.706 | 0.691 | 0.318 | 0.296 | 0.01 | 0.034 | 0.05 | 0.073 | 0.056 | 0.059 | 0.044 | 0.02 |
| | N | 8 | 8 | 8 | 8 | 7 | 7 | 8 | 8 | 8 | 8 | 8 | 7 | 7 |
| **Dissolved Iron (µg/L)** | $R^2$ | 0.533 | 0.682 | 0.635 | 0.589 | 0.734 | N | N | N | N | N | N | N | N |
| | Significance F | 0.04 | 0.011 | 0.018 | 0.026 | 0.014 | N | N | N | N | N | N | N | N |
| | Intercept | 55.4 | 48.2 | 1.5 | 22.2 | 8.7 | N | N | N | N | N | N | N | N |
| | Coefficient | 9.28 | 9.63 | 20.01 | 8.13 | 6.37 | N | N | N | N | N | N | N | N |
| | *p*-value intercept | 0.04 | 0.024 | 0.968 | 0.228 | 0.461 | N | N | N | N | N | N | N | N |
| | *p*-value coefficient | 0.04 | 0.011 | 0.018 | 0.026 | 0.014 | N | N | N | N | N | N | N | N |
| | N | 8 | 8 | 8 | 8 | 7 | N | N | N | N | N | N | N | N |

This table shows:

- For total metals the most significant models are found from T6 to T15 indicating that the effects of raking extend through the mid to lower estuary for 3 weeks after raking ceases. Note that significant models at these sites have $R^2$ values between 0.5 and 0.767 indicating that the models explain a lot of the variation in observed concentrations. This is consistent with the results from the previous analysis that found relationships generally became more significant further downstream over longer periods.
- Models for total aluminium are significant downstream and including T6, with highly significant relationships at T6, T7, T9, T14 and T15 and weakly significant relationships at T10, T12 and T13. $R^2$ values for highly significant models vary between 0.502 and 0.716 indicating they explain a large amount of the variation in the data.
- Models for total zinc are only weakly significant from T6 to T9, although *p*-values at these sites fall just outside the highly significant threshold of 0.05. These models are likely to be affected by the increased number of days with '<2' values at these sites (50% of data at T9 is '<2' obscuring any variation in values below this threshold).
- Models for total and dissolved manganese are generally less significant than was the case for other metals. This is consistent with fewer significant models found when non-raking days were included in the regression. Weakly significant models were found for total manganese for sites T6 to T12 with the exception of T7 that had a highly significant regression model. T6 was the only site with a weakly significant model for dissolved manganese with all other models insignificant (and having *p*-values generally well above the weakly significant threshold).
- Models for total iron are highly to weakly significant at all sites including and downstream of T6. Weakly significant models were found at T10 to T13 although the *p*-value at these sites is just outside the highly significant threshold.
- Models for dissolved iron are highly significant at all sites from T1 to T5 with good $R^2$ values for all models (0.533 to 0.734) indicating that they explain a good proportion of the variation in the data. There was insufficient data below T5 on which to fit models of dissolved iron.

## 4.3 Discussion of heavy metals results

Data on heavy metals is generally poorer and less fit for purpose for assessing the potential impacts of sediment raking than was the case for other physico-chemical measures of water quality. Given this, the results of the analysis for heavy metals when considered alone have a higher degree of uncertainty than was the case for other pollutants and so must be interpreted with care, acknowledging the limitations of the data on which they are built. Comparison with the results from other pollutants does however give an indication of the veracity of results providing multiple lines of evidence for the types of processes affecting water quality in the period after sediment raking and the types of impacts which can be expected. The results of the analysis of correlations between sediment raking effort and heavy metals concentrations are very consistent with the general relationships found with other pollutants:

- Impacts on total pollutants in the upper estuary around raked areas tend to be shorter term. This is consistent with pollutants attached to the raked sediment being suspended into the water column for the days immediately after raking before being deposited back on the estuary bottom or being pushed downstream. Dissolved pollutants are more likely to persist in these upper estuary areas with models of dissolved iron showing a relationship with sediment raking appears to persist for 3 weeks after raking ceases with a gradual decrease in dissolved iron concentrations over this period. Unfortunately adequate data is not available for aluminium or zinc to confirm this result for these metals. The generally weaker relationship between both total and dissolved manganese and sediment raking effort appears to indicate raked sediments are not a substantial source of this pollutant and so results for dissolved manganese are not reflective of what could be expected for aluminium or zinc (which were strongly correlated with sediment raking effort in parts at a number of sites).

- Total metal concentrations for aluminium, zinc and iron are significantly correlated with sediment raking efforts to T6 in the period immediately after sediment raking (likely to be for several days after raking at least). Impacts in the mid to lower estuary are also seen for aluminium and iron for the 3 week period after sediment raking ceases. In these cases the increased metal concentrations gradually fall over the 3 week period as the period since the cessation of raking increases (data for zinc is compromised due to the large number of data points below the limits of reporting). The lack of dissolved data for these metals makes it impossible to tell whether this impact is due to increased dissolved forms of these metals downstream, however given the consistency of these impacts with those seen on dissolved nutrients in the lower estuary it is considered that transport of dissolved metals past T6 is a feasible explanation for these persistent impacts on concentrations further down the estuary.

While these results are not conclusive, given the paucity of the data, they do indicate that there is a strong possibility that heavy metal concentrations are being impacted by sediment raking into the lower estuary and for an extended period after raking ceases (2 to 3 weeks). While the number of observations for each water quality parameter is relatively low, the consistency of results both between sites for a given parameter and between parameters increases the confidence that the impacts described are true water quality impacts and not a reflection of uncertainty in a relatively small data set.

These results also show that monitoring of sediment raking (or similar activities) should be designed to allow for broader scale temporal and spatial impacts to be assessed. This would mean monitoring concentrations before and after sediment raking events over the course of several weeks through the mid and lower estuary to detect longer spatial and temporal scale changes.

# 5 Discussion and conclusions

This report has analysed the impacts of sediment raking on bathymetry in the upper estuary and water quality for the length the estuary to Clarence Point (T15) to assess the extent to which sediment raking has achieved its stated objectives and the nature and extent of unintended impacts on water quality.

## 5.1 Extent to which objectives have been met

Table 25 summarises the results of this analysis in terms of the extent to which sediment raking has met its objectives. Cells are coloured to indicate the extent to which evidence suggests sediment raking has been able to meet the objective – green cells are where evidence supports the case that sediment raking has met this objective, orange cells are where there is some evidence that the objective has not/would not be met but where the strength of this evidence is relatively weak, and red cells are objectives which have not been met and which have been negatively impacted by sediment raking.

*TABLE 25. EXTENT TO WHICH SEDIMENT RAKING HAS MET ITS OBJECTIVES BASED ON DATA REVIEW*

| Objective | Impact of sediment raking |
|---|---|
| Flood defence | No benefit and possibly negative impact – channel has more sediment and floods are less effective at scouring the channel than before. Primary indicator used previously for flood defence is mass movement out of the upper estuary which has not been achieved. |
| Mass movement out of areas around Launceston | Net sediment increase during raking before 2016 flood. |
| Improved aesthetics – West Bank | Sediment levels in West Bank have been reduced |
| Improved aesthetics – Royal Park and North Bank | No sustained benefit, higher maximum sediment in Royal Park after raking than before |
| Navigation and open channels | Channel infill by 0.5m-1m compared to pre-raking with even 2016 flood not halting the increase in sediment in Mid Channel |
| Recreational access | Channel infill likely to be negatively impacting recreational access as channels, North Bank and Royal Park infill |
| Seaport – access | Access to the seaport through the channel has been reduced |
| Seaport – aesthetics | Sediment levels in the Seaport have decreased but require frequent prop washing to sustain |
| Ship lift | Infilling of channel reducing access and likely to be increasing sediment immediately in and around Ship lift |
| Home point tourist point | Reduced navigability and access to Home Point with infilling of channel |
| Ecosystem health | Sediment raking negatively impacts on water quality for at least 2 weeks after sediment raking campaigns end with increases well above WQO/default guideline levels in many cases. Increases in nutrients and heavy metals extend to the lower estuary. Impacts on TSS are largely confined to Zones 1 and 2 but turbidity is raised at all sites in Zone 3. |

## 5.2 Impacts on water quality

Analysis of localised water quality impacts shows that sediment raking releases large amounts of sediments, nutrients and heavy metals into the water column. These increases are seen across all total pollutants as well as for some dissolved pollutants. While NOx and dissolved aluminium do not show an immediate increase in the plume, both TN and total aluminium increase markedly so it is likely that this initial impact reflects the large concentration of sediment, and thus sediment attached pollutants, in the plume. There is some evidence that a delay in collecting samples, even by small amounts of time (ie. the difference in collecting samples in the plume from the sediment raking boat versus from a fixed point, Ti Tree Bend, downstream of raking activities) is enough time for these pollutants to begin detaching from sediments and dissolved concentrations to begin to increase. Increases in pollutant concentrations are in many cases one to two orders of magnitude greater than the ANZECC default guideline value for the pollutant (and in the case of total aluminium nearly 3 orders of magnitude), indicating impacts on localised water quality that are likely to be associated with environmental harm and which may be toxic to aquatic life.

This analysis also shows that the water quality impacts of sediment raking are seen down the length of the estuary to at least Clarence Point. In particular there is evidence that dissolved nutrients and total metals such as aluminium and iron are elevated in the lower estuary for weeks after a sediment raking event. The number of data points on which this observation is based is limited and the data have not been collected for the purpose of analysing the impacts of sediment raking, however considering the consistency of results, strength of the relationships found and the feasibility of findings given the way in which these pollutants are transported on the tide through the estuary, it is likely that these results reflect a true impact of raking on water quality. The results do suggest that in order to accurately determine what the impacts of sediment raking are in the estuary, a 'fit for purpose' monitoring regime requires data collection through the mid and lower estuary, should consider nutrients and metals as well as sediments and should be event based, measuring water quality before, during and for a period of several weeks after sediment raking.

## 5.3 Conclusions

The sediment raking does not meet the majority of the objectives for which it has been proposed in the past. In fact the only objectives that sediment raking has met are improved aesthetics in the West Bank and Seaport but these have been achieved with significant trade-offs in terms of reduced navigability, access and aesthetics in other parts of Zone 1 and impacts on water quality. They also require continued sediment raking effort, particularly prop washing in the Seaport, to maintain these aesthetic benefits. Importantly while much of the sediment mobilised with sediment raking returns fairly rapidly to the upper estuary around Launceston, the impacts of sediment raking on water quality extend into the lower estuary (at least to Clarence Point). The extent of impacts is greatest for dissolved nutrients, in particular NOx and ammonia. Data for heavy metals is sparse but indicates that aluminium and iron concentrations are elevated in the mid to lower estuary for at least 3 weeks after raking. Evidence suggests that aluminium, iron and zinc are also elevated in the upper estuary for days to weeks after sediment raking. Water quality impacts persist for at least 2 weeks after sediment raking ceases and are of a magnitude to be of concern relative to water quality objectives and ANZECC default guideline values.

Historically raking occurred at relatively high frequencies over many months of the year, with many sediment raking campaigns being separated by only a few days. For example in 2014 individual raking campaigns varied from 3 to 33 days long with gaps ranging from 2 to 18 days long. In light of the impacts on water quality estimated in this report that were shown to persist for a period of 2 to 3 weeks after raking in many cases, these small gaps would mean parameter concentrations would be expected to remain elevated for long periods of time. The raking campaigns described above for 2014 occurred over 4 months meaning significantly elevated pollutant levels could be expected to have occurred for 4.5 or more months of that year. No assessment has been made of the ecological impacts of these changes but it is expected that changes of this nature and magnitude could impact on the ecological health of the estuary.

# 6 References

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# Appendix 1. Detailed Regression Model Results

Table 13 and Table 14 provide a simple summary of the statistical significance of regression models developed as part of the analysis of the effects of sediment raking on water quality. These simplified summaries were developed to make interpretation of the results easier. This Appendix contains details of the full regression models underlying these simplified summaries. Table 26 to

Table 37 provide regression model parameters for weighted sediment raking effort over 7 days, 10 days and 14 days and then sediment raking effort and flow over the preceding 2 weeks for each of the pollutants and monitoring sites. 'N' indicates combinations for which no model was fit as prior models indicated that results were unlikely to be significant.

Parameters provided in tables in this Appendix are:

- $R^2$ – the proportion of the variance of the dependent variable explained by the independent variable
- Significance F – the statistical significance of the F value of the regression, which tests whether the model has predictive capacity. A value of 0.05 indicates that the model has predictive value at the 95% level of significance.
- Intercept and Coefficient – the regression model parameters. The intercept is a fixed value, the coefficient is the value by which the relevant parameter is multiplied. Note that two types of models are fit – one with a single coefficient (WSRE) and a second with both WRSE and flow as independent variables for which a coefficient value is estimated.
- *p*-value of Intercept and Coefficient – tests the null hypothesis that the independent variable has no correlation to the dependent variable.

Regression relationships have been coloured to indicate how significant they are:

- Green cells are indicative of a highly significant coefficient value (*p*-value <0.05).
- Orange cells are indicative of a weakly significant coefficient value (*p*-value <0.15).
- Uncoloured cells are insignificant at 85% level (ie. *p*-value >=0.15).

## A1.1 Effects of sediment raking effort on pollutant concentrations – Regression models

*Table 26. TSS – Regression results for TSS concentration (mg/L) versus weighted sediment raking effort in preceding period*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.008 | 0.334 | 0.18 | 0.455 | 0.454 | 0.655 | 0.039 | N | N | N | N | N | N |
| Intercept | 21 | 14.1 | 41.1 | 8.8 | 9.7 | 5.4 | 9.6 | N | N | N | N | N | N |
| Coefficient | -0.6 | 11.5 | 6.1 | 11.6 | 11.2 | 5.8 | 0.4 | N | N | N | N | N | N |
| *p*-value Intercept | 0.022 | 0.45 | 0.02 | 0.539 | 0.491 | 0.291 | 0.004 | N | N | N | N | N | N |
| *p*-value Coefficient | 0.805 | 0.08 | 0.222 | 0.032 | 0.033 | 0.008 | 0.583 | N | N | N | N | N | N |
| **10 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.019 | 0.204 | 0.104 | 0.285 | 0.341 | 0.542 | 0.172 | 0.087 | 0.112 | N | N | N | N |
| Intercept | 16 | 24.2 | 46.9 | 18.9 | 16.6 | 8 | 8.3 | 10.9 | 8.7 | N | N | N | N |
| Coefficient | 0.7 | 6.1 | 3.1 | 6.2 | 6.6 | 3.5 | 0.6 | -0.6 | -0.5 | N | N | N | N |
| *p*-value Intercept | 0.034 | 0.164 | 0.004 | 0.179 | 0.21 | 0.117 | 0.002 | 0.002 | 0.001 | N | N | N | N |
| *p*-value Coefficient | 0.684 | 0.164 | 0.334 | 0.091 | 0.059 | 0.015 | 0.204 | 0.378 | 0.314 | N | N | N | N |
| **14 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.07 | 0.154 | 0.176 | 0.078 | 0.184 | 0.481 | 0.545 | 0.042 | 0.037 | N | N | N | N |
| Intercept | 14.2 | 31.6 | 43.2 | 32.5 | 26.1 | 9.8 | 5.6 | 6.4 | 7.8 | N | N | N | N |
| Coefficient | 0.9 | 3.5 | 3.1 | 2.4 | 3.5 | 2.4 | 1 | 0.3 | -0.2 | N | N | N | N |
| *p*-value Intercept | 0.005 | 0.011 | 0 | 0.01 | 0.028 | 0.014 | 0.001 | 0.008 | 0 | N | N | N | N |
| *p*-value Coefficient | 0.359 | 0.165 | 0.135 | 0.335 | 0.144 | 0.009 | 0.003 | 0.48 | 0.51 | N | N | N | N |

*TABLE 27. TURBIDITY – REGRESSION RESULTS FOR TURBIDITY (NTU) VERSUS WEIGHTED SEDIMENT RAKING EFFORT IN PRECEDING PERIOD*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.031 | 0.25 | 0.022 | 0.286 | 0.154 | 0.024 | 0.021 | N | N | N | N | N | N |
| Intercept | 19.9 | 22.2 | 31.2 | 21.2 | 16.2 | 37.4 | 35.5 | N | N | N | N | N | N |
| Coefficient | 1.9 | 9.6 | -2.7 | 7 | 6 | 2.4 | -0.5 | N | N | N | N | N | N |
| *p*-value Intercept | 0.128 | 0.256 | 0.151 | 0.13 | 0.322 | 0.051 | 0 | N | N | N | N | N | N |
| *p*-value Coefficient | 0.626 | 0.141 | 0.68 | 0.138 | 0.262 | 0.668 | 0.691 | N | N | N | N | N | N |
| **10 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.124 | 0.334 | 0.001 | 0.451 | 0.29 | 0.712 | 0.326 | 0.286 | 0.258 | N | N | N | N |
| Intercept | 13.2 | 16.2 | 20.5 | 14 | 9.6 | 2.7 | 4.2 | 2.3 | 2.3 | N | N | N | N |
| Coefficient | 2.8 | 8.3 | 0.5 | 6.8 | 5.9 | 3.3 | 0.8 | 0.6 | 0.5 | N | N | N | N |
| *p*-value Intercept | 0.224 | 0.325 | 0.249 | 0.206 | 0.458 | 0.445 | 0.041 | 0.099 | 0.096 | N | N | N | N |
| *p*-value Coefficient | 0.289 | 0.063 | 0.913 | 0.033 | 0.088 | 0.008 | 0.108 | 0.111 | 0.134 | N | N | N | N |
| **14 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.003 | 0.246 | 0.043 | 0.053 | 0.063 | 0.639 | 0.491 | 0.335 | 0.386 | 0.483 | 0.395 | 0.006 | 0.19 |
| Intercept | 23.8 | 24.7 | 34.8 | 31.9 | 24.4 | 3.8 | 3.4 | 2.5 | 2.2 | 2.1 | 2 | 3.2 | 2.2 |
| Coefficient | 0.4 | 5.1 | -2.1 | 2.2 | 2.1 | 2.4 | 0.8 | 0.4 | 0.4 | 0.2 | 0.2 | 0.1 | 0.1 |
| *p*-value Intercept | 0.042 | 0.051 | 0.017 | 0.018 | 0.053 | 0.171 | 0.009 | 0.011 | 0.011 | 0 | 0 | 0.036 | 0 |
| *p*-value Coefficient | 0.856 | 0.071 | 0.478 | 0.447 | 0.409 | 0.003 | 0.011 | 0.038 | 0.023 | 0.006 | 0.016 | 0.793 | 0.119 |

*TABLE 28. TP – REGRESSION RESULTS FOR TP (µG/L) VERSUS WEIGHTED SEDIMENT RAKING EFFORT IN PRECEDING PERIOD*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.001 | 0.291 | 0.004 | 0.283 | 0.305 | 0.024 | 0.021 | N | N | N | N | N | N |
| Intercept | 57 | 55.9 | 103.1 | 61.6 | 36.5 | 37.4 | 35.5 | N | N | N | N | N | N |
| Coefficient | 0.4 | 16.1 | 1.9 | 14.1 | 13.4 | 2.4 | -0.5 | N | N | N | N | N | N |
| *p*-value Intercept | 0.002 | 0.076 | 0.015 | 0.036 | 0.137 | 0.051 | 0 | N | N | N | N | N | N |
| *p*-value Coefficient | 0.934 | 0.107 | 0.868 | 0.114 | 0.098 | 0.668 | 0.691 | N | N | N | N | N | N |
| **10 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.108 | 0.084 | 0.027 | 0.257 | 0.282 | 0.069 | 0.027 | 0.117 | N | N | N | N | N |
| Intercept | 44.8 | 81.8 | 122.6 | 66.5 | 41.6 | 34.1 | 32.1 | 26.3 | N | N | N | N | N |
| Coefficient | 3 | 5.9 | -3.5 | 9.2 | 8.8 | 2.7 | 0.4 | 1.8 | N | N | N | N | N |
| *p*-value Intercept | 0.004 | 0.012 | 0.002 | 0.011 | 0.052 | 0.029 | 0 | 0.003 | N | N | N | N | N |
| *p*-value Coefficient | 0.324 | 0.387 | 0.627 | 0.112 | 0.092 | 0.437 | 0.632 | 0.303 | N | N | N | N | N |
| **14 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.123 | 0.141 | 0.002 | 0.164 | 0.287 | 0.154 | 0.178 | 0.216 | 0.003 | 0.26 | 0.134 | 0.108 | 0.085 |
| Intercept | 45.1 | 72.2 | 108.9 | 76.4 | 40.7 | 31.4 | 30 | 25.2 | 28.7 | 26.6 | 26.9 | 27.3 | 27.7 |
| Coefficient | 2.3 | 6.2 | -0.6 | 5.4 | 7.2 | 2.7 | 0.8 | 1.7 | 0.2 | 1.3 | 1 | 0.9 | 0.8 |
| *p*-value Intercept | 0 | 0.003 | 0 | 0 | 0.016 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *p*-value Coefficient | 0.218 | 0.186 | 0.886 | 0.15 | 0.048 | 0.164 | 0.133 | 0.094 | 0.85 | 0.063 | 0.198 | 0.251 | 0.313 |

*Table 29. DRP – Regression results for TN (µg/L) versus weighted sediment raking effort in preceding period*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0 | 0.001 | 0 | 0.08 | 0.045 | 0.012 | 0.059 | N | N | N | N | N | N |
| Intercept | 17.8 | 14.1 | 13.3 | 11.8 | 12.3 | 22.1 | 12.6 | N | N | N | N | N | N |
| Coefficient | -0.1 | -0.1 | 0 | 0.9 | 0.6 | -1.2 | 0 | N | N | N | N | N | N |
| *p*-value Intercept | 0.014 | 0.007 | 0.001 | 0.006 | 0.003 | 0.123 | 0 | N | N | N | N | N | N |
| *p*-value Coefficient | 0.957 | 0.915 | 0.987 | 0.428 | 0.555 | 0.783 | 0.498 | N | N | N | N | N | N |
| **10 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.04 | 0.043 | 0.077 | 0.096 | 0.106 | 0.006 | 0.128 | 0.157 | 0.129 | N | N | N | N |
| Intercept | 14.4 | 16.1 | 11 | 11.7 | 11.4 | 16 | 11.1 | 9.9 | 9.6 | N | N | N | N |
| Coefficient | 0.7 | -0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.5 | 0.6 | 0.6 | N | N | N | N |
| *p*-value Intercept | 0.014 | 0.001 | 0.001 | 0.001 | 0.001 | 0.162 | 0 | 0.001 | 0.001 | N | N | N | N |
| *p*-value Coefficient | 0.553 | 0.539 | 0.409 | 0.354 | 0.329 | 0.828 | 0.28 | 0.228 | 0.278 | N | N | N | N |
| **14 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.114 | 0.053 | 0.05 | 0.158 | 0.166 | 0.074 | 0.402 | 0.422 | 0.416 | 0.587 | 0.617 | 0.385 | 0.361 |
| Intercept | 12.9 | 16 | 11.6 | 11.4 | 11.1 | 10.9 | 8.3 | 6.8 | 6.4 | 4.4 | 4.7 | 4.8 | 5.4 |
| Coefficient | 0.9 | -0.4 | 0.3 | 0.6 | 0.6 | 1.4 | 0.9 | 1.1 | 1 | 1.2 | 1 | 0.8 | 0.7 |
| *p*-value Intercept | 0.001 | 0 | 0 | 0 | 0 | 0.122 | 0 | 0.001 | 0.001 | 0.006 | 0.001 | 0.002 | 0.001 |
| *p*-value Coefficient | 0.238 | 0.429 | 0.443 | 0.16 | 0.168 | 0.369 | 0.015 | 0.012 | 0.013 | 0.001 | 0.001 | 0.018 | 0.023 |

*TABLE 30. TN – REGRESSION RESULTS FOR TN (µG/L) VERSUS WEIGHTED SEDIMENT RAKING EFFORT IN PRECEDING PERIOD*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.217 | 0.038 | 0.084 | 0.302 | 0.412 | 0.026 | 0.057 | N | N | N | N | N | N |
| Intercept | 562.6 | 594.5 | 768.5 | 544.5 | 378.9 | 412.8 | 390 | N | N | N | N | N | N |
| Coefficient | 40.9 | 39.8 | 33 | 79.8 | 105.1 | 26.9 | 20.7 | N | N | N | N | N | N |
| *p*-value Intercept | 0 | 0.026 | 0 | 0.003 | 0.024 | 0.049 | 0.003 | N | N | N | N | N | N |
| *p*-value Coefficient | 0.175 | 0.59 | 0.417 | 0.1 | 0.045 | 0.653 | 0.508 | N | N | N | N | N | N |
| **10 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.512 | 0.045 | 0.266 | 0.468 | 0.507 | 0.522 | 0.229 | 0.049 | N | N | N | N | N |
| Intercept | 448.3 | 609.7 | 684.4 | 500.7 | 360.7 | 328.1 | 331.1 | 342.3 | N | N | N | N | N |
| Coefficient | 56 | 29.3 | 43.8 | 70.1 | 82.2 | 56.6 | 29.6 | 13.2 | N | N | N | N | N |
| *p*-value Intercept | 0 | 0.008 | 0 | 0.001 | 0.009 | 0.002 | 0.001 | 0.002 | N | N | N | N | N |
| *p*-value Coefficient | 0.013 | 0.532 | 0.104 | 0.02 | 0.014 | 0.018 | 0.136 | 0.515 | N | N | N | N | N |
| **14 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.685 | 0.084 | 0.43 | 0.483 | 0.405 | 0.671 | 0.469 | 0.255 | 0.192 | 0.267 | 0.134 | N | N |
| Intercept | 408.4 | 611.4 | 626.7 | 520.9 | 436.3 | 290 | 289.6 | 284.4 | 281.8 | 277.5 | 290.2 | N | N |
| Coefficient | 51.9 | 26.3 | 46.2 | 54 | 52.5 | 52 | 32.2 | 22.2 | 17.3 | 13.9 | 5.4 | N | N |
| *p*-value Intercept | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N | N |
| *p*-value Coefficient | 0 | 0.313 | 0.011 | 0.006 | 0.019 | 0.001 | 0.007 | 0.065 | 0.117 | 0.058 | 0.198 | N | N |

*TABLE 31. NOX – REGRESSION RESULTS FOR NOX (μG/L) VERSUS WEIGHTED SEDIMENT RAKING EFFORT IN PRECEDING PERIOD*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.2 | 0.216 | 0.067 | 0.108 | 0.275 | 0.344 | 0.119 | N | N | N | N | N | N |
| Intercept | 197.3 | 185.4 | 197.4 | 196.5 | 170 | 122.7 | 115.5 | N | N | N | N | N | N |
| Coefficient | 31.3 | 29.1 | 15.2 | 19.5 | 28.9 | 34.2 | 19.1 | N | N | N | N | N | N |
| *p*-value Intercept | 0.02 | 0.016 | 0.013 | 0.012 | 0.011 | 0.055 | 0.076 | N | N | N | N | N | N |
| *p*-value Coefficient | 0.195 | 0.176 | 0.469 | 0.354 | 0.12 | 0.097 | 0.329 | N | N | N | N | N | N |
| **10 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.452 | 0.253 | 0.327 | 0.316 | 0.487 | 0.51 | 0.267 | 0.186 | 0.174 | N | N | N | N |
| Intercept | 130.7 | 187.5 | 132.6 | 158.3 | 139.2 | 103.6 | 91.4 | 77.9 | 65.3 | N | N | N | N |
| Coefficient | 38.2 | 21.4 | 26.3 | 23.7 | 28.6 | 29.3 | 20.1 | 15.1 | 13.5 | N | N | N | N |
| *p*-value Intercept | 0.045 | 0.004 | 0.027 | 0.008 | 0.006 | 0.032 | 0.069 | 0.098 | 0.129 | N | N | N | N |
| *p*-value Coefficient | 0.023 | 0.115 | 0.066 | 0.072 | 0.017 | 0.02 | 0.103 | 0.185 | 0.201 | N | N | N | N |
| **14 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.608 | 0.457 | 0.426 | 0.445 | 0.505 | 0.713 | 0.542 | 0.473 | 0.454 | 0.461 | 0.547 | 0.381 | 0.367 |
| Intercept | 108.8 | 165.9 | 136.1 | 155.1 | 151.8 | 68.1 | 53.5 | 36.9 | 30.5 | 14.7 | 10.3 | 2.6 | 8.6 |
| Coefficient | 34.5 | 21.6 | 21.1 | 20.5 | 21.1 | 29.8 | 23.4 | 20 | 17.6 | 14.1 | 10.9 | 10.6 | 6.5 |
| *p*-value Intercept | 0.01 | 0 | 0.001 | 0 | 0 | 0.021 | 0.077 | 0.199 | 0.242 | 0.468 | 0.437 | 0.884 | 0.446 |
| p-value Coefficient | 0.001 | 0.008 | 0.011 | 0.009 | 0.006 | 0 | 0.003 | 0.007 | 0.008 | 0.008 | 0.002 | 0.019 | 0.022 |

*TABLE 32. AMMONIA – REGRESSION RESULTS FOR AMMONIA (µG/L) VERSUS WEIGHTED SEDIMENT RAKING EFFORT IN PRECEDING PERIOD*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.012 | 0.259 | 0.257 | 0.147 | 0.493 | 0.398 | 0.16 | N | N | N | N | N | N |
| Intercept | 42.7 | 44.4 | 43.7 | 31.8 | 28.6 | 21.1 | 22.1 | N | N | N | N | N | N |
| Coefficient | -2.2 | 9.2 | 6.8 | 7.8 | 10.1 | 7.2 | 4.2 | N | N | N | N | N | N |
| *p*-value Intercept | 0.084 | 0.031 | 0.009 | 0.158 | 0.033 | 0.071 | 0.07 | N | N | N | N | N | N |
| *p*-value Coefficient | 0.765 | 0.133 | 0.135 | 0.273 | 0.024 | 0.068 | 0.252 | N | N | N | N | N | N |
| **10 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0 | 0.085 | 0.336 | 0.084 | 0.27 | 0.324 | 0.201 | 0.171 | 0.161 | N | N | N | N |
| Intercept | 35.5 | 58.1 | 40.5 | 39.8 | 37.9 | 24.5 | 21.3 | 15.8 | 12.9 | N | N | N | N |
| Coefficient | -0.3 | 3.6 | 5.7 | 4 | 5.1 | 4.3 | 3.3 | 2.9 | 2.6 | N | N | N | N |
| *p*-value Intercept | 0.088 | 0.005 | 0.004 | 0.049 | 0.008 | 0.023 | 0.037 | 0.094 | 0.139 | N | N | N | N |
| *p*-value Coefficient | 0.949 | 0.383 | 0.062 | 0.388 | 0.101 | 0.086 | 0.167 | 0.206 | 0.221 | N | N | N | N |
| **14 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.004 | 0.235 | 0.231 | 0.068 | 0.1 | 0.425 | 0.38 | 0.372 | 0.388 | 0.447 | 0.59 | 0.364 | 0.322 |
| Intercept | 36.6 | 43.8 | 41.4 | 43.3 | 47.1 | 19.7 | 15.3 | 10.6 | 8 | 8.8 | 5.6 | 5.7 | 7.6 |
| Coefficient | -0.6 | 5.4 | 4.3 | 2.5 | 2.2 | 4.2 | 3.7 | 3.3 | 3.1 | 2.4 | 2.1 | 1.7 | 1 |
| *p*-value Intercept | 0.014 | 0.004 | 0.001 | 0.004 | 0 | 0.011 | 0.026 | 0.076 | 0.129 | 0.023 | 0.032 | 0.075 | 0.001 |
| *p*-value Coefficient | 0.833 | 0.079 | 0.082 | 0.368 | 0.291 | 0.016 | 0.019 | 0.021 | 0.017 | 0.009 | 0.001 | 0.022 | 0.034 |

*Table 33. Enterococci – Regression results for Enterococci (cfu/100mL) versus weighted sediment raking effort in preceding period*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **7 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.124 | 0.079 | 0.109 | 0.008 | 0.003 | 0.036 | 0.002 | N | N | N | N | N | N |
| Intercept | 594.2 | 942.3 | 904.7 | 209.7 | 79 | 30.4 | 26.9 | N | N | N | N | N | N |
| Coefficient | -137.8 | -182.8 | -192.5 | -13.8 | 3 | 5.5 | -1 | N | N | N | N | N | N |
| *p*-value Intercept | 0.175 | 0.203 | 0.17 | 0.252 | 0.188 | 0.349 | 0.316 | N | N | N | N | N | N |
| *p*-value Coefficient | 0.319 | 0.431 | 0.352 | 0.809 | 0.872 | 0.597 | 0.902 | N | N | N | N | N | N |
| **10 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.055 | 0.06 | 0.048 | 0 | 0.035 | 0.069 | N | N | N | N | N | N | N |
| Intercept | 414.2 | 810.3 | 651.4 | 172.4 | 58.8 | 34.1 | N | N | N | N | N | N | N |
| Coefficient | -61.8 | -106.9 | -86.3 | -1.6 | 6.6 | 2.7 | N | N | N | N | N | N | N |
| *p*-value Intercept | 0.258 | 0.185 | 0.236 | 0.251 | 0.232 | 0.029 | N | N | N | N | N | N | N |
| *p*-value Coefficient | 0.489 | 0.468 | 0.518 | 0.966 | 0.58 | 0.437 | N | N | N | N | N | N | N |
| **14 days weighted raking effort** | | | | | | | | | | | | | |
| $R^2$ | 0.013 | 0.012 | 0.005 | 0.021 | 0.121 | 0.204 | 0.043 | N | N | N | N | N | N |
| Intercept | 236.5 | 490.4 | 353.1 | 105.7 | 37.8 | 15.1 | 12.9 | N | N | N | N | N | N |
| Coefficient | -19.6 | -31.9 | -18.8 | 10.4 | 8.7 | 6.1 | 2.1 | N | N | N | N | N | N |
| *p*-value Intercept | 0.307 | 0.207 | 0.311 | 0.265 | 0.232 | 0.353 | 0.343 | N | N | N | N | N | N |
| *p*-value Coefficient | 0.7 | 0.706 | 0.806 | 0.618 | 0.223 | 0.105 | 0.479 | N | N | N | N | N | N |

## A1.1. Effects of sediment raking relative to flow – Regression models

*TABLE 34. SEDIMENTS (TSS AND TURBIDITY) - IMPACTS OF FLOW RELATIVE TO SEDIMENT RAKING EFFORT IN PAST 2 WEEKS*

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TSS** | | | | | | | | | | | | | |
| $R^2$ | 0.091 | 0.163 | 0.341 | 0.197 | 0.184 | 0.484 | 0.679 | 0.044 | 0.162 | N | N | N | N |
| Sig F | 0.591 | 0.375 | 0.101 | 0.299 | 0.362 | 0.036 | 0.002 | 0.78 | 0.377 | N | N | N | N |
| Intercept | 13.9 | 32.12 | 45.09 | 34.46 | 25.98 | 9.91 | 5.27 | 6.31 | 7.56 | N | N | N | N |
| Weighted sediment raking days in previous 2 weeks | 0.74 | 3.73 | 3.92 | 3.25 | 3.46 | 2.47 | 0.88 | 0.31 | -0.3 | N | N | N | N |
| Flow in previous fortnight | 0.027 | -0.048 | -0.168 | -0.168 | 0.006 | -0.011 | 0.028 | 0.004 | 0.02 | N | N | N | N |
| *p*-value Intercept | 0.008 | 0.014 | 0 | 0.007 | 0.038 | 0.018 | 0 | 0.013 | 0 | N | N | N | N |
| *p*-value Weighted sediment raking effort | 0.466 | 0.171 | 0.06 | 0.208 | 0.178 | 0.013 | 0.004 | 0.54 | 0.331 | N | N | N | N |
| *p*-value Flow | 0.627 | 0.731 | 0.125 | 0.227 | 0.958 | 0.809 | 0.055 | 0.886 | 0.226 | N | N | N | N |
| **Turbidity** | | | | | | | | | | | | | |
| $R^2$ | 0.014 | 0.247 | 0.046 | 0.054 | 0.07 | 0.693 | 0.795 | 0.726 | 0.886 | 0.699 | 0.739 | 0.006 | 0.632 |
| Sig F | 0.926 | 0.21 | 0.772 | 0.757 | 0.697 | 0.009 | 0.001 | 0.002 | 0 | 0.001 | 0.001 | 0.966 | 0.004 |
| Intercept | 23.29 | 24.97 | 34.4 | 32.03 | 23.97 | 3.4 | 3.07 | 2.21 | 1.92 | 2.01 | 1.82 | 3.23 | 2.02 |
| Weighted sediment raking days in previous 2 weeks | 0.2 | 5.17 | -2.22 | 2.26 | 1.93 | 2.19 | 0.6 | 0.32 | 0.3 | 0.19 | 0.17 | 0.09 | 0.08 |
| Flow in previous fortnight | 0.048 | -0.021 | 0.032 | -0.014 | 0.035 | 0.039 | 0.033 | 0.027 | 0.027 | 0.009 | 0.012 | -0.001 | 0.011 |
| *p*-value Intercept | 0.058 | 0.062 | 0.024 | 0.025 | 0.072 | 0.219 | 0.002 | 0.003 | 0 | 0 | 0 | 0.047 | 0 |
| *p*-value Weighted sediment raking effort | 0.94 | 0.089 | 0.482 | 0.477 | 0.477 | 0.008 | 0.006 | 0.036 | 0.003 | 0.007 | 0.014 | 0.799 | 0.213 |
| *p*-value Flow | 0.731 | 0.893 | 0.85 | 0.927 | 0.795 | 0.266 | 0.005 | 0.004 | 0 | 0.017 | 0.003 | 0.96 | 0.004 |

*Table 35. Phosphorus (TP and DRP) - Impacts of flow relative to sediment raking effort in past 2 weeks*

| Parameter | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TP** | | | | | | | | | | | | | |
| $R^2$ | 0.129 | 0.165 | 0.15 | 0.257 | 0.172 | 0.43 | 0.397 | 0.732 | 0.087 | 0.321 | 0.157 | 0.156 | 0.128 |
| Sig F | 0.467 | 0.371 | 0.41 | 0.195 | 0.39 | 0.06 | 0.062 | 0.001 | 0.605 | 0.119 | 0.39 | 0.393 | 0.472 |
| Intercept | 45.45 | 73.88 | 112.45 | 79.02 | 52.08 | 32.37 | 29.51 | 23.47 | 28.13 | 27.03 | 26.64 | 27.7 | 28.07 |
| Weighted sediment raking days in previous 2 weeks | 2.43 | 6.93 | 0.93 | 6.57 | 4.84 | 3.41 | 0.53 | 0.97 | -0.08 | 1.48 | 0.91 | 1.1 | 0.98 |
| Flow in previous fortnight | -0.028 | -0.145 | -0.31 | -0.229 | 0.033 | 0 | 0.047 | 0.147 | 0.051 | -0.035 | 0.024 | -0.035 | -0.033 |
| *p*-value Intercept | 0 | 0.004 | 0 | 0 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *p*-value Weighted sediment raking effort | 0.229 | 0.171 | 0.827 | 0.097 | 0.207 | 0.025 | 0.256 | 0.13 | 0.935 | 0.046 | 0.284 | 0.203 | 0.258 |
| *p*-value Flow | 0.792 | 0.583 | 0.194 | 0.266 | 0.859 | 1 | 0.071 | 0.001 | 0.335 | 0.341 | 0.593 | 0.445 | 0.477 |
| **DRP** | | | | | | | | | | | | | |
| $R^2$ | 0.123 | 0.058 | 0.066 | 0.158 | 0.256 | 0.11 | 0.484 | 0.489 | 0.504 | 0.678 | 0.68 | 0.541 | 0.419 |
| Sig F | 0.485 | 0.719 | 0.689 | 0.389 | 0.228 | 0.558 | 0.026 | 0.025 | 0.021 | 0.002 | 0.002 | 0.014 | 0.05 |
| Intercept | 12.71 | 16.06 | 11.69 | 11.36 | 10.76 | 10.3 | 7.99 | 6.5 | 6.12 | 4.13 | 4.46 | 4.46 | 5.19 |
| Weighted sediment raking days in previous 2 weeks | 0.78 | -0.38 | 0.33 | 0.56 | 0.47 | 1.11 | 0.82 | 0.95 | 0.9 | 1.1 | 0.93 | 0.63 | 0.62 |
| Flow in previous fortnight | 0.014 | -0.007 | -0.009 | 0.001 | 0.022 | 0.054 | 0.024 | 0.024 | 0.026 | 0.027 | 0.018 | 0.027 | 0.016 |
| *p*-value Intercept | 0.002 | 0 | 0 | 0 | 0 | 0.16 | 0 | 0.002 | 0.002 | 0.007 | 0.001 | 0.002 | 0.001 |
| *p*-value Weighted sediment raking effort | 0.312 | 0.504 | 0.412 | 0.197 | 0.257 | 0.501 | 0.031 | 0.026 | 0.027 | 0.003 | 0.002 | 0.035 | 0.047 |
| *p*-value Flow | 0.738 | 0.807 | 0.674 | 0.976 | 0.296 | 0.537 | 0.214 | 0.257 | 0.19 | 0.105 | 0.168 | 0.079 | 0.316 |

*TABLE 36. NITROGEN (TN, NOX AND AMMONIA) - IMPACTS OF FLOW RELATIVE TO SEDIMENT RAKING EFFORT IN PAST 2 WEEKS*

| Parameter | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TN** | | | | | | | | | | | | | |
| $R^2$ | 0.717 | 0.121 | 0.45 | 0.495 | 0.453 | 0.759 | 0.784 | 0.661 | 0.719 | 0.637 | 0.411 | 0.511 | 0.271 |
| Sig F | 0.001 | 0.491 | 0.037 | 0.023 | 0.049 | 0.001 | 0 | 0.003 | 0.001 | 0.004 | 0.054 | 0.019 | 0.175 |
| Intercept | 401.17 | 600.22 | 620.36 | 515.53 | 423.69 | 277.74 | 272.67 | 266.42 | 263.38 | 266.99 | 285.27 | 258.2 | 256.5 |
| Weighted sediment raking days in previous 2 weeks | 48.78 | 21.49 | 43.42 | 51.63 | 48.28 | 46.59 | 24.88 | 14.43 | 9.33 | 9.31 | 3.21 | 5.52 | 3.61 |
| Flow in previous fortnight | 0.634 | 0.976 | 0.558 | 0.47 | 0.926 | 1.046 | 1.481 | 1.571 | 1.609 | 0.914 | 0.432 | 0.646 | 0.318 |
| *p*-value Intercept | 0 | 0 | 0 | 0 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *p*-value Weighted sediment raking effort | 0.001 | 0.436 | 0.022 | 0.012 | 0.035 | 0.001 | 0.004 | 0.1 | 0.183 | 0.092 | 0.381 | 0.238 | 0.38 |
| *p*-value Flow | 0.285 | 0.511 | 0.54 | 0.624 | 0.373 | 0.086 | 0.002 | 0.004 | 0.001 | 0.007 | 0.044 | 0.02 | 0.163 |
| **NOx** | | | | | | | | | | | | | |
| $R^2$ | 0.652 | 0.599 | 0.613 | 0.594 | 0.647 | 0.83 | 0.751 | 0.713 | 0.886 | 0.742 | 0.761 | 0.794 | 0.691 |
| Sig F | 0.003 | 0.007 | 0.005 | 0.007 | 0.005 | 0 | 0 | 0.001 | 0 | 0.001 | 0 | 0 | 0.002 |
| Intercept | 102.83 | 158.17 | 127.14 | 147.51 | 143.9 | 60.21 | 44.2 | 27.79 | 1.92 | 7.65 | 5.9 | -4.52 | 4.72 |
| Weighted sediment raking days in previous 2 weeks | 31.95 | 18.26 | 17.24 | 17.19 | 18.45 | 26.3 | 19.35 | 16.02 | 0.3 | 11.02 | 9.03 | 7.55 | 4.79 |
| Flow in previous fortnight | 0.521 | 0.677 | 0.786 | 0.665 | 0.576 | 0.673 | 0.815 | 0.799 | 0.027 | 0.618 | 0.384 | 0.621 | 0.342 |
| *p*-value Intercept | 0.015 | 0 | 0.001 | 0 | 0 | 0.015 | 0.065 | 0.216 | 0 | 0.604 | 0.56 | 0.679 | 0.571 |
| *p*-value Weighted sediment raking effort | 0.002 | 0.015 | 0.02 | 0.017 | 0.009 | 0 | 0.002 | 0.007 | 0.003 | 0.007 | 0.002 | 0.01 | 0.026 |
| *p*-value Flow | 0.264 | 0.073 | 0.042 | 0.07 | 0.072 | 0.026 | 0.011 | 0.011 | 0 | 0.005 | 0.009 | 0.001 | 0.006 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ammonia** | | | | | | | | | | | | | |
| $R^2$ | 0.027 | 0.273 | 0.29 | 0.086 | 0.12 | 0.45 | 0.49 | 0.611 | 0.684 | 0.727 | 0.78 | 0.758 | 0.516 |
| Sig F | 0.858 | 0.173 | 0.152 | 0.611 | 0.529 | 0.05 | 0.025 | 0.006 | 0.002 | 0.001 | 0 | 0 | 0.019 |
| Intercept | 37.55 | 42.35 | 39.98 | 44.1 | 47.79 | 19.05 | 14.05 | 8.94 | 6.32 | 7.6 | 4.81 | 4.54 | 7.07 |
| Weighted sediment raking days in previous 2 weeks | -0.19 | 4.77 | 3.71 | 2.9 | 2.43 | 3.87 | 3.12 | 2.54 | 2.31 | 1.84 | 1.81 | 1.21 | 0.78 |
| Flow in previous fortnight | -0.086 | 0.122 | 0.122 | -0.072 | -0.05 | 0.057 | 0.111 | 0.147 | 0.149 | 0.105 | 0.068 | 0.1 | 0.043 |
| *p*-value Intercept | 0.017 | 0.007 | 0.002 | 0.005 | 0.001 | 0.017 | 0.033 | 0.075 | 0.119 | 0.011 | 0.021 | 0.035 | 0.001 |
| *p*-value Weighted sediment raking effort | 0.952 | 0.135 | 0.145 | 0.341 | 0.278 | 0.033 | 0.039 | 0.034 | 0.021 | 0.009 | 0.001 | 0.018 | 0.066 |
| *p*-value Flow | 0.616 | 0.461 | 0.36 | 0.654 | 0.65 | 0.512 | 0.151 | 0.025 | 0.008 | 0.006 | 0.011 | 0.001 | 0.06 |

*TABLE 37. ENTEROCOCCI - IMPACTS OF FLOW RELATIVE TO SEDIMENT RAKING EFFORT IN PAST 2 WEEKS*

| Parameter | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T9 | T10 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R^2$ | 0.03 | 0.039 | 0.033 | 0.08 | 0.176 | 0.313 | 0.045 | N | N | N | N | N | N |
| Sig F | 0.846 | 0.803 | 0.831 | 0.63 | 0.38 | 0.153 | 0.776 | N | N | N | N | N | N |
| Intercept | 251.09 | 520.63 | 381.07 | 116.76 | 54.85 | 17.69 | 12.52 | N | N | N | N | N | N |
| Weighted sediment raking days in previous 2 weeks | -13.26 | -18.75 | -6.64 | 15.18 | 8.63 | 7.58 | 1.99 | N | N | N | N | N | N |
| Flow in previous fortnight | -1.277 | -2.644 | -2.439 | -0.968 | -0.441 | -0.142 | 0.029 | N | N | N | N | N | N |
| *p*-value Intercept | 0.302 | 0.201 | 0.296 | 0.233 | 0.145 | 0.274 | 0.381 | N | N | N | N | N | N |
| *p*-value Weighted sediment raking effort | 0.809 | 0.836 | 0.935 | 0.491 | 0.283 | 0.059 | 0.542 | N | N | N | N | N | N |
| *p*-value Flow | 0.667 | 0.59 | 0.584 | 0.418 | 0.274 | 0.473 | 0.87 | N | N | N | N | N | N |

## Appendix 3 Raw water quality results: Seaport Marina prop washing May-June 2019

Table 7 Field data and observations

| Site | Sampling Date | Sampling Time | Electrical conductivity us/cm | pH | Turbidity NTU | Dissolved Oxygen mg/L | Dissolved Oxygen % saturation | Temperature C | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Downstream: 1st Tamar Pontoon | 14/05/2019 | 13:20 | 529 | 7.0 | 170 | 8.56 | 78.3 | 11.4 | Prop washing at Seaport Marina |
| | 14/05/2019 | 13:40 | 395 | 7.2 | 126 | 8.78 | 79.7 | 12.9 | |
| | 14/05/2019 | 13:55 | 354 | 7.1 | 150 | 9.01 | 80.3 | 12.3 | |
| | 14/05/2019 | 14:10 | 310 | 7.1 | 148 | 8.96 | 79.9 | 12.6 | |
| Upstream: Charles St Bridge | 14/05/2019 | 14:20 | 286 | 7.1 | 81 | 9.16 | 82.3 | 12.0 | |
| Downstream: 1st Tamar Pontoon | 15/05/2019 | 13:55 | 156 | 7.0 | 104 | 9.33 | 84.0 | 13.5 | Prop washing at Seaport Marina; NRM North conducting EHAP monitoring - observed sediment plume to Hunters Cut |
| | 15/05/2019 | 14:10 | 134 | 7.2 | 58 | 9.78 | 85.8 | 11.1 | |
| | 15/05/2019 | 14:25 | 121 | 7.1 | 106 | 9.77 | 85.7 | 12.9 | |
| | 15/05/2019 | 14:40 | 114 | 7.1 | 116 | 9.80 | 86.1 | 12.1 | |
| Upstream: Charles St Bridge | 15/05/2019 | 14:55 | 106 | 7.3 | 51 | 9.70 | 86.4 | 10.7 | |
| Downstream: 1st Tamar Pontoon | 16/05/2019 | 13:40 | 605 | 7.1 | 104 | 9.30 | 83.2 | 11.0 | Prop washing at Seaport Marina |
| | 16/05/2019 | 13:55 | 568 | 7.3 | 77 | 9.29 | 83.1 | 10.6 | |
| | 16/05/2019 | 14:10 | 588 | 7.1 | 112 | 9.30 | 81.2 | 10.2 | |
| | 16/05/2019 | 14:25 | 560 | 7.1 | 115 | 9.47 | 83.9 | 10.1 | |
| Upstream: Charles St Bridge | 16/05/2019 | 14:35 | 452 | 7.2 | 69 | 9.68 | 85.3 | 10.5 | |
| Downstream: 1st Tamar Pontoon | 17/05/2019 | 14:35 | 717 | 7.1 | 88 | 9.10 | 81.4 | 10.9 | Prop washing at Seaport Marina |
| | 17/05/2019 | 14:50 | 713 | 7.2 | 79 | 9.18 | 80.9 | 10.5 | |
| | 17/05/2019 | 15:05 | 649 | 7.1 | 120 | 8.81 | 77.4 | 10.4 | |
| | 17/05/2019 | 15:20 | 583 | 7.1 | 75 | 9.52 | 83.5 | 10.3 | |
| Upstream: Charles St Bridge | 17/05/2019 | 15:28 | 559 | 7.2 | 61 | 9.50 | 83.9 | 10.6 | |
| Downstream: 1st Tamar Pontoon | 18/05/2019 | 16:58 | 794 | | 64 | | | | Not prop washing |
| Upstream: Charles St Bridge | 18/05/2019 | 16:50 | 767 | | 62 | | | | |
| Downstream: 1st Tamar Pontoon | 24/05/2019 | 9:10 | 1169 | 7.2 | 55 | 9.33 | 83.2 | 10.6 | Not prop washing yet |
| | 24/05/2019 | 9:25 | 1128 | 7.3 | 63 | 9.26 | 82.4 | 10.5 | |
| | 24/05/2019 | 9:40 | 1026 | 7.3 | 85 | 9.22 | 82.0 | 10.4 | |
| Downstream: 1st Tamar Pontoon | 24/05/2019 | 9:55 | 898 | 7.3 | 257 | 9.06 | 80.5 | 10.4 | Prop washing at Seaport Marina |
| | 24/05/2019 | 10:25 | 547 | 7.3 | 141 | 9.29 | 83.0 | 10.2 | |
| | 24/05/2019 | 10:40 | 495 | 7.5 | 142 | 9.19 | 82.6 | 10.8 | |
| | 24/05/2019 | 10:55 | 443 | | 178 | 9.15 | 82.2 | 10.8 | |
| Upstream: Charles St Bridge | 24/05/2019 | 10:10 | 543 | 7.5 | 63 | 9.35 | 83.1 | 10.4 | |
| Downstream: 1st Tamar Pontoon | 25/05/2019 | 11:15 | 517 | 6.9 | 79 | 9.28 | 84.4 | 10.9 | Prop washing at Seaport Marina |
| | 25/05/2019 | 11:30 | 408 | 7.3 | 90 | 9.31 | 83.9 | 10.6 | |

| Site | Sampling Date | Sampling Time | Electrical conductivity us/cm | pH | Turbidity NTU | Dissolved Oxygen mg/L | Dissolved Oxygen % saturation | Temperature C | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | 25/05/2019 | 11:45 | 374 | 7.3 | 86 | 9.32 | 84.0 | 11.1 | |
| | 25/05/2019 | 12:00 | 358 | 7.3 | 87 | 9.21 | 83.1 | 10.6 | |
| Upstream: Charles St Bridge | 25/05/2019 | 10:40 | 589 | 7.0 | 60 | 9.35 | 85.6 | 11.0 | |
| Downstream: 1st Tamar Pontoon | 26/05/2019 | 11:30 | 526 | 7.5 | 112 | 9.19 | 83.2 | 10.8 | Prop washing at Seaport Marina; many birds on mudflats & foraging |
| | 26/05/2019 | 11:45 | 470 | 7.3 | 160 | 9.14 | 82.5 | 10.5 | |
| | 26/05/2019 | 12:00 | 402 | 7.3 | 99 | 9.28 | 83.7 | 10.6 | |
| | 26/05/2019 | 12:15 | 361 | 7.3 | 118 | 9.16 | 82.8 | 11.0 | |
| Upstream: Charles St Bridge | 26/05/2019 | 11:10 | 536 | 7.5 | 58 | 9.32 | 84.7 | 10.9 | |
| Downstream: 1st Tamar Pontoon | 27/05/2019 | 12:20 | 255 | 6.9 | 71 | 9.58 | 86.4 | 10.2 | Prop washing at Seaport Marina |
| | 27/05/2019 | 12:35 | 249 | 7.3 | 118 | 9.69 | 87.0 | 10.0 | |
| | 27/05/2019 | 12:50 | 232 | 7.3 | 33 | 9.65 | 86.7 | 10.0 | No visible plume at time of sampling |
| | 27/05/2019 | 13:05 | 224 | 7.3 | 31 | 9.66 | 86.6 | 9.9 | No visible plume at time of sampling |
| Upstream: Charles St Bridge | 27/05/2019 | 13:17 | 215 | 7.6 | 23 | 9.72 | 87.8 | 10.2 | Almost slack tide |
| Downstream: 1st Tamar Pontoon | 27/05/2019 | 12:27 | | | 188 | | | | Visible plume |
| Downstream: 1st Tamar Pontoon | 27/05/2019 | 12:40 | | | 98 | | | | Visible plume |
| Downstream: 1st Tamar Pontoon | 27/05/2019 | 12:55 | | 7.3 | 114 | 9.26 | 83.2 | 10.0 | Visible plume |
| Downstream: 1st Tamar Pontoon | 10/06/2019 | 10:20 | 3500 | 7.2 | 53 | 9.81 | 84.8 | 8.2 | Prop washing at Seaport Marina |
| | 10/06/2019 | 10:35 | 3420 | 7.5 | 82 | 9.68 | 82.5 | 8.3 | |
| | 10/06/2019 | 10:50 | 3250 | 7.5 | 75 | 9.74 | 83.1 | 8.2 | |
| | 10/06/2019 | 11:05 | 3050 | 7.5 | 63 | 9.98 | 84.8 | 8.3 | |
| Upstream: Charles St Bridge | 10/06/2019 | 11:20 | 2040 | 7.5 | 59 | | | 8.2 | DO probe failed |
| Downstream: 1st Tamar Pontoon | 11/06/2019 | 10:08 | 1555 | 7.4 | 84 | 9.82 | 83.6 | 8.6 | Moving boats in marina |
| | 11/06/2019 | 10:23 | 1196 | 7.3 | 92 | 10.11 | 84.4 | 8.2 | Prop washing started 10:23 |
| | 11/06/2019 | 10:38 | 1088 | 7.3 | 100 | 9.83 | 83.6 | 10.9 | 2nd plum |
| | 11/06/2019 | 10:53 | 682 | 7.4 | 97 | 9.90 | 84.0 | 11.4 | |
| Upstream: Charles St Bridge | 11/06/2019 | 11:02 | 476 | 7.7 | 59 | 10.06 | 85.5 | 8.4 | |
| Downstream: 1st Tamar Pontoon | 11/06/2019 | 10:30 | | | 250 | | | | Visible plume |
| Downstream: 1st Tamar Pontoon | 11/06/2019 | 10:31 | | | 269 | | | | Visible plume |
| Downstream: 1st Tamar Pontoon | 11/06/2019 | 10:32 | | | 184 | | | | Visible plume |
| Downstream: 1st Tamar Pontoon | 12/06/2019 | 11:31 | 433 | 7.4 | 104 | 10.08 | 88.5 | 9.2 | Prop washing |
| | 12/06/2019 | 11:46 | 324 | 7.3 | 92 | 10.43 | 89.3 | 9.0 | |
| | 12/06/2019 | 10:01 | 254 | 7.3 | 121 | 10.31 | 88.3 | 8.7 | |
| | 12/06/2019 | 12:16 | | 7.2 | 125 | 10.21 | 87.4 | 8.5 | Lost EC probe overboard |
| Upstream: Charles St Bridge | 12/06/2019 | 12:45 | | 7.3 | 54 | 10.35 | 89.4 | 8.9 | |
| Downstream: 1st Tamar Pontoon | 13/06/2019 | 13:00 | 110 | 6.8 | 88 | 10.40 | 91.5 | 8.9 | Heavy afternoon & evening rain >20mm |

| Site | Sampling Date | Sampling Time | Electrical conductivity us/cm | pH | Turbidity NTU | Dissolved Oxygen mg/L | Dissolved Oxygen % saturation | Temperature C | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | 13/06/2019 | 13:15 | 106 | 7.3 | 78 | 10.66 | 92.2 | 8.9 | |
| | 13/06/2019 | 13:30 | 104 | 7.3 | 80 | 10.56 | 91.3 | 8.9 | |
| | 13/06/2019 | 13:45 | 109 | 7.2 | 205 | 10.44 | 90.8 | 8.9 | Raining |
| Upstream: Charles St Bridge | 13/06/2019 | 13:58 | 104 | 7.4 | 98 | 10.61 | 92.5 | 8.9 | Raining, river turbid |
| Downstream: 1st Tamar Pontoon | 13/06/2019 | 13:06 | | | 216 | | | | Visible plume |
| Downstream: 1st Tamar Pontoon | 14/06/2019 | 13:40 | 87 | 6.5 | 54 | 10.67 | 91.9 | 8.8 | Prop washing at Seaport Marina |
| | 14/06/2019 | 14:15 | 79 | 7.1 | 74 | 10.81 | 91.7 | 8.2 | |
| | 14/06/2019 | 14:30 | 83 | 7.1 | 130 | 10.42 | 88.4 | 8.2 | |
| | 14/06/2019 | 14:50 | 78 | 7.2 | 331 | 10.78 | 91.4 | 8.2 | |
| Upstream: Charles St Bridge | 14/06/2019 | 14:55 | 77 | 7.2 | 57 | 10.95 | 93.4 | 8.4 | |
| Downstream: 1st Tamar Pontoon | 14/06/2019 | 14:45 | 76 | 7.1 | 72 | 10.98 | 93.0 | 8.1 | |
| Downstream: 1st Tamar Pontoon | 15/06/2019 | 13:55 | 101 | 7.2 | 40 | 10.60 | 83.3 | 8.0 | |
| Downstream: 1st Tamar Pontoon | 15/06/2019 | 14:10 | 103 | 7.2 | 62 | 10.69 | 89.8 | 8.0 | |
| Downstream: 1st Tamar Pontoon | 15/06/2019 | 14:25 | 97 | 7.2 | 43 | 10.70 | 90.0 | 8.0 | |
| Downstream: 1st Tamar Pontoon | 15/06/2019 | 14:45 | 95 | | 34 | 10.82 | 90.4 | 7.9 | 15 minutes after the start of prop washing |
| | 15/06/2019 | 15:00 | 93 | | 39 | 10.51 | 86.9 | 7.9 | |
| | 15/06/2019 | 15:15 | 93 | 7.1 | 61 | 10.84 | 90.5 | 7.8 | |
| | 15/06/2019 | 15:30 | 96 | 7.1 | 95 | 10.72 | 89.4 | 7.8 | |
| Upstream: Charles St Bridge | 15/06/2019 | 15:45 | 87 | 7.2 | 31 | 10.99 | 91.4 | 7.8 | |
| Downstream: 1st Tamar Pontoon | 16/06/2019 | 14:30 | 116 | 6.0 | 64 | 10.49 | 88.2 | 7.8 | Not prop washing yet; pH seems unusually low |
| Downstream: 1st Tamar Pontoon | 16/06/2019 | 14:45 | 118 | 6.0 | 51 | 10.60 | 88.1 | 7.8 | Not prop washing yet; pH seems unusually low |
| Downstream: 1st Tamar Pontoon | 16/06/2019 | 15:10 | 113 | 6.0 | 76 | 10.67 | 88.4 | 7.7 | Prop wash start 15:00; pH seems unusually low |
| | 16/06/2019 | 15:25 | 111 | 6.0 | 218 | 10.34 | 85.4 | 7.6 | pH seems unusually low |
| | 16/06/2019 | 15:40 | 107 | 6.0 | 151 | 10.54 | 87.0 | 7.5 | pH seems unusually low |
| | 16/06/2019 | 15:55 | 105 | 6.0 | 174 | 10.63 | 87.6 | 7.5 | pH seems unusually low |
| Upstream: Charles St Bridge | 16/06/2019 | 16:02 | 96 | 6.1 | 45 | 11.01 | 90.7 | 7.2 | pH seems unusually low |
| Downstream: 1st Tamar Pontoon | 17/06/2019 | 16:35 | 123 | 6.9 | 93 | 10.49 | 87.9 | 7.7 | Prop washing at Seaport Marina |
| | 17/06/2019 | 16:50 | 124 | 7.2 | 82 | 10.47 | 86.8 | 7.6 | |
| | 17/06/2019 | 17:05 | 122 | 7.3 | 86 | 10.65 | 87.8 | 7.4 | |
| | 17/06/2019 | 17:20 | 109 | 7.3 | 56 | 10.87 | 89.3 | 7.3 | |
| Upstream: Charles St Bridge | 17/06/2019 | 17:30 | 103 | 7.2 | 37 | 10.97 | 90.6 | 7.2 | |

Table 8 Suspended sediments and nutrient concentrations

| Sample date | Daily rainfall (mm) | Total Suspended Sediment (mg/L) | | Total Nitrogen (mg/L) | | Total Phosphorus (mg/L) | | Nitrate (mg/L) | | Nitrite (mg/L) | | Ammonia (mg/L) | | Dissolved Reactive Phosphorus (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CSB | 1TP | CSB | 1TP | CSB | 1TP | CSB | 1TP | CSB | 1TP | CSB | 1TP | CSB | 1TP |
| 14-May | 1.8 | 91 | 199 | 1.20 | 1.30 | 0.23 | 0.23 | 0.35 | 0.33 | 0.007 | 0.006 | 0.09 | 0.15 | 0.008 | 0.019 |
| 15-May | 0 | 61 | 138 | 0.83 | 1.20 | 0.14 | 0.28 | 0.19 | 0.21 | 0.003 | 0.003 | 0.036 | 0.064 | 0.012 | 0.012 |
| 16-May | 0 | 56 | 94 | 0.91 | 0.98 | 0.14 | 0.15 | 0.24 | 0.23 | 0.004 | 0.005 | 0.075 | 0.12 | 0.008 | 0.014 |
| 17-May | 0.3 | 64 | 170 | 0.84 | 1.40 | 0.13 | 0.3 | 0.24 | 0.24 | 0.005 | 0.005 | 0.086 | 0.15 | 0.006 | 0.011 |
| 24-May | 0 | 72 | 202 | 0.82 | 1.40 | 0.15 | 0.28 | 0.21 | 0.24 | 0.005 | 0.005 | 0.074 | 0.16 | 0.007 | 0.015 |
| 25-May | 12.4 | 62 | 112 | 0.90 | 1.20 | 0.14 | 0.22 | 0.34 | 0.33 | 0.006 | 0.006 | 0.13 | 0.094 | 0.018 | 0.014 |
| 26-May | 0.4 | 61 | 177 | 0.95 | 1.60 | 0.14 | 0.35 | 0.37 | 0.35 | 0.008 | 0.008 | 0.095 | 0.13 | 0.014 | 0.023 |
| 27-May | 9.8 | 21 | 70 | 0.62 | 0.87 | 0.08 | 0.15 | 0.25 | 0.26 | 0.006 | 0.007 | 0.056 | 0.079 | 0.027 | 0.021 |
| 10-Jun | 8.5 | 59 | 97 | 1.00 | 0.75 | 0.13 | 0.16 | 0.38 | 0.035 | 0.006 | 0.006 | 0.15 | 0.15 | 0.020 | 0.008 |
| 11-Jun | 9 | 78 | 113 | 0.98 | 1.30 | 0.17 | 0.22 | 0.035 | 0.042 | 0.007 | 0.008 | 0.082 | 0.13 | 0.033 | 0.016 |
| 12-Jun | 0.4 | 48 | 117 | 1.10 | 1.40 | 0.11 | 0.19 | 0.39 | 0.38 | 0.004 | 0.005 | 0.046 | 0.069 | 0.011 | 0.009 |
| 13-Jun | 24.8 | 105 | 216 | 1.50 | 1.80 | 0.17 | 0.29 | 0.41 | 0.42 | 0.005 | 0.005 | 0.37 | 0.053 | 0.013 | 0.011 |
| 14-Jun | 2.5 | 42 | 71 | 0.98 | 0.93 | 0.08 | 0.16 | 0.43 | 0.15 | 0.004 | <0.002 | 0.029 | 0.053 | 0.013 | 0.006 |
| 15-Jun | 0.3 | 36 | 64 | 0.77 | 0.95 | 0.04 | 0.09 | 0.41 | 0.41 | 0.003 | 0.004 | 0.031 | 0.062 | 0.010 | 0.009 |
| 16-Jun | 0 | 42 | 199 | 0.83 | 1.50 | 0.09 | 0.22 | 0.42 | 0.48 | 0.004 | 0.006 | 0.038 | 0.099 | 0.014 | 0.01 |
| 17-Jun | 0 | 30 | 84 | 0.90 | 1.20 | 0.08 | 0.13 | 0.44 | 0.51 | 0.005 | 0.007 | 0.048 | 0.072 | 0.016 | 0.013 |

Table 9 Total metals

| Site | | Total metals (ug/L) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date | Al | As | Ba | Ca | Cd | Co | Cr | Cu | Fe | K | Mg | Mn | Mo | Na | Ni | Pb | Se | Zn |
| Downstream: 1st Tamar Pontoon | 14/05/2019 | 4930 | 4 | 16 | 4850 | 0.2 | 4 | 13 | 12 | 9190 | 2590 | 8050 | 330 | <0.5 | 52400 | 6.6 | 10.2 | <2 | 57 |
| | 15/05/2019 | 3620 | 3 | 15 | 3760 | 0.2 | 3.1 | 9 | 9 | 6670 | 1150 | 3900 | 245 | <0.5 | 14900 | 4.7 | 8.5 | <2 | 38 |
| | 16/05/2019 | 2480 | 2 | 9 | 5710 | 0.1 | 1.9 | 6 | 6 | 4190 | 3630 | 10900 | 186 | <0.5 | 84700 | 3.3 | 3.6 | <2 | 26 |
| | 17/05/2019 | 4210 | 4 | 15 | 6000 | 0.2 | 3.5 | 11 | 11 | 7710 | 3950 | 11500 | 282 | <0.5 | 94900 | 5.6 | 6.6 | <2 | 50 |
| | 24/05/2019 | 4890 | 4 | 17 | 6170 | 0.2 | 3.9 | 12 | 12 | 8930 | 3470 | 11100 | 325 | <0.5 | 85200 | 7.1 | 7.3 | <2 | 56 |
| | 25/05/2019 | 3150 | 3 | 10 | 5470 | 0.1 | 2.3 | 8 | 7 | 5390 | 2640 | 8640 | 213 | <0.5 | 53400 | 4.3 | 4.1 | <2 | 32 |
| | 26/05/2019 | 4390 | 4 | 16 | 5870 | 0.2 | 3.8 | 11 | 11 | 8220 | 2780 | 9380 | 285 | <0.5 | 58600 | 6.2 | 6.8 | <2 | 54 |
| | 27/05/2019 | 2110 | 2 | 11 | 5320 | <0.1 | 1.7 | 5 | 5 | 3550 | 1730 | 6200 | 136 | <0.5 | 29000 | 3 | 2.9 | <2 | 24 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10/06/2019 | 3490 | 3 | 11 | 25600 | 0.1 | 2.1 | 7 | 7 | 4980 | 20000 | 67600 | 266 | 0.7 | 553000 | 3.6 | 4.7 | <2 | 29 |
| | 11/06/2019 | 4090 | 3 | 12 | 12200 | 0.1 | 2.5 | 8 | 7 | 6190 | 7500 | 25800 | 238 | <0.5 | 191000 | 4.3 | 4.6 | <2 | 36 |
| | 12/06/2019 | 3330 | 2 | 16 | 4660 | 0.1 | 2.7 | 8 | 7 | 5220 | 2050 | 6270 | 194 | <0.5 | 36700 | 4.6 | 4.1 | <2 | 28 |
| | 13/06/2019 | 5650 | 4 | 31 | 4300 | 0.3 | 5.2 | 15 | 12 | 9930 | 1100 | 4060 | 307 | <0.5 | 10600 | 8.6 | 8.1 | <2 | 57 |
| | 14/06/2019 | 5030 | 3 | 21 | 3150 | 0.2 | 3.2 | 11 | 9 | 7070 | 1110 | 2890 | 213 | <0.5 | 8060 | 6 | 5.4 | <2 | 38 |
| | 15/06/2019 | 2620 | 2 | 13 | 3420 | 0.1 | 1.8 | 6 | 5 | 3920 | 960 | 3020 | 142 | <0.5 | 9740 | 3.4 | 3.2 | <2 | 22 |
| | 16/06/2019 | 5170 | 4 | 21 | 3900 | 0.3 | 3.8 | 13 | 11 | 8440 | 1260 | 3660 | 246 | <0.5 | 11400 | 6.9 | 7.4 | <2 | 49 |
| | 17/06/2019 | 2840 | 2 | 12 | 4170 | 0.1 | 2 | 7 | 6 | 4340 | 1230 | 3730 | 155 | <0.5 | 11900 | 3.8 | 3.5 | <2 | 24 |
| Upstream: Charles St Bridge | 14/05/2019 | 1970 | 2 | 7 | 4450 | <0.1 | 1.7 | 5 | 5 | 3780 | 2050 | 6350 | 180 | <0.5 | 35600 | 2.7 | 3.1 | <2 | 23 |
| | 15/05/2019 | 2050 | 2 | 10 | 3550 | <0.1 | 1.6 | 5 | 4 | 3530 | 920 | 3300 | 153 | <0.5 | 11300 | 2.7 | 2.8 | <2 | 17 |
| | 16/05/2019 | 1700 | 2 | 8 | 5100 | <0.1 | 1.4 | 4 | 4 | 2970 | 2780 | 8770 | 141 | <0.5 | 59900 | 2.2 | 2.3 | <2 | 18 |
| | 17/05/2019 | 1700 | 2 | 6 | 5480 | <0.1 | 1.3 | 4 | 4 | 2910 | 3370 | 10600 | 140 | <0.5 | 76200 | 2.3 | 2.4 | <2 | 18 |
| | 24/05/2019 | 1940 | 2 | 6 | 6020 | <0.1 | 1.3 | 5 | 4 | 3250 | 3180 | 10700 | 140 | <0.5 | 69300 | 2.5 | 2.4 | <2 | 18 |
| | 25/05/2019 | 2000 | 2 | 7 | 6230 | <0.1 | 1.5 | 5 | 4 | 3370 | 3410 | 11200 | 151 | <0.5 | 75600 | 2.7 | 2.5 | <2 | 20 |
| | 26/05/2019 | 1840 | 2 | 7 | 6160 | <0.1 | 1.4 | 5 | 4 | 3220 | 3090 | 10200 | 143 | <0.5 | 64700 | 2.6 | 2.5 | <2 | 20 |
| | 27/05/2019 | 656 | <1 | 7 | 5190 | <0.1 | 0.6 | 2 | 2 | 1200 | 1500 | 5580 | 75 | <0.5 | 24000 | 1.3 | 0.9 | <2 | 9 |
| | 10/06/2019 | 2180 | 2 | 8 | 19300 | <0.1 | 1.4 | 4 | 5 | 3100 | 14300 | 48600 | 202 | 0.5 | 393000 | 2.9 | 2.5 | <2 | 23 |
| | 11/06/2019 | 2260 | 2 | 10 | 7060 | <0.1 | 1.7 | 5 | 5 | 3710 | 2810 | 10400 | 150 | <0.5 | 59100 | 3.1 | 2.9 | <2 | 26 |
| | 12/06/2019 | 1550 | 1 | 11 | 3520 | <0.1 | 1.2 | 4 | 3 | 2340 | 1210 | 3450 | 116 | <0.5 | 15300 | 2.2 | 1.5 | <2 | 11 |
| | 13/06/2019 | 2650 | 1 | 20 | 4230 | <0.1 | 2.5 | 7 | 5 | 4090 | 1040 | 3660 | 161 | <0.5 | 9450 | 4.5 | 2.6 | <2 | 19 |
| | 14/06/2019 | 1770 | <1 | 13 | 3150 | <0.1 | 1.2 | 4 | 3 | 2190 | 900 | 2560 | 81 | <0.5 | 7660 | 2.5 | 1.3 | <2 | 9 |
| | 15/06/2019 | 903 | <1 | 7 | 3200 | <0.1 | 0.6 | 2 | 2 | 1090 | 770 | 2650 | 61 | <0.5 | 8750 | 1.5 | 0.7 | <2 | 4 |
| | 16/06/2019 | 1480 | 1 | 9 | 3390 | <0.1 | 1 | 4 | 4 | 2120 | 860 | 2940 | 83 | <0.5 | 10000 | 2 | 1.6 | <2 | 11 |
| | 17/06/2019 | 1470 | 1 | 8 | 3620 | <0.1 | 1 | 3 | 5 | 2080 | 950 | 3220 | 89 | <0.5 | 10500 | 1.9 | 1.7 | <2 | 11 |

Table 10 Dissolved metals

| | | Dissolved metals (ug/L) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Date | Al | As | Ba | Ca | Cd | Co | Cr | Cu | Fe | K | Mg | Mn | Mo | Na | Ni | Pb | Se | Zn |
| Downstream: 1st Tamar Pontoon | 14/05/2019 | 16 | <1 | 2 | 4800 | <0.1 | <0.5 | <1 | <1 | 119 | 2710 | 7930 | 145 | <0.5 | 51400 | <0.5 | <0.5 | <2 | <2 |
| | 15/05/2019 | 27 | <1 | 2 | 3470 | <0.1 | <0.5 | <1 | <1 | 167 | 1040 | 3550 | 88 | <0.5 | 14700 | <0.5 | <0.5 | <2 | <2 |
| | 16/05/2019 | 11 | <1 | 3 | 5670 | <0.1 | <0.5 | <1 | <1 | 93 | 3640 | 10900 | 118 | <0.5 | 81700 | <0.5 | <0.5 | <2 | <2 |
| | 17/05/2019 | 8 | <1 | 3 | 5920 | <0.1 | <0.5 | <1 | <1 | 78 | 3980 | 11500 | 153 | <0.5 | 91300 | <0.5 | <0.5 | <2 | <2 |
| | 24/05/2019 | 9 | <1 | 3 | 6220 | <0.1 | <0.5 | <1 | <1 | 175 | 3570 | 11200 | 178 | <0.5 | 82400 | <0.5 | <0.5 | <2 | <2 |
| | 25/05/2019 | 10 | <1 | 2 | 5520 | <0.1 | <0.5 | <1 | <1 | 136 | 2710 | 8660 | 112 | <0.5 | 53200 | <0.5 | <0.5 | <2 | <2 |
| | 26/05/2019 | 12 | <1 | 3 | 5820 | <0.1 | <0.5 | <1 | <1 | 156 | 2830 | 9340 | 117 | <0.5 | 57700 | <0.5 | <0.5 | <2 | <2 |
| | 27/05/2019 | 15 | <1 | 3 | 5260 | <0.1 | <0.5 | <1 | <1 | 169 | 1700 | 6120 | 74 | <0.5 | 29000 | 0.5 | <0.5 | <2 | <2 |
| | 10/06/2019 | <8 | <1 | 6 | 24800 | <0.1 | <0.5 | <1 | <1 | 93 | 19600 | 66300 | 183 | 0.6 | 545000 | <0.5 | <0.5 | <2 | 3 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 11/06/2019 | <8 | <1 | 4 | 11600 | <0.1 | <0.5 | <1 | <1 | 66 | 7150 | 24400 | 122 | <0.5 | 185000 | <0.5 | <0.5 | <2 | 2 |
| | 12/06/2019 | 26 | <1 | 4 | 4460 | <0.1 | <0.5 | <1 | <1 | 137 | 2000 | 6070 | 46 | <0.5 | 37700 | 0.8 | <0.5 | <2 | <2 |
| | 13/06/2019 | 57 | <1 | 4 | 3870 | <0.1 | <0.5 | <1 | <1 | 236 | 940 | 3480 | 90 | <0.5 | 10400 | 0.7 | <0.5 | <2 | <2 |
| | 14/06/2019 | 123 | <1 | 2 | 2700 | <0.1 | <0.5 | <1 | <1 | 327 | 910 | 2370 | 91 | <0.5 | 7870 | 0.7 | <0.5 | <2 | <2 |
| | 15/06/2019 | 70 | <1 | 3 | 3040 | <0.1 | <0.5 | <1 | <1 | 221 | 830 | 2660 | 69 | <0.5 | 9510 | 0.6 | <0.5 | <2 | <2 |
| | 16/06/2019 | 41 | <1 | 2 | 3380 | <0.1 | <0.5 | <1 | <1 | 186 | 1090 | 3140 | 95 | <0.5 | 11300 | 0.6 | <0.5 | <2 | <2 |
| | 17/06/2019 | 31 | <1 | 2 | 3820 | <0.1 | <0.5 | <1 | <1 | 125 | 1100 | 3400 | 69 | <0.5 | 11500 | <0.5 | <0.5 | <2 | <2 |
| Upstream: Charles St Bridge | 14/05/2019 | 24 | <1 | 2 | 4350 | <0.1 | <0.5 | <1 | <1 | 125 | 2040 | 6220 | 95 | <0.5 | 35500 | <0.5 | <0.5 | <2 | <2 |
| | 15/05/2019 | 31 | <1 | 2 | 3350 | <0.1 | <0.5 | <1 | <1 | 159 | 820 | 3020 | 71 | <0.5 | 11200 | <0.5 | <0.5 | <2 | <2 |
| | 16/05/2019 | 16 | <1 | 3 | 5050 | <0.1 | <0.5 | <1 | <1 | 92 | 2760 | 8630 | 75 | <0.5 | 58000 | <0.5 | <0.5 | <2 | <2 |
| | 17/05/2019 | 11 | <1 | 2 | 5460 | <0.1 | <0.5 | <1 | <1 | 69 | 3350 | 10500 | 81 | <0.5 | 72700 | <0.5 | <0.5 | <2 | <2 |
| | 24/05/2019 | 9 | <1 | 2 | 5970 | <0.1 | <0.5 | <1 | <1 | 100 | 3160 | 10500 | 70 | <0.5 | 65700 | <0.5 | <0.5 | <2 | <2 |
| | 25/05/2019 | 9 | <1 | 3 | 6240 | <0.1 | <0.5 | <1 | <1 | 98 | 3460 | 11100 | 85 | <0.5 | 73200 | <0.5 | <0.5 | <2 | <2 |
| | 26/05/2019 | 11 | <1 | 3 | 6120 | <0.1 | <0.5 | <1 | <1 | 103 | 3090 | 10100 | 79 | <0.5 | 63100 | <0.5 | <0.5 | <2 | <2 |
| | 27/05/2019 | 20 | <1 | 5 | 5100 | <0.1 | <0.5 | <1 | <1 | 170 | 1480 | 5460 | 59 | <0.5 | 23700 | 0.5 | <0.5 | <2 | 2 |
| | 10/06/2019 | <8 | <1 | 5 | 18900 | <0.1 | <0.5 | <1 | <1 | 35 | 14200 | 48000 | 138 | <0.5 | 390000 | 0.5 | <0.5 | <2 | 6 |
| | 11/06/2019 | 8 | <1 | 4 | 7120 | <0.1 | <0.5 | <1 | <1 | 89 | 2820 | 10400 | 74 | <0.5 | 61900 | <0.5 | <0.5 | <2 | 3 |
| | 12/06/2019 | 55 | <1 | 4 | 3430 | <0.1 | <0.5 | <1 | <1 | 185 | 1150 | 3320 | 67 | <0.5 | 15500 | 0.6 | <0.5 | <2 | <2 |
| | 13/06/2019 | 76 | <1 | 5 | 3960 | <0.1 | <0.5 | <1 | 1 | 234 | 960 | 3310 | 56 | <0.5 | 9710 | 1 | <0.5 | <2 | <2 |
| | 14/06/2019 | 142 | <1 | 5 | 3130 | <0.1 | <0.5 | <1 | 1 | 215 | 810 | 2340 | 34 | <0.5 | 7520 | 1 | <0.5 | <2 | 5 |
| | 15/06/2019 | 83 | <1 | 4 | 3090 | <0.1 | <0.5 | <1 | <1 | 188 | 730 | 2530 | 46 | <0.5 | 8560 | 0.6 | <0.5 | <2 | <2 |
| | 16/06/2019 | 58 | <1 | 3 | 3200 | <0.1 | <0.5 | <1 | <1 | 149 | 780 | 2760 | 44 | <0.5 | 9820 | 0.5 | <0.5 | <2 | <2 |
| | 17/06/2019 | 41 | <1 | 3 | 3400 | <0.1 | <0.5 | <1 | <1 | 134 | 870 | 3000 | 54 | <0.5 | 10500 | <0.5 | <0.5 | <2 | <2 |

## Appendix 4 Known threatened flora and fauna in the Tamar Valley (NVA 2019)

| Species | Common name | TSPA/EPBCA^ Status | Habitat |
|---|---|---|---|
| **Animalia** | | | |
| *Accipiter novaehollandiae* | Grey goshawk | e/- | Riparian nesting & foraging |
| *Alcedo azurea* subsp. *diemenensis* | Azure kingfisher | e/EN | Riparian nesting & foraging |
| *Botaurus poiciloptilus* | Australasian bittern | -/EN | Wetland nesting & foraging |
| *Haliaeetus leucogaster* | White-bellied sea eagle | v/- | Riparian nesting & foraging |
| *Litoria raniformis* | Growling grass frog | v/VU | Wetland dependent |
| *Limnodynastes peroni* | Striped marsh frog | e/- | Wetland dependent |
| *Prototoctes maraena* | Australian grayling | -/VU | Aquatic |
| **Plantae** | | | |
| *Alternanthera denticulata* | Lesser joyweed | e/- | Riparian, swamp forests |
| *Aphelia gracilis* | Slender fanwort | r/- | Wet soaks |
| *Aphelia pumilio* | Dwarf fanwort | r/- | Wet soaks |
| *Bolboschoenus caldwellii* | Sea clubsedge | r/- | Emergent reed |
| *Boronia gunnii* | River boronia | v/VU | Locally extinct |
| *Callitris oblonga* subsp. *oblonga* | South Esk pine | v/EN | Riparian |
| *Calystegia sepium* | Hedge bindweed | r/- | Riparian |
| *Carex gunniana* | Mountain sedge | r/- | Riparian |
| *C. longebrachiata* | Australian sedge | r/- | Riparian |
| *Epacris exserta* | South Esk heath | e/EN | Riparian |
| *Epilobium pallidiflorum* | Showy willowherb | r/- | Wet soaks, swamp forests |
| *Euphrasia collina* subsp. *deflexifolia* | Eastern eyebright | r/- | Springs, wet soaks |
| *E. scabra* | Rough Eyebright | e/- | Wet soaks |
| *Hypolepis muelleri* | Harsh groundfern | r/- | Riparian, swamp forests |
| *Juncus amabilis** | Gentle rush | r/- | Wet soaks |
| *Lycopus australis* | Australian gypsywort | e/- | Riparian, swamp forests |
| *Lythrum salicaria* | Purple loosestrife | v/- | Riparian |
| *Persicaria decipiens* | Slender knotweed | v/- | Riparian, swamp forest |
| *P. subsessilis* | Bristly waterpepper | e/- | Riparian, swamp forest |
| *Pilularia novae-hollandiae* | Australian pillwort | r/- | Aquatic/semi-aquatic |
| *Prostanthera rotundifolia* | Round-leaved mint bush | v/- | Riparian |
| *Schoenoplectus tabernaemontani* | River clubsedge | r/- | Riparian, emergent reed |
| *Senecio campylocarpus* | Fireweed | v/- | Semi-aquatic |
| *Siloxerus multiflorus* | Small wrinklewort | r/- | Riparian, wet soaks |
| *Veronica plebeia* | Creeping speedwell | r/- | Swamp forest. Tamar stronghold |

^ TSPA - Threatened Species Protection Act (Tasmania) 1995; EPBCA - *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth); e/EN = endangered, v/VU = vulnerable, r = rare

* delisting under consideration