An investment plan for improving water quality in the Tamar estuary: Combined system overflows

Technical Report

December 2017

isNRM

Acknowledgements

This report has been developed for the Tamar Estuary Management Taskforce to aid in the development of a River Action Plan for the Tamar Estuary. The modelling and analysis contained in this reports has been undertaken by Dr Rebecca Kelly of isNRM Pty Ltd using data from a hydraulic model and costings provided by City of Launceston staff – Michael Newby, Kathryn Pugh, Randall Langdon, Ray Dodson. The development of this report has been oversighted by a Combined System Overflow working group consisting of: Shane Eberhardt (City of Launceston), Andrew Truscott, (TasWater), Geoff Brayford (Johnstone, McGee and Gandy Pty Ltd) and Stewart Sharples (Infrastructure Tasmania).

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Executive Summary

This report provides a detailed analysis of the effects of a series of potential investment options for reducing CSOs which have been developed by City of Launceston. This analysis has been undertaken using an improved version of the TEER CAPER DSS that was originally developed to support the TEER Water Quality Improvement Plan. In order to be used for analysis of these CSO options significant changes have been made to the DSS to allow results from the CoL hydraulic model to be incorporated and to better represent connections between the combined system and Ti Tree Bend STP. This analysis first looked at the benefits of individual projects before developing a recommended pathway of preferred options.

The final options which have been assessed using the City of Launceston hydraulic model and which are analysed in this report are:

- Esplanade storage – 3 ML storage located in the vicinity of Black Bridge and Boland st.
- Forster st storage – 2.5ML underground storage adjacent to Forster st Pump station.
- New Margaret st storage – 4.2ML storage in Kings Park adjacent to New Margaret st Pump station.
- South Launceston diversion – takes the separated sewage from South Launceston including Kings Meadows/Newstead and Boland st direct to TBB away from the Forster st pump station.
- West Launceston diversion – takes the separated sewage from West Launceston and Trevallyn and diverts this directly to TTB STP along the West Tamar highway and directly across the Tamar estuary via a new main reducing the load on new Margaret st.
- New combined rising main – divert flows to New Margaret st with decommissioning of Old Margaret st, installation of new sewage pumps to increase sewage pump capacity, Installation of new rising main works to connect New Margaret st to a storage at TTB and to the TTB STP, reconfiguration of Forster st and St John SPS to increase pump rate to TTB and construction of a storage or wetland at TTB.

From the analysis a preferred pathway of investment has been developed, maximising benefits with minimal costs and disruption. This pathway of options and costs is shown in Table A.

TABLE A. PATHWAY OF PREFERRED INVESTMENT OPTIONS FOR REDUCING CSOS

Option	Description	Cost ($ million)
Option 1	West Launceston Diversion	4.6
Option 2	Option 1 plus New Combined Rising Main	31.4
Option 3	Option 2 plus offline storage located at New Margaret st Pump station	41.4
Option 4	Option 3 plus South Launceston Diversion in conjunction with Esplanade offline storage	66.2
Option 5	Option 4 plus offline storage located at Forster st Pump Station	74.6
Full separation[1]	Development of a full separated sewer and stormwater system in the combined area	435

[1] Note that full separation is not considered to be a feasible option due to the enormous disruption it would cause to residents and business in the combined system area. This option has been included for comparison with feasible alternatives to demonstrate their effectiveness and cost relative to this frequently cited option.

The potential for avoided CSOs to put additional pressures on treatment at TTB has also been explored and the potential benefits of an additional $10 million investment in upgraded nutrient treatment capacity at Ti Tree Bend has been explored.

Figure A shows the impact of the preferred CSO Investment Options in conjunction with a treatment upgrade at TTB on Greater TEER catchment total loads. Note that loads and concentrations of TSS and enterococci are assumed to be unaffected by this upgrade. This figure shows that with this upgrade included Greater TEER catchment nutrient loads can be expected to decrease by 3 to 4%. Investment in the combined system can be expected to lead to large decreases in enterococci loads. The curve shows decreasing returns to scale of the investment, such that the initial investment in Option 1 (West Launceston diversion) achieves approximately 20% of the decrease in enterococci loads from full separation at 1% of the cost. Option 5 achieves roughly 85% of the full benefit at 17% of the total cost, and with significantly less disruption to the residents and businesses in the combined system area.

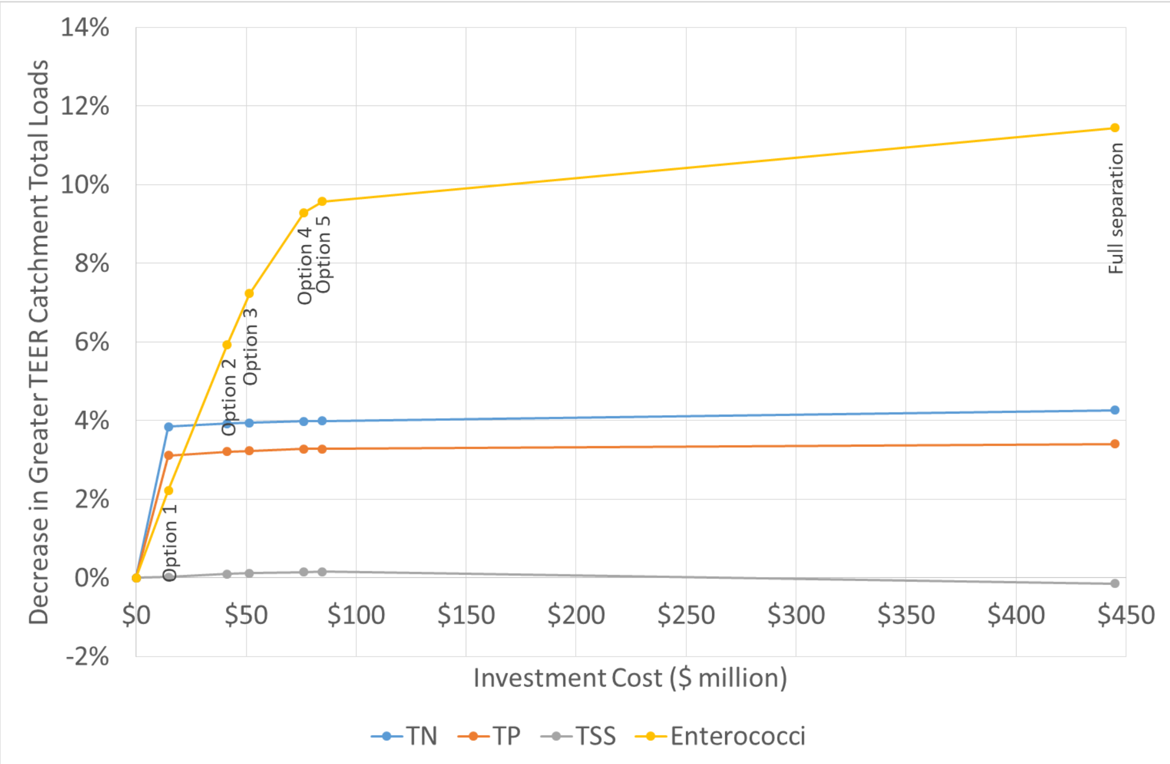

FIGURE A. COST VERSUS ESTIMATED DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS

Figure B shows the impacts of these Investment Options with the treatment upgrade at TTB on Tamar Estuary Zone 1 concentrations. CSOs are the largest contributor to Tamar Estuary Zone 1 concentrations. This pathway of preferred investment in reducing CSOs can be expected to have very large and significant benefits in terms of reduced enterococci concentrations in the upper estuary. As shown in this figure, enterococci concentrations can be expected to decrease by nearly 10%. Investment in Option 5 can be expected to decrease enterococci concentrations by 37%, which can be expected to have very significant benefits for recreational users of the upper estuary.

Costs attached to this option may be significantly underestimated given the many unknowns involved in a project of this scale and type.

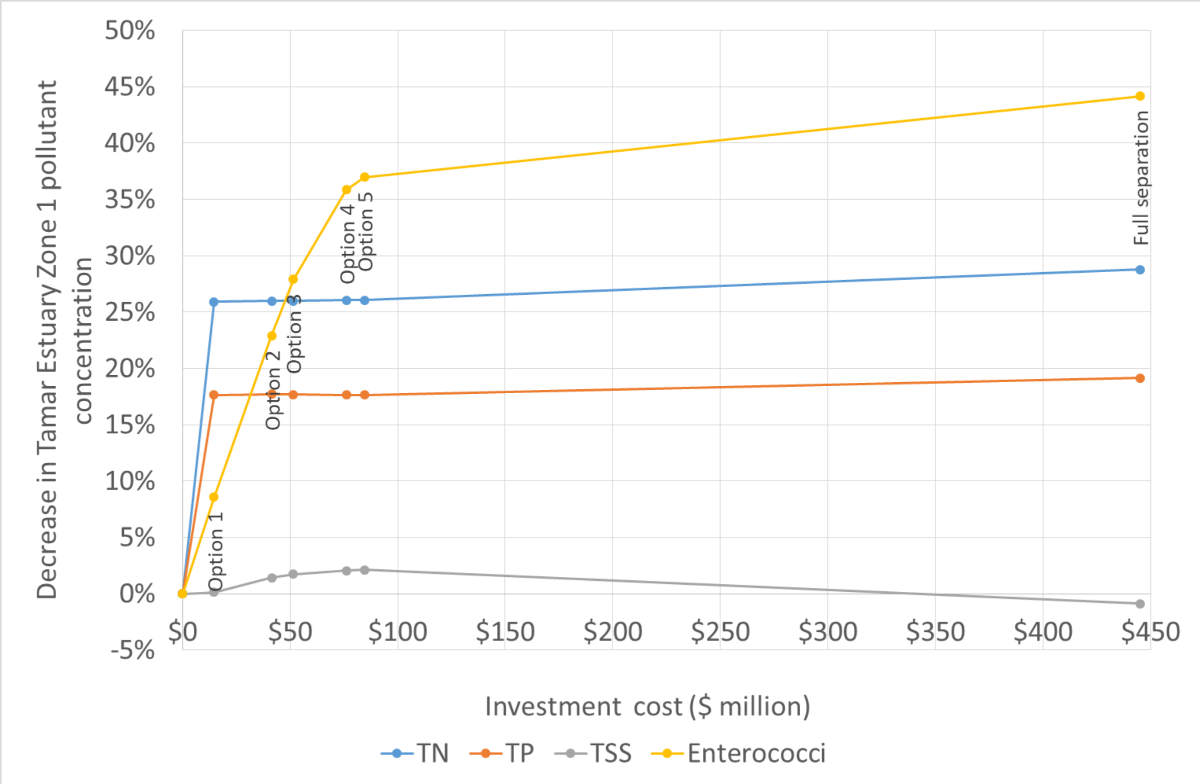

FIGURE B. COST VERSUS ESTIMATED DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS

This figure also shows very substantial benefits of the treatment upgrade in terms of decreased nutrient concentrations. It is estimated that TP concentrations would be expected to decrease by 18% and TN by 26%. This investment option allows the benefits of reduced CSOs in terms of enterococci to be retained while substantially decreasing nutrient concentrations, avoiding the potential decline that could be expected without such an upgrade.

Based on the analysis in this report:

- There is a clear pathway of investments in reduced CSOs that has the potential to provide large improvements in enterococci (and other pathogen) concentrations in Zone 1. These investments could be undertaken using a staged approach, progressively capturing the benefits of full investment. Decreasing returns to the scale of investment mean that this approach captures most of the benefits in the early stages of the investment pathway. Investment in Option 5 is expected to lead to a 37% decrease in Tamar Estuary Zone 1 enterococci concentrations for a total cost of roughly $75 million. This represents 85% of the total benefit that could be achieved by fully separating sewage and stormwater in the combined system at 17% of the cost. Full separation is considered to be infeasible given the enormous disruption that would be caused over many years to businesses and residents in the combined system. These results demonstrate that this option is not needed to effect very large decreases in pathogen concentrations in the upper estuary.
- Increased influent volumes to Ti Tree Bend STP from avoided CSOs have the potential to increase nutrient concentrations in the upper estuary. Very little data is available to accurately estimate this impact but significant trends in treatment effectiveness with increased influent volume are observed in the data that is available. Ti Tree Bend was not designed to effectively reduce nutrient concentrations. It is recommended that nutrient treatment upgrades at Ti Tree Bend are considered as part of the investment pathway to

reduce CSOs. TasWater already have some preliminary investigations of upgrade options which could be further developed in the design phase of any investment in CSOs. The analysis here shows this type of upgrade in conjunction with the CSO investment options could lead to significant water quality benefits in the upper estuary with concentrations of TN and TP decreasing by 26% and 18% respectively.

- More data on influent and effluent volumes and pollutant concentrations at Ti Tree Bend would significantly reduce the uncertainty of estimates of the impacts of increased influent volumes on treatment effectiveness. TasWater should continue to add to their understanding through continuation and refinement of their monitoring program.

1 Introduction

The Tamar Estuary and Esk Rivers (TEER) drain approximately 15% of Tasmania, consisting of the North Esk, South Esk, Brumbys-Lake, Macquarie, Meander and Tamar foreshore catchments (see Figure 1). The Tamar estuary is a drowned river valley, running for approximately 70km from Launceston to Bass Strait. The majority of flows to the estuary come from the North Esk river and the South Esk river, with flows passing from the South Esk river through Trevallyn Dam to the upper estuary.

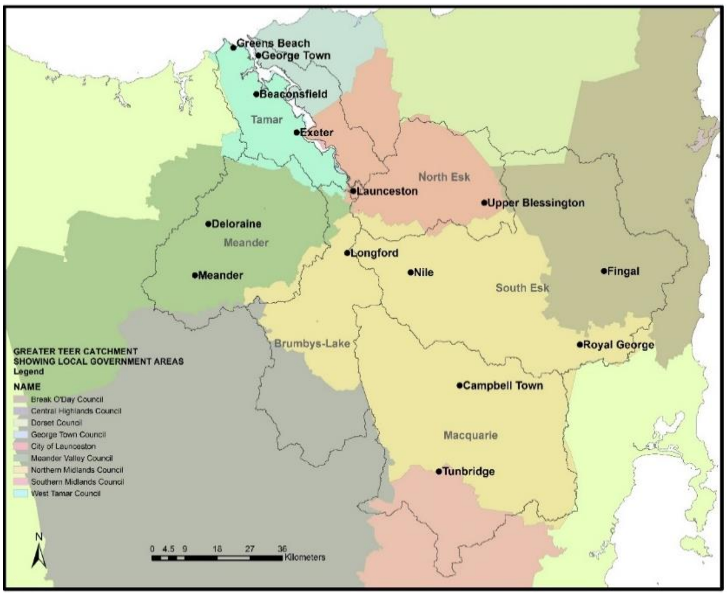

FIGURE 1. LOCATION OF THE TAMAR ESTUARY AND ITS CATCHMENT (GREATER TEER CATCHMENT), INCLUDING MAJOR SUBCATCHMENTS AND LOCAL GOVERNMENT AREAS

The City of Launceston sits at the top of the Tamar River Estuary. Parts of Launceston city drain into a combined sewer-stormwater system where sewage and stormwater are directed to the Ti Tree Bend sewage treatment plant in a single piped network. This combined system is designed to provide some level of treatment to both sewage and stormwater in the combined area, with flows greater than the volume able to be carried by the network or treated at the STP being discharged as combined system overflows from other parts of the network directly to the estuary. In this way flows may overflow from the combined pipe network itself at pump stations or at Ti Tree Bend if insufficient capacity is available at the STP to treat the volume of water arriving there. This provides a detailed a description of the results from modelling and analysis undertaken to develop an Investment Plan for managing combined system overflows (CSOs). It provides further analysis of a suite of options developed by City of Launceston and detailed in their Technical report (City of Launceston, 2017), considering their impacts at a catchment scale and on the estuary itself. This CSO Investment Plan complements a second Investment Plan being developed by the Catchment Action working group under the TEMT objectives. That Plan is focused on reducing pollutants exported from diffuse catchment sources into the estuary (see Kelly, 2017). The Investment Plans have been developed as part of a broader suite of management recommendations forming a River Health Action Plan under preparation by the Tamar Estuary Management Taskforce.

The recommended actions within the Investment Plans target the upper reaches of the Tamar Estuary from Launceston to Legana (referred to as Tamar Estuary Zone 1). They build on the work previously undertaken in development of a Tamar Estuary and Esk Rivers (TEER) Water Quality

Improvement Plan (WQIP) by NRM North for the catchment and are a considerable step forward in its implementation (Tamar Estuary and Esk Rivers Program, 2015).

The WQIP and these Investment Plans consider the impact of investment actions on four major pollutants: Total Nitrogen (TN); Total Phosphorus (TP); Total Suspended Sediments (TSS); and enterococci. TN and TP are nutrients. Elevated nutrient levels can feed the growth of nuisance algal growth in streams, dams and the estuary. This algae can increase turbidity and can smother and replace native plant and animal species. It can also make water dangerous for recreation and drinking. High levels of TSS make water turbid and dirty looking and can smother and replace native plant and animal species, decreasing the health of waterways. Sediment exports from the freshwater system to the estuary can also contribute to sediment accumulation in the upper estuary. Enterococci is a bacteria used as an indicator of pathogen pollution. Pathogens come from animal or human faeces and when elevated can make people sick if they drink or recreate in water.

2 The role of CSOs in water quality in the Tamar Estuary and its catchment

Pollutant loads in the TEER catchment come from a range of diffuse and point sources – directly off the catchment from the various land uses that cover the land surface (diffuse), 26 sewage treatment plants in the catchment and some discharging directly into the estuary, a salmon farm operating in the lower reaches of the estuary, and from combined system overflows. Figure 2 provides an estimate of the proportion of pollutant loads derived from each of these sources.

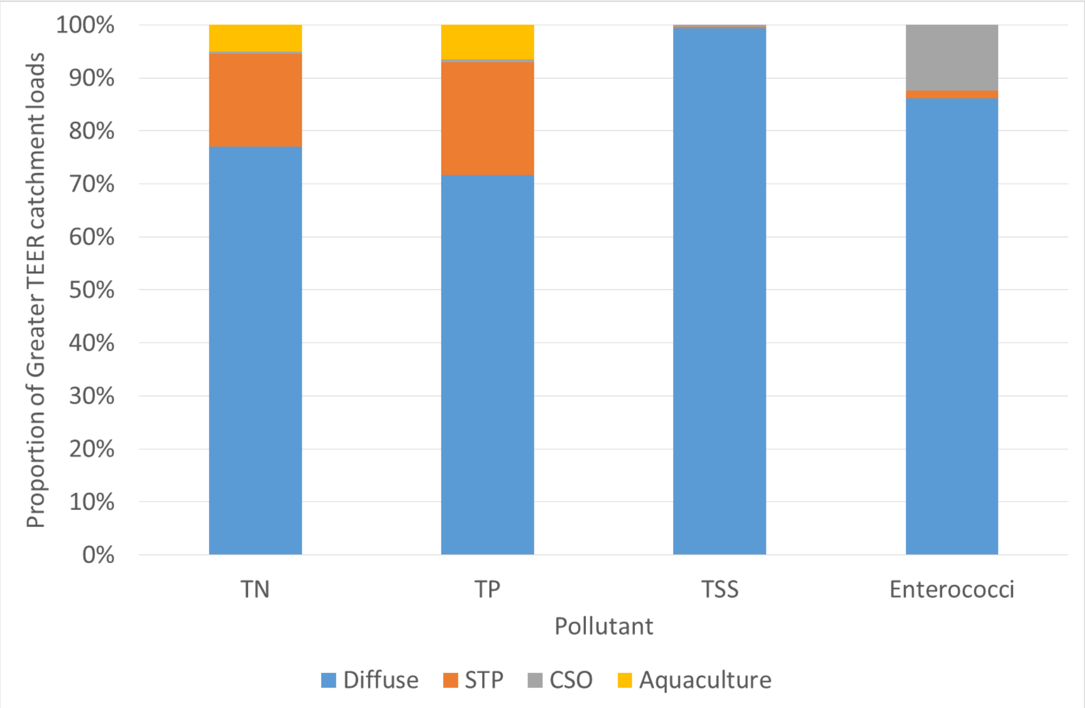

FIGURE 2. PROPORTION OF GREATER TEER CATCHMENT POLLUTANT LOADS FROM VARIOUS SOURCES

This figure shows that diffuse sources, that is pollutants delivered through runoff from the land surface (or as groundwater input to stream influenced by pollutant infiltration to groundwater) from the land surface is the dominate source of pollutants catchment wide, producing 99% of sediments, 86% of enterococci and over 70% of nutrient loads in the catchment. Sewage treatment plants are a significant contributor to nutrient loads in the catchment (17% to 21%) with aquaculture also producing approximately 5% to 7% of nutrient loads. CSOs make their largest contribution to enterococci concentrations, producing approximately 12% of the enterococci load for the Greater TEER catchment.

In terms of the impact on Tamar Estuary Zone 1 concentrations the size of pollutant loads of each source is moderated by how directly it enters this portion of the estuary. So sewage treatment plants discharging in the upper estuary, urban areas around Launceston and combined system overflows can be expected to have a significantly greater impact on Tamar Estuary Zone 1 pollutant concentrations than loads generated higher up in the catchment, particularly those upstream of Trevallyn Dam. Figure 3 shows an estimate of the influence of all these sources on average pollutant concentrations in Tamar Estuary Zone 1. This figure should be read with several caveats. Results shown here presume that each pollutant source is 'switched off'. For example this means that it is assumed that no flow enters the estuary from the catchment. In reality management changes can impact on loads without reducing flows. A background concentration of nutrients is assumed in the modelling. This accounts for the influence of processes such as nutrient cycling within the estuary and oceanic inputs of nutrients to the estuary. This is treated as a fixed value so doesn't respond to the changes in flow and loads from other sources being modelled here. Background concentrations are not considered to be 'controllable', rather they are naturally occurring and not subject to management. This information is intended to show the relative leverage of actions to reduce loads from these sources on Tamar Estuary Zone 1 concentrations only and should be read in this context.

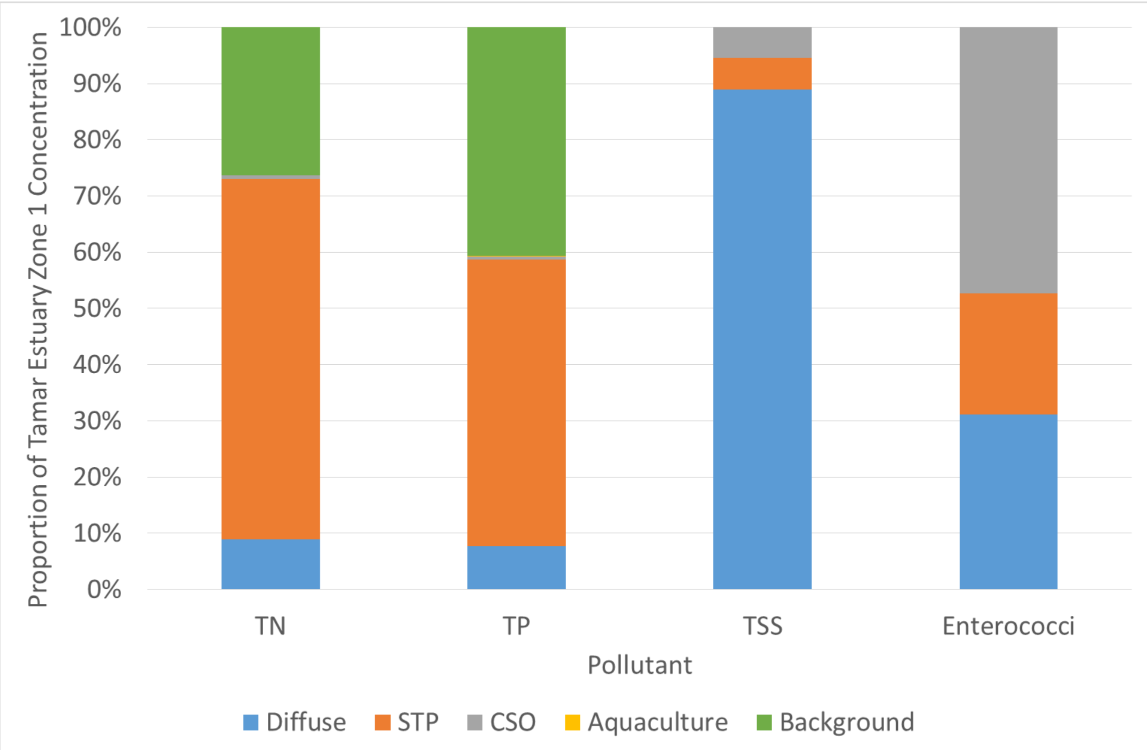

FIGURE 3.ESTIMATED CONTRIBUTION OF VARIOUS SOURCES ON POLLUTANT CONCENTRATIONS IN TAMAR ESTUARY ZONE 1

This figure shows that Tamar Estuary Zone 1 nutrient contributions are driven to a large extent by STP discharge direct to the estuary. Diffuse sources have a significantly smaller impact on Tamar Estuary Zone 1 concentrations. Most of this impact will come from catchment areas that are directly contributing to the estuary, so the upper Tamar foreshore and North Esk River catchments. There is some tidal influence on pollutants entering Zone 1, so for example aquaculture and urban areas further down the estuary can have a small impact on Zone 1. TSS concentrations are largely driven by diffuse rather than point sources, with much of this delivered from urban areas around Launceston and other land use areas in the North Esk catchment. CSOs and STPs do make some contribution to TSS concentrations in Tamar Estuary Zone 1, but this is estimated to be in the order of 5% for each compared to 90% from diffuse sources. CSOs are a very significant drivers of enterococci concentrations in the Tamar Estuary Zone 1, contributing nearly half of the average concentration. The remaining portion come from a mix of diffuse and STP sources, with diffuse inputs estimated to be having slightly more impact than STPs on enterococci concentrations.

3 Focus of the Investment Plan

This Investment Plan focuses entirely on combined system overflows and their impacts at Ti Tree Bend. The primary focus of both investment plans is the reduction of pathogen concentrations in the Tamar Estuary Zone 1. It is however recognised that the goal of the TEMT is to improve water quality in all its facets and so impacts on nutrients and sediments are also discussed. This is particularly important as some actions recommended to reduce CSOs can have negative impacts on nutrient concentrations in the estuary. This report considers not only the benefits of the proposed investments for enterococci concentrations in the upper estuary but also actions to address these negative trade-offs for nutrients.

This report is entirely focused on management of pollutants entering the estuary from combined system overflows and issues around the impact of these investments at Ti Tree Bend. The Catchment Action working group Technical report (Kelly, 2017) contains similar analysis and recommendations for catchment management actions to manage diffuse pollutant sources.

4 Potential actions to reduce CSOs

City of Launceston (CoL) staff have undertaken a significant assessment of potential options for reducing combined system overflows. These options were considered in light of their feasibility, cost and potential impact. A detailed analysis and justification of the final options selected can be found in City of Launceston (2017).

The final options which have been assessed using the CoL hydraulic model are:

- Esplanade storage – 3 ML storage located in the vicinity of Black Bridge and Boland st.
- Forster st storage – 2.5ML underground storage adjacent to Forster st Pump station.
- New Margaret st storage – 4.2ML storage in Kings Park adjacent to New Margaret st Pump station.
- South Launceston diversion – takes the separated sewage from South Launceston including Kings Meadows/Newstead and Boland st direct to TBB away from the Forster st pump station.
- West Launceston diversion – takes the separated sewage from West Launceston and Trevallyn and diverts this directly to TTB STP along the West Tamar highway and directly across the Tamar estuary via a new main reducing the load on new Margaret st.
- New combined rising main – divert flows to New Margaret st with decommissioning of Old Margaret st, installation of new sewage pumps to increase sewage pump capacity, Installation of new rising main works to connect New Margaret st to a storage at TTB and to the TTB STP, reconfiguration of Forster st and St John SPS to increase pump rate to TTB and construction of a storage or wetland at TTB.

The estimated cost of each potential action is given in Table 1.

Table 1. Estimates cost of potential actions to reduce CSOs

Project	Cost ($ million)
Esplanade storage	6.7
Forster st storage	8.4
New Margaret st storage	10
South Launceston Diversion	18.1
West Launceston Diversion	4.6
New combined rising main	26.8

These options were all assessed for their relative impact on total loads from the Greater TEER catchment (as a percentage reduction against the sum of diffuse and point source loads) and on Tamar Estuary Zone 1 concentrations. This allows options to be compared with actions recommended in the Diffuse Management Investment Plan.

This section describes these impacts. The first section considers impacts of reduced combined system overflows only, assuming that avoided overflows are able to be treated at Ti Tree Bend STP without any impact on treatment effectiveness. The second section explores the potential impacts on treatment effectiveness of increased flows to Ti Tree Bend from reduced CSOs and the potential changes that could be expected in Greater TEER catchment loads and Tamar Estuary Zone 1 concentrations resulting from this.

4.1 Water quality improvements assuming no impact on treatment effectiveness at TTB

In this section it is assumed that avoided overflows pass for treatment at TTB STP. A uniform rate of treatment is assumed to be achieved regardless of the flow that enters the plant.

4.1.1 Impacts of individual actions on Greater TEER catchment diffuse and point source loads

The impact of each of the potential actions on Greater TEER catchment total nutrient and sediment loads (diffuse plus point source) is shown in Figure 4. Figure 5 shows impacts on enterococci loads. Note that impacts are shown in terms of the decrease in load – so a negative value means an increase in load and decline in water quality.

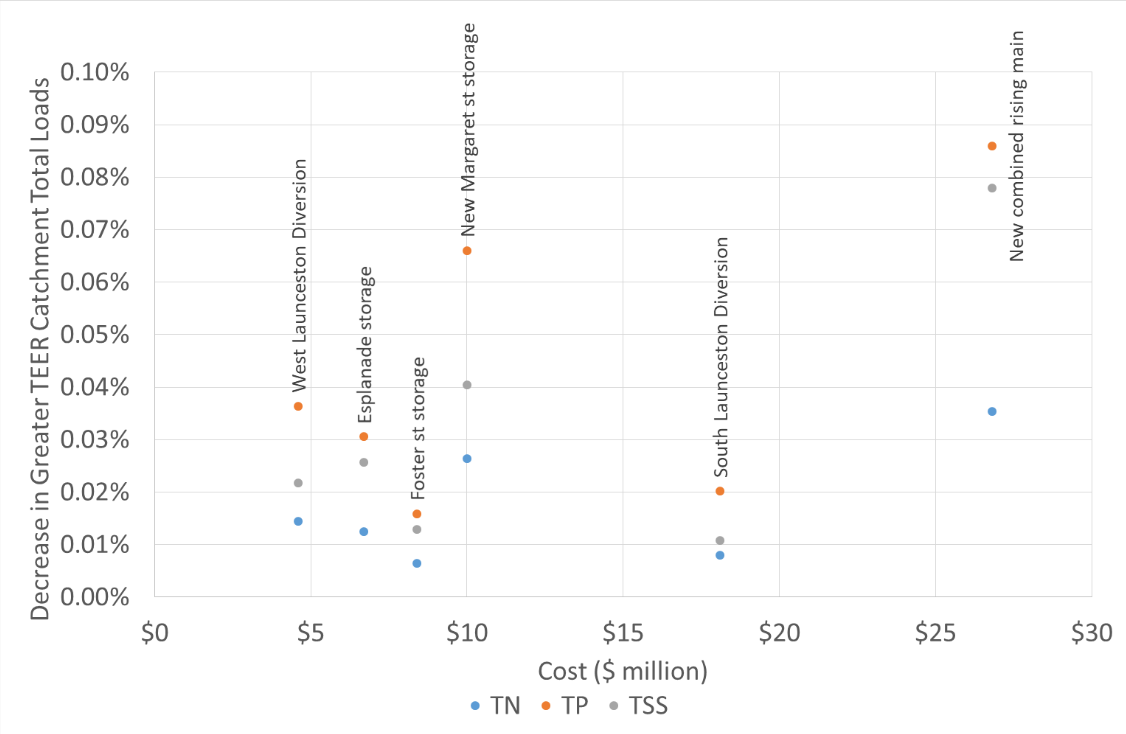

FIGURE 4. DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS - NUTRIENTS AND SEDIMENTS

This figure shows that the impact on Greater TEER catchment total nutrient and sediment loads is relatively small. If no change in treatment effectiveness at TTB is considered then all options would be expected to lead to a very small decrease in sediment and nutrient loads, with the greatest benefits for TP loads and smallest for TN.

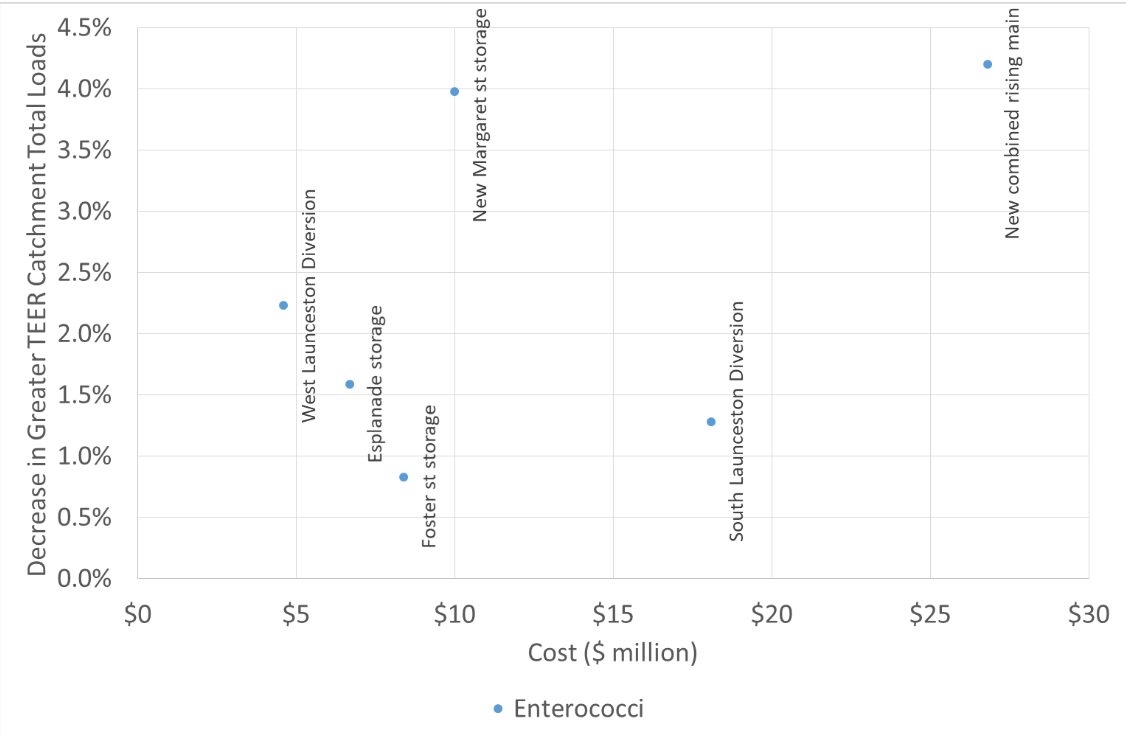

FIGURE 5. DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS - ENTEROCOCCI

This figure shows that the scale of decreases of enterococci loads is significantly greater than for nutrient or sediment loads, with decreases of over 4% of loads expected for some options. The most cost effective action is shown to be the West Launceston diversion which achieves over 2% decrease in enterococci loads for a budget of less than $5 million. By comparison the Forster st storage is expected to cost over $8 million and achieve less than a 1% decrease in loads. The New Margaret st storage is also very cost effective achieving a 4% decrease in enterococci loads for approximately $10 million.

4.1.2 Impacts of individual actions on Tamar Estuary Zone 1 concentrations

Impacts of these individual actions on Tamar Estuary Zone 1 concentrations are shown in Figures 6 and 7 for nutrients and sediments, and enterococci respectively.

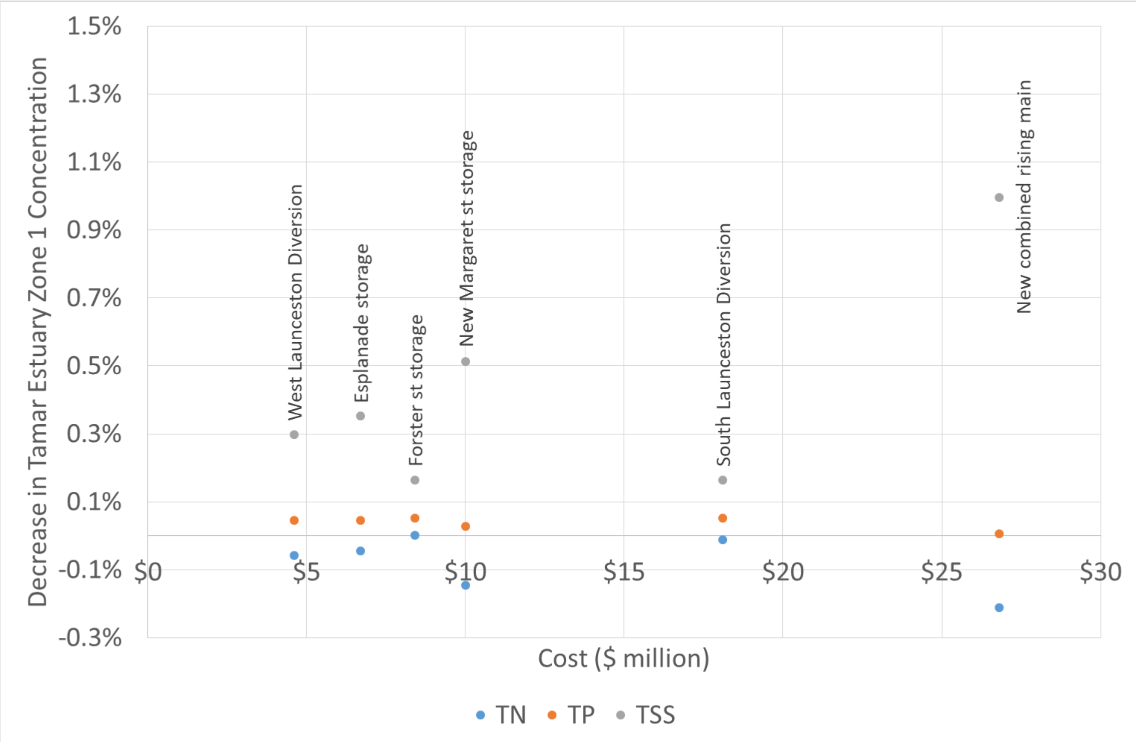

FIGURE 6. DECREASE IN TAMAR ESTUARY ZONE 1 CONCENTRATION – NUTRIENTS AND SEDIMENTS

This figure shows that the scale of potential impacts on Tamar Estuary Zone 1 concentrations of nutrients and sediments is greater than was the case for Greater TEER catchment total loads but is still fairly small, at least for nutrients. TN concentrations have the potential to increase slightly even though total loads are reduced. This is in part due to the effect of averaging concentrations across Zone 1, where a spike in the vicinity of Ti Tree Bend has a greater impact on the average value than a smaller reduction across other areas of the Zone where CSOs are avoided. Very little impact on TP is expected. Impacts on TSS are greater, with the greatest benefit with the new combined rising main option expected to decrease TSS concentrations by roughly 1%.

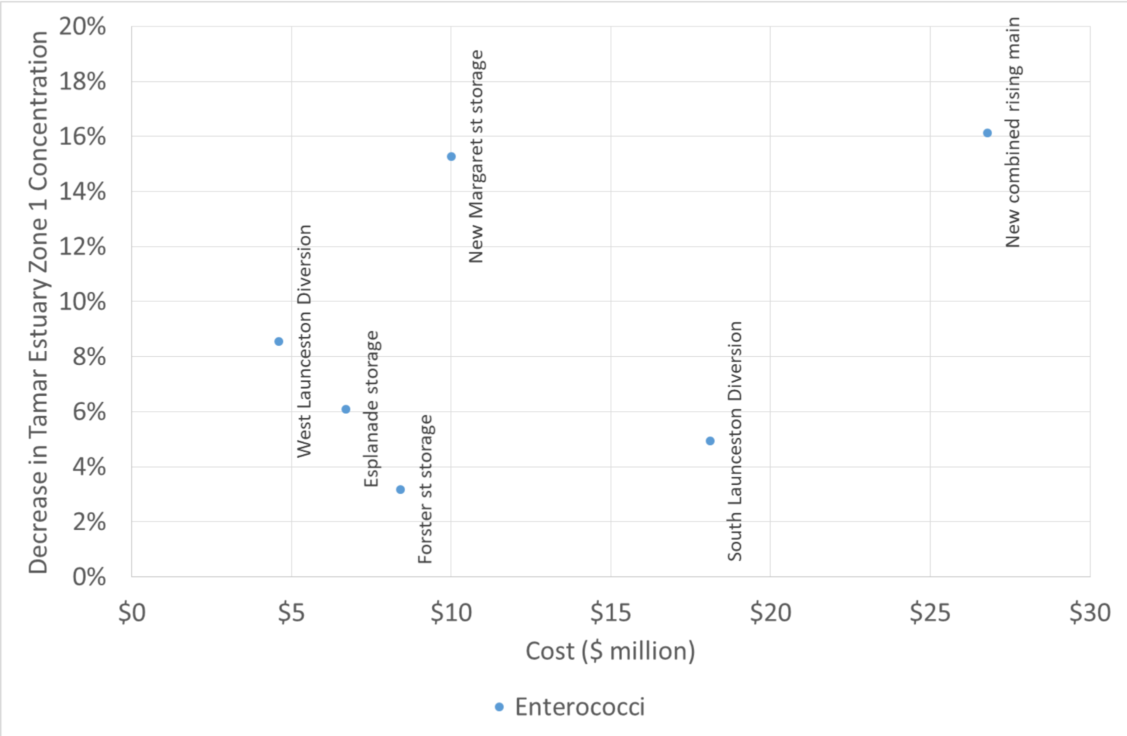

FIGURE 7. DECREASE IN TAMAR ESTUARY ZONE 1 CONCENTRATION - ENTEROCOCCI

As was the case for Greater TEER catchment loads, impacts of these individual actions on Tamar Estuary Zone 1 concentrations are significantly greater than for nutrients and sediments. The New Margaret st storage and New combined rising main can both be expected to lead to very substantial decreases in Tamar Estuary Zone 1 enterococci concentrations (15% to 16%). The West Launceston diversion is also very cost effective, leading to an 8% decrease in concentrations for less than 20% of the cost of the New combined rising main.

4.2 An exploration of water quality impacts if reduced CSOs impact treatment effectiveness at TTB

The results in Section 4.1 assume that increased flows at Ti Tree Bend STP due to avoided CSOs have no impact on the treatment effectiveness of the plant. This is however not the case. Figure 8 shows a very simplified schematic of the operation of Ti Tree Bend. This figure shows that the STP works with a series of bypasses. Flows up to 200ML/day are able to pass through screening, removing a significant proportion of sediments. Primary treatment has a capacity to treat up to 120ML/day. Flows above this bypass the STP and effectively overflow at STP site direct to the estuary. The treatment capacity of the secondary treatment phase is approximately 60ML/day. Flows greater than this bypass secondary treatment and are discharged direct to the estuary. Chlorination does occur that reduces pathogen concentrations of bypassed flows. Both primary and secondary treatment effectiveness are reduced as flows increase through the plant. Flows near capacity have the potential to mobilise pollutants, particularly nitrogen, and the lower treatment time effects, for example, the amount of sediments that fall out during treatment. Ti Tree Bend was not designed to remove TN and TP so generally removes significantly less of these pollutants than it does TSS or enterococci.

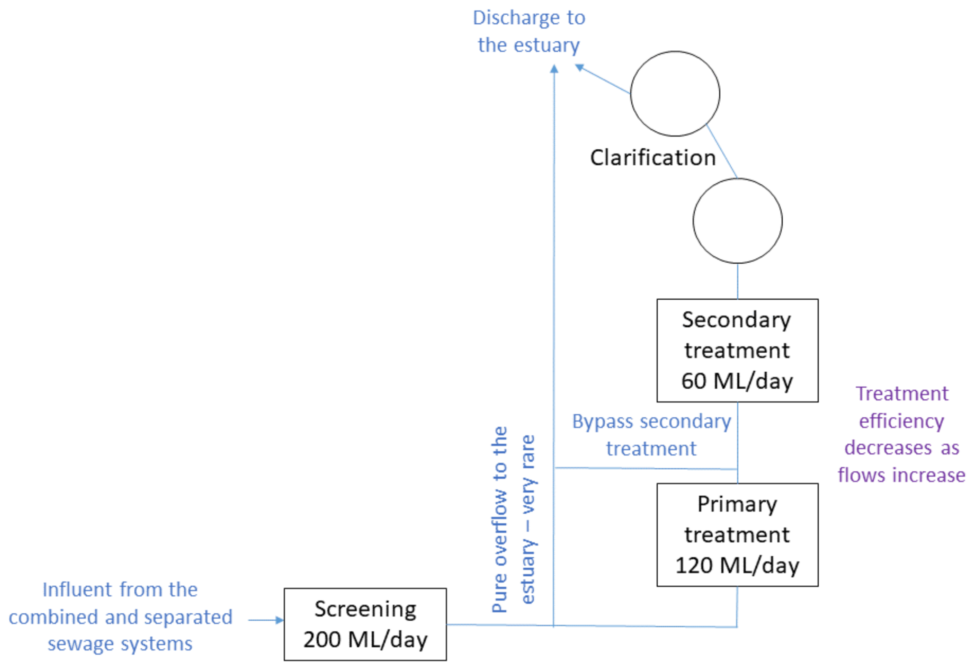

FIGURE 8. SIMPLIFIED SCHEMATIC OF TREATMENT AT TI TREE BEND STP (PERS COMM: ANDREW TRUSCOTT)

Limited concentration data was available before and after treatment to estimate the effects of increased influents on treatment effectiveness. Available data was used to create an empirical model. A full description of this analysis and the final models used is given in Appendix 2. These models were significant with very good p-values on fitted trends but had a significant scatter around the fitted line and relatively low R^2 values. These characteristics indicate that increased influent significantly impacts on treatment effectiveness but that there is a lower degree of certainty around the magnitude of this effect. Given this a model based on these fits has been used to explore the potential impacts this decrease in effectiveness has on load and concentration decreases. These models are shown in Figure 9 for nutrients and Figure 10 for sediments and enterococci. They use a multiplier for the proportion of influent load for each pollutant that becomes discharged load. Note the different scale of multipliers for nutrients, sediments and enterococci. Nutrient multipliers were capped at 100%. There was some indication that these actually continue to increase over 100% as flows increase indicating that additional nutrients are mobilised from those within the plant system once flows increase over a given threshold (in the case of TN estimated to be between 30,000 and 40,000 kL). Given the quality of the data available for fitting the model it was decided to cap this multiplier to 100% to avoid large overestimates of the impact on nutrient loads. This may mean that impacts shown here are a conservative estimate (note a range of impact is also provided with this cap removed). Given the uncertainties involved these results should be considered indicative of the magnitude and direction of changes which may be expected while acknowledging that the true impact is likely to vary from the modelled impact.

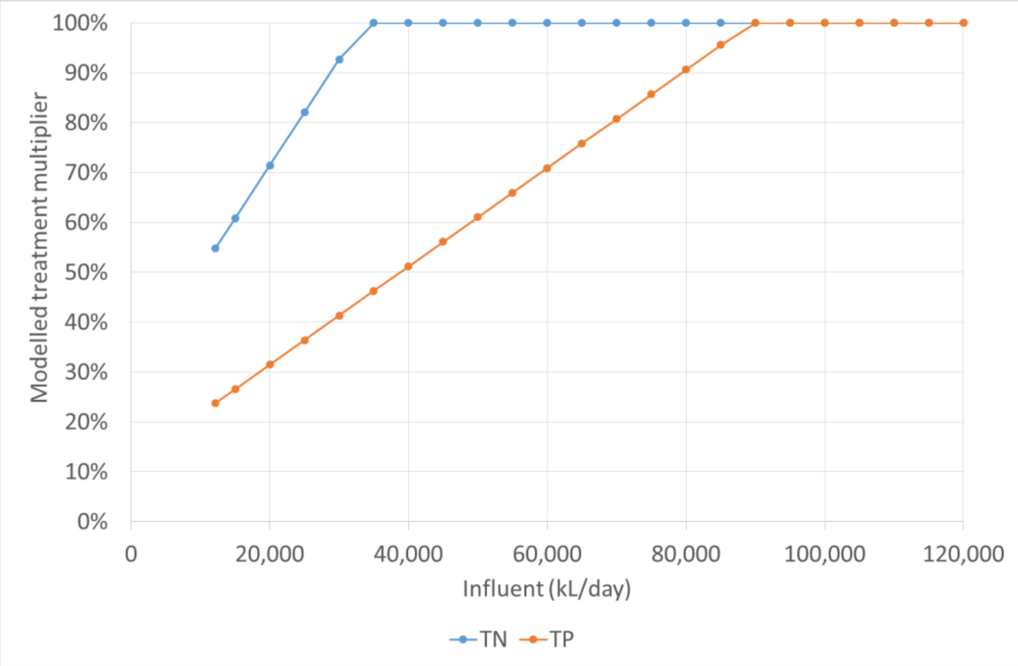

FIGURE 9. MODELLED IMPACTS OF INCREASED FLOWS THROUGH TTB STP ON TREATMENT EFFECTIVENESS – NUTRIENTS

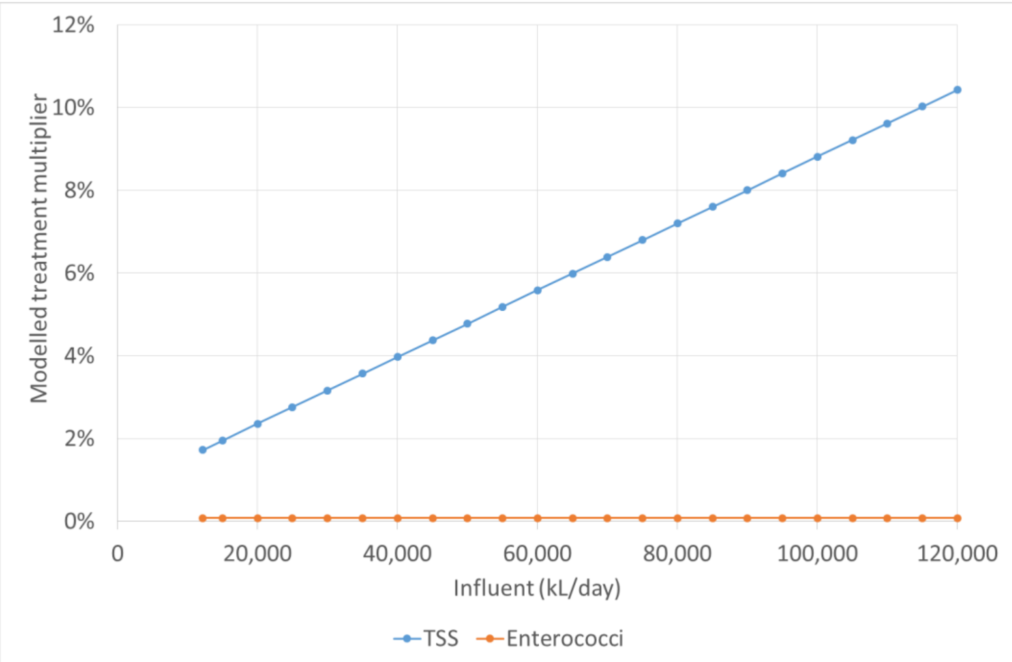

FIGURE 10. MODELLED IMPACTS OF INCREASED FLOWS THROUGH TTB STP ON TREATMENT EFFECTIVENESS – SEDIMENTS AND ENTEROCOCCI

The consequence of these changes in treatment effectiveness can be that total loads to the estuary increase even though CSOs are avoided and loads that would have been discharged untreated are now receiving some level of treatment at TTB STP. Figure 11 demonstrates this effect for TN load. In this figure the influent TN load for each flow volume is estimated as a mix of sewage and stormwater. Note that the slope of this reflects the relatively lower concentration of TN in stormwater compared to sewage (increasing influent adds TN load through additional stormwater rather than additional sewage). The TN effluent is then the multiplier for each influent volume multiplied by the influent load. As this figure shows the gradient of the effluent curve is significantly steeper than for the influent curve reflecting the decreasing treatment effectiveness as influent increases. Importantly this impact occurs for every kL of flow influent not just for the additional volume entering the plant. The green and red lines demonstrate the relative scale of avoided CSOs (which is equal to the increase in influent load to TTB) versus the additional effluent load from TTB for a shift from 25,000kL to 30,000kL influent to the plant. As is seen in the figure the scale of increase of effluent from TTB is significantly greater than the avoided CSOs (87kg versus 10kg). In this way avoided CSOs have the potential to increase nutrient loads discharged to the estuary. This effect does not occur for enterococci as no decline in treatment effectiveness was found. For TSS the scale of the increase in effluent loads from TTB is significantly less than the decrease in loads from avoided CSOs (54kg versus 700kg) meaning overall a net improvement in water quality is still achieved.

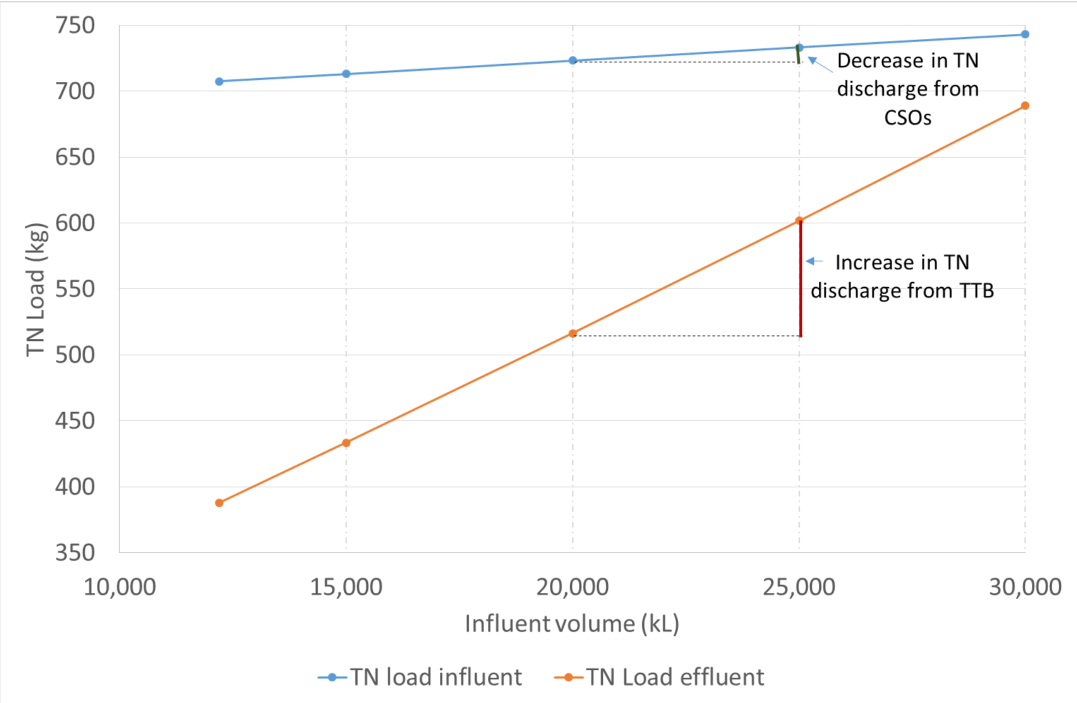

FIGURE 11. EXAMPLE OF CHANGE IN TN LOAD DISCHARGED WITH A CHANGE IN INFLUENT VOLUME

4.2.1 Impacts of individual actions on Greater TEER catchment diffuse and point source loads

Figures 12 and 13 show the effect of the individual actions on Greater TEER catchment total loads of nutrients and sediments, and enterococci respectively. These figures incorporate the effect of decreasing treatment effectiveness as influent volumes increase due to avoided CSOs.

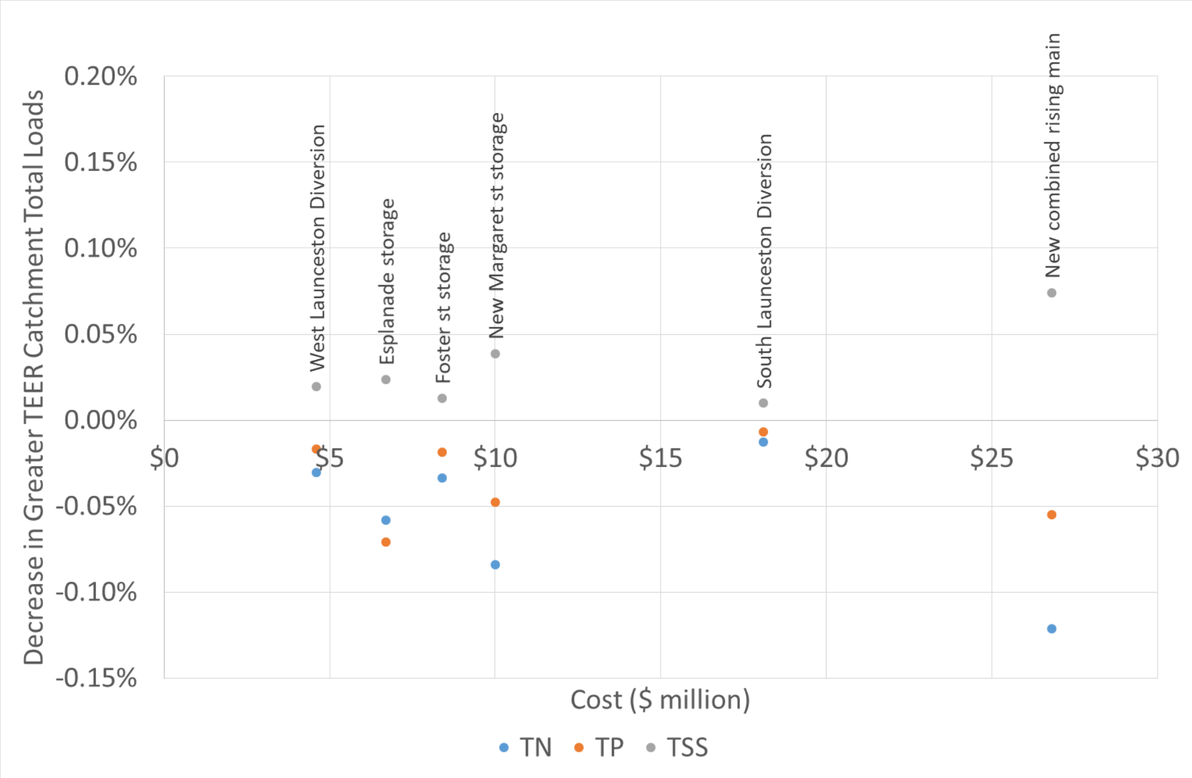

FIGURE 12. DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS - NUTRIENTS AND SEDIMENTS

This Figure shows that decreasing treatment effectiveness has the capacity to effect nutrient removal to the extent that loads increase for both TN and TP. The greater the effect of the action is on reducing CSOs the larger the increase in nutrient loads.

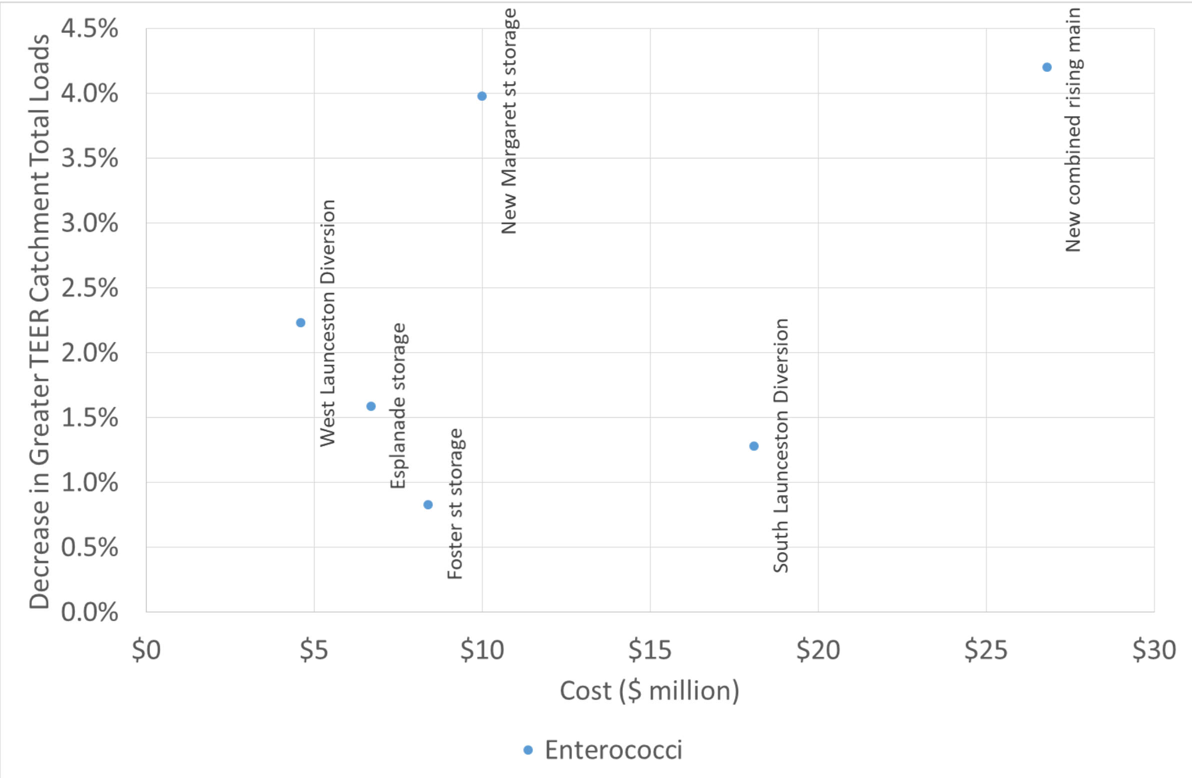

FIGURE 13. DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS - ENTEROCOCCI

No significant relationship between increased influent volume and enterococci removal was found so increasing influent does not impact on the decreases in enterococci expected.

4.2.2 Impacts of individual actions on Tamar Estuary Zone 1 concentrations

The effects of these actions on Tamar Estuary Zone 1 concentrations is shown in Figures 14 and 15 for nutrients and sediments, and enterococci respectively. These results include the impact of increasing influent volumes on treatment effectiveness.

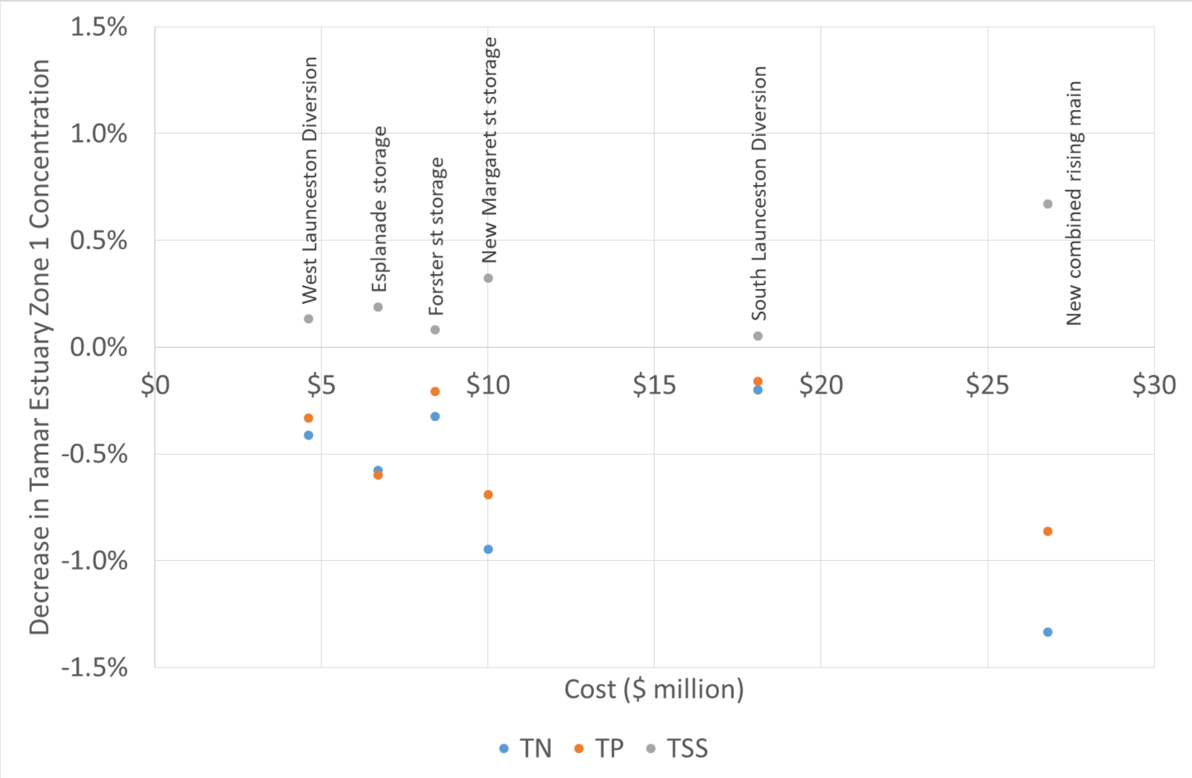

Figure 14. Decrease in Tamar Estuary Zone 1 Concentration – Nutrients and sediments

This figure shows these actions have the potential to significantly increase nutrient concentrations in Tamar Estuary Zone 1. The largest increase is expected for the New combined rising main action, with an estimated 1.3% increase in TN and 0.9% increase in TP concentrations. All options lead to some decreases in TSS concentrations, though these are lower than what was estimated when impacts on treatment effectiveness were not accounted for (reduced from 1% down to 0.7%).

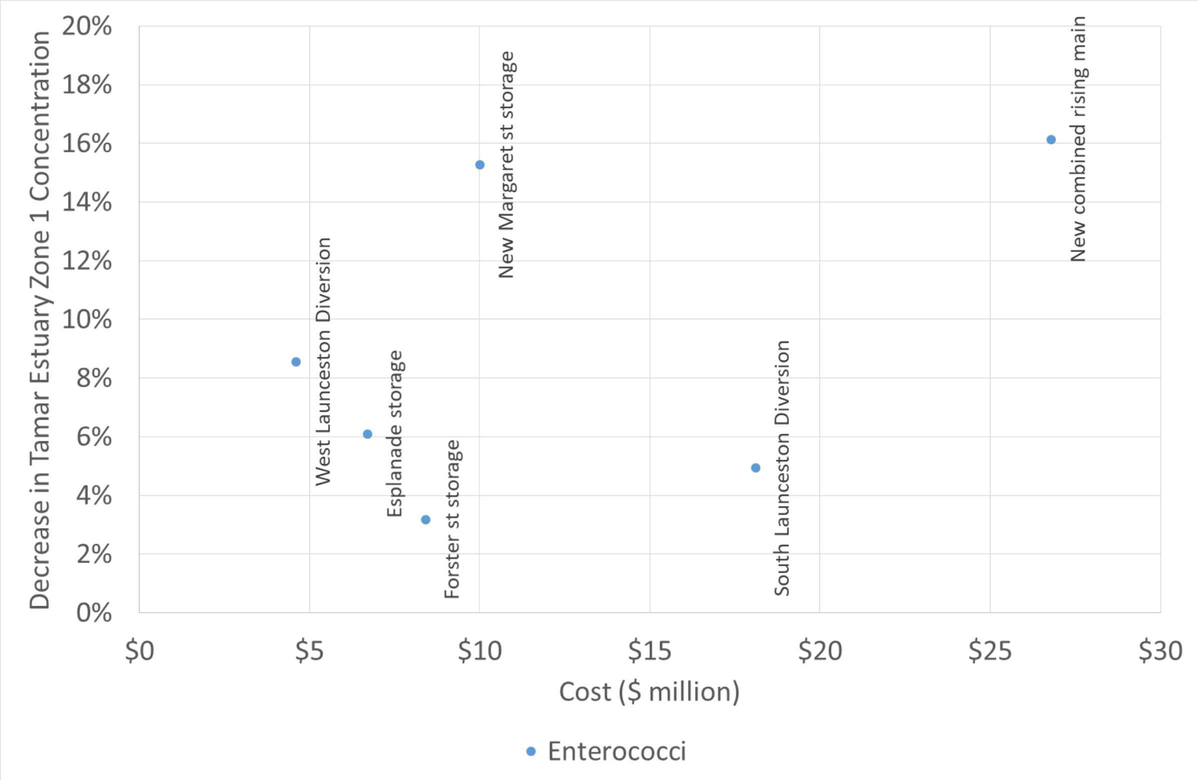

FIGURE 15. DECREASE IN TAMAR ESTUARY ZONE 1 CONCENTRATION - ENTEROCOCCI

As was the case for Greater TEER catchment loads, no change in enterococci treatment effectiveness is expected. Estimated decreases in Tamar Estuary Zone 1 enterococci concentrations are substantial, up to a maximum of 15% to 16% for the New combined rising main and the New Margaret st storage.

These results show the importance of considering the impacts of increased effluent at TTB on treatment effectiveness. It is very important that the combined sewer-stormwater network and TTB STP are considered as a whole system. In order to avoid negative impacts on nutrient concentrations in the estuary resulting from decreased CSOs it will be important to consider upgrades to the treatment capacity of TTB for removing nutrients as part of the package of recommended projects. The individual actions investigated here are all effective at reducing Tamar Estuary Zone 1 enterococci concentrations. The next section outlines a recommended priority of these projects undertaken in combination provided by City of Launceston from their analysis of the Combined System Hydraulic model. Effects are considered first with no impact on treatment effectiveness at TTB, before an analysis with treatment impacts is undertaken. The final part of this section explores impacts with a further project to upgrade nutrient removal at TTB incorporated into the Options.

5 Investment Options and their impacts

The individual actions described Section 4 were prioritised based on their relative cost and water quality benefit. These actions can interact with each other affecting both the cost of the combined action and its impact on water quality. For example the cost for building two pieces of infrastructure together can be lower than the sum of costs for the two individual projects. Also one option may reduce overflows at a point that mean the reductions from building the second project component are less than if that component was built as a standalone project.

Prioritised actions are shown as a series of investment options in Table 2. The total cost of each of these options is provided. Note that full separation has been included as an option in this analysis even though it is not considered to be a feasible action due to the enormous disruption it would cause to businesses and residents in the combined system. This option has been included for comparison to show the proportion of the maximum potential decrease in CSOs achieved by each of the recommended options.

TABLE 2. DESCRIPTION AND COSTS ASSOCIATED WITH PRIORITISED FEASIBLE CSO REDUCTION OPTIONS

Option	Description	Cost ($ million)
Option 1	West Launceston Diversion	4.6
Option 2	Option 1 plus New Combined Rising Main	31.4
Option 3	Option 2 plus offline storage located at New Margaret st Pump station	41.4
Option 4	Option 3 plus South Launceston Diversion in conjunction with Esplanade offline storage	66.2
Option 5	Option 4 plus offline storage located at Forster st Pump Station	74.6
Full separation[2]	Development of a full separated sewer and stormwater system in the combined area	435

As in section 4 these options are assessed first considering no impact on treatment effectiveness at TTB then with potential impacts on treatment effectiveness from increased flows. A third analysis is then undertaken applying an upgrade option for TTB for which TasWater has some data in terms of its cost and potential impacts on effluent quality.

5.1 Impacts without considering effects on treatment at TTB

This section explores the impacts of recommended investment options without considering effects on treatment effectiveness at TTB of increased effluent volumes. The decrease in Greater TEER catchment total loads is shown in Figure 16. This Figure shows the substantial decreases in Greater TEER catchment loads of enterococci that could be achieved with these investments. Option 5 achieves nearly 85% of the potential benefits of full separation at only 17% of the cost (and with significantly less disruption to businesses and residents in the combined system). Option 1, the West Launceston diversion is very cost effective, with nearly 20% of the potential benefits achieved at only 1% of the cost. Prioritising the most cost effective actions means that there are decreasing returns to scale of investment – for the additional spend each project achieves a relatively smaller water quality benefit. The cost benefit curve is still very steep out to Option 5 indicating that each additional benefit cost-effectively achieves additional benefits. Very small impacts on Greater TEER catchment nutrient and sediment loads are expected. Interestingly full separation can be expected to increase TSS loads. This is both because of the high concentration of sediments in urban stormwater and because of the effectiveness of TTB STP at removing sediments. This has further water quality implications as sediment exports in urban areas generally carry other pollutants such

[2] Note that full separation is not considered to be a feasible option due to the enormous disruption it would cause to residents and business in the combined system area. This option has been included for comparison with feasible alternatives to demonstrate their effectiveness and cost relative to this frequently cited option. Costs attached to this option may be significantly underestimated given the many unknowns involved in a project of this scale and type.

as heavy metals and hydrocarbons, so increased sediment loads could also be expected to infer increased heavy metal and other pollutant loads to the estuary.

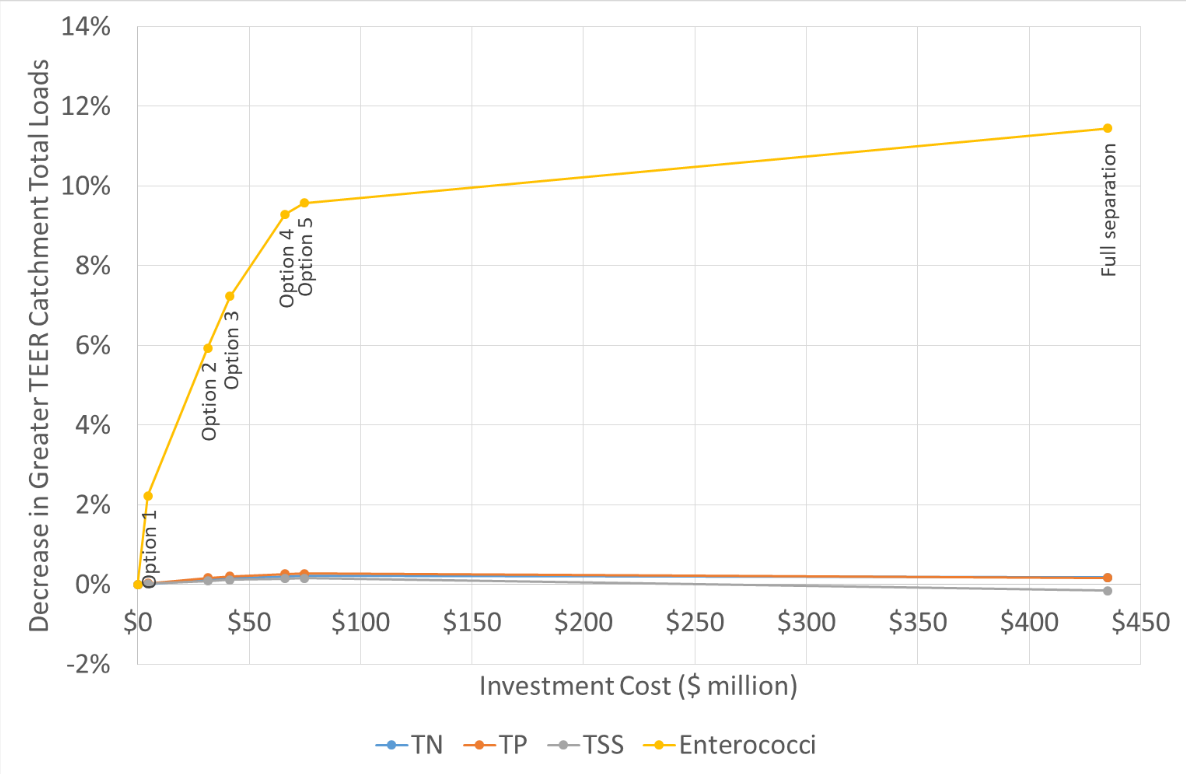

FIGURE 16. COST VERSUS ESTIMATED DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS

Impacts of these prioritised options on Tamar Estuary Zone 1 concentrations are shown in Figure 17. These results do not account for any impact of increased influent on treatment effectiveness at TTB STP. This figure shows that very large decreases in enterococci concentrations can be expected from these investments. As was the case for loads, the majority of benefits in terms of enterococci concentrations are achieved by investment to Option 5. Investment in Option 2 achieves over 50% of the potential benefit at 7% of the cost. Little impact is expected on Tamar Estuary Zone 1 nutrient concentrations (remembering that no impact on treatment effectiveness is accounted for here. Increases in Tamar Estuary Zone 1 sediment concentrations can be expected (1.8%) for full separation. Investment Options 1 to 5 decrease TSS concentrations as greater volumes of stormwater are reach TTB for screening and treatment.

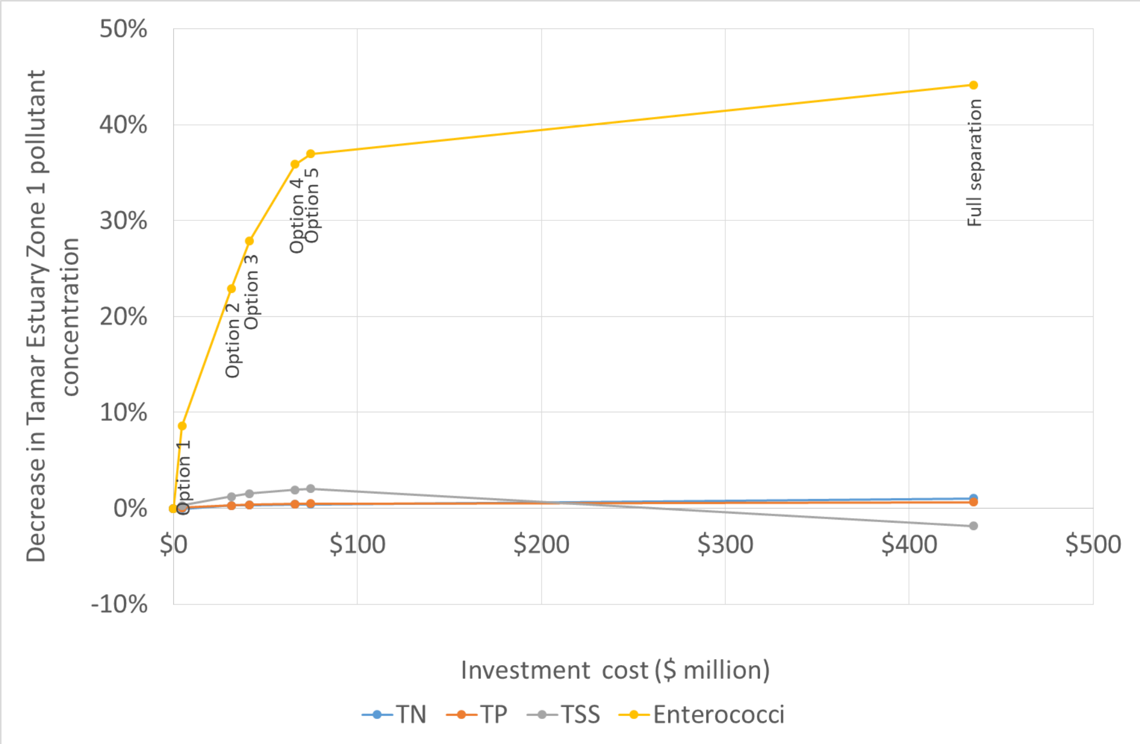

FIGURE 17. COST VERSUS ESTIMATED DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS

5.2 Impacts considering potential impacts on treatment at TTB

Section 4.2 demonstrated the potential effect of declining treatment effectiveness with increased influent volumes to TTB STP and showed that with these accounted for individual investment actions have the potential to increase both Greater TEER catchment total loads and Tamar Estuary Zone 1 concentrations. This section shows the results from prioritised investment options where these potential impacts on treatment effectiveness have been accounted for.

Figure 18 shows the decrease in Greater TEER catchment total loads when impacts of increased influent volumes on treatment effectiveness are accounted for. Note that impacts on enterococci are identical to those shown in the previous section as enterococci treatment effectiveness is assumed to be unaffected by increasing influent volumes. Impacts on nutrient loads vary from increases to decreases depending on the scale of the investment. This is affecting by the assumption that the multiplier is capped at 100%. If this is not the case then all investment options could be expected to lead to a net increase in nutrient loads except full separation where nutrient loads decrease due to the greater treatment effectiveness of TTB STP at this lower influent level.

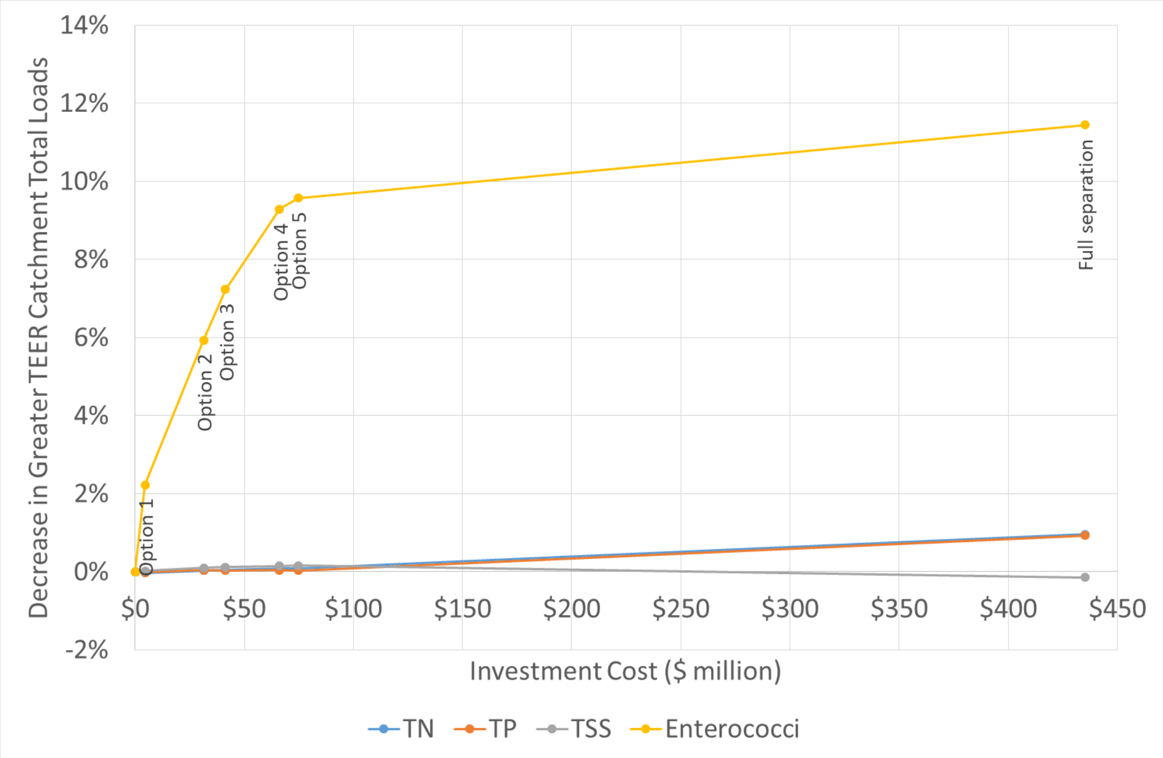

FIGURE 18. COST VERSUS ESTIMATED DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS

Figure 19 shows the impact of these investment options on Tamar Estuary Zone 1 concentrations assuming treatment effectiveness is affected at TTB. As was the case with Greater TEER catchment total loads, decreases in Tamar Estuary Zone 1 concentrations are the same as for the previous section. In this case nutrient concentrations can be expected to increase for all investment options (except full separation) as reduced treatment capacity increases the nutrient loads discharged from TTB STP. Note that the scale of this increase is larger and more consistent than for loads due to the effect of the spike in concentrations around TTB relative to the broader spread of changes in CSOs across the Zone. Option 5 is associated with a 1% increase in TP concentrations and a 0.4% increase in TN concentrations. This estimated change in TN concentrations is strongly affected by capping the multiplier at 100% (such that as investment increases progressively few design events are affected by declining treatment effectiveness). If treatment effectiveness is allowed to continue to decline past this point in the model such that increased flows mobilise TN then this increase in TN concentrations would be expected to be significantly greater than shown here. Analysis of this option with no cap on the impact on treatment effectiveness shows an increase in concentration of 2.7% for TN and 1.3% for TP is feasible.

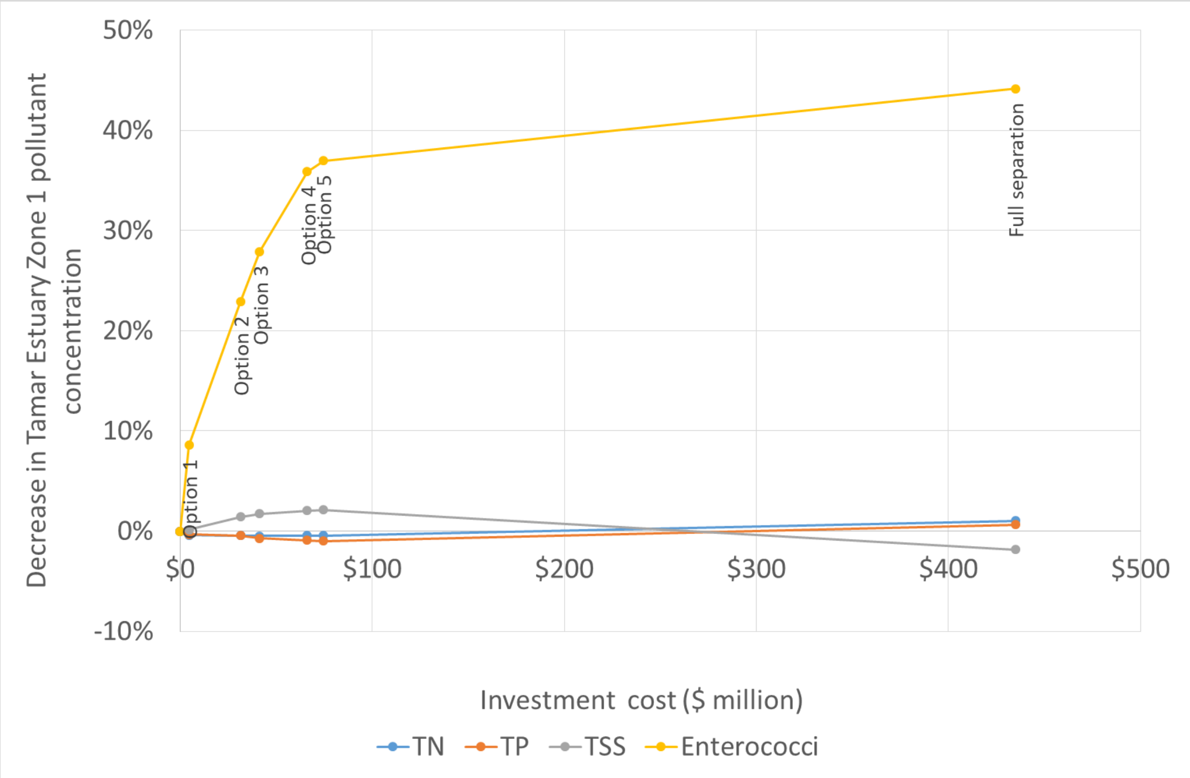

Figure 19. Cost versus estimated decrease in Tamar Estuary Zone 1 concentrations

5.3 Additional benefits of potential nutrient removal upgrades at TTB

Given the potential for Tamar Estuary Zone 1 nutrient concentrations to increase as CSOs are avoided and more flows are sent to TTB a scenario looking at the potential benefits of upgraded nutrient treatment at TTB in conjunction with these CSO Options has been investigated. This upgrade option uses analysis conducted by CH2M Australia Pty Ltd for TasWater looking at the costs and effectiveness of several potential upgrade options. The upgrade option considered here incorporates an intermittently aerated bioreactor, aerobic bioreactor and sidestream deammonification components. The cost of this option was estimated at roughly $10 million. CH2M Australia estimated TN effluent loads would decrease by roughly 53% and TP by 72% as a result of this upgrade. For the purposes of the analysis here these reductions were applied uniformly across all flow rates to the already estimated treatment effectiveness for each influent volume. Further investigation would be required to understand how the effectiveness of this upgrade might itself vary with influent volumes.

Figure 20 shows the impact of the preferred CSO Investment Options in conjunction with a treatment upgrade at TTB on Greater TEER catchment total loads. Note that loads and concentrations of TSS and enterococci are assumed to be unaffected by this upgrade. This figure shows that with this upgrade included Greater TEER catchment nutrient loads can be expected to decrease by 3 to 4%. Note that the cost axis has changed compared to results in the previous sections, reflecting the additional $10 million required to undertake the treatment upgrade at TTB.

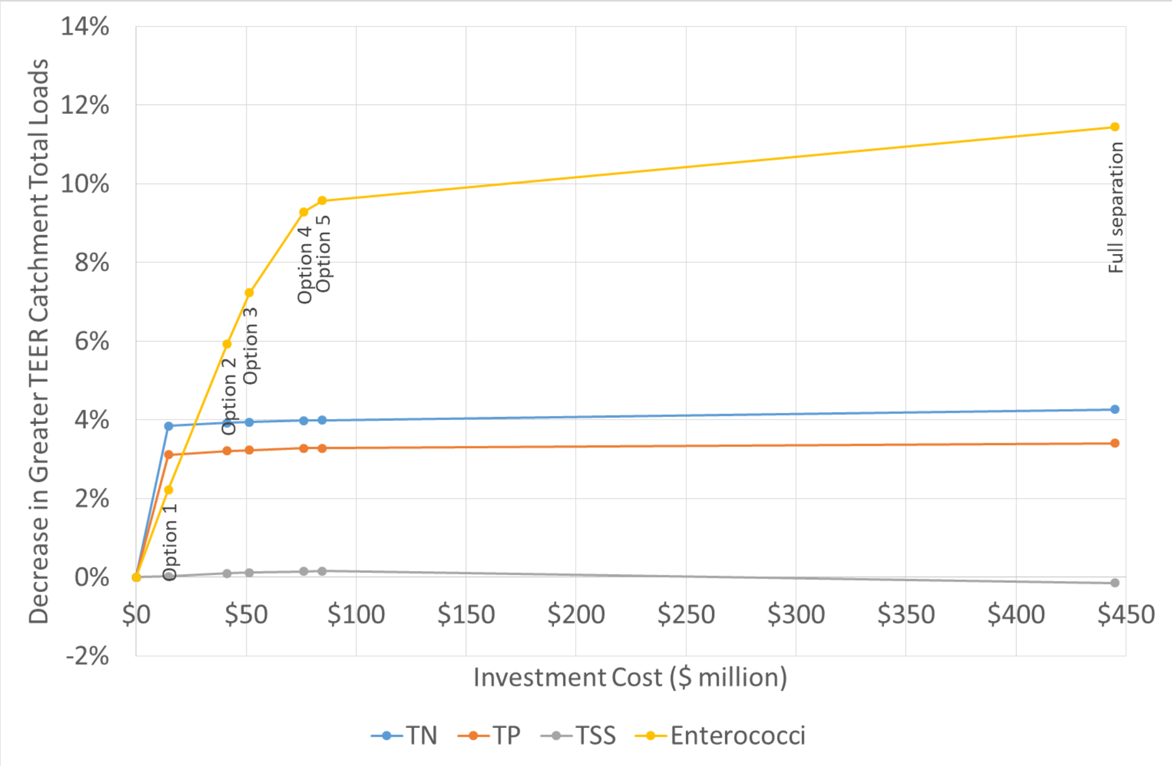

FIGURE 20. COST VERSUS ESTIMATED DECREASE IN GREATER TEER CATCHMENT DIFFUSE AND POINT SOURCE LOADS

Figure 21 shows the impacts of these Investment Options with the treatment upgrade at TTB on Tamar Estuary Zone 1 concentrations. This figure shows very substantial benefits of the treatment upgrade in terms of decreased nutrient concentrations. It is estimated that TP concentrations would be expected to decrease by 18% and TN by 26%. This investment option allows the benefits of reduced CSOs in terms of enterococci to be retained while substantially decreasing nutrient concentrations, avoiding the potential decline that could be expected without such an upgrade.

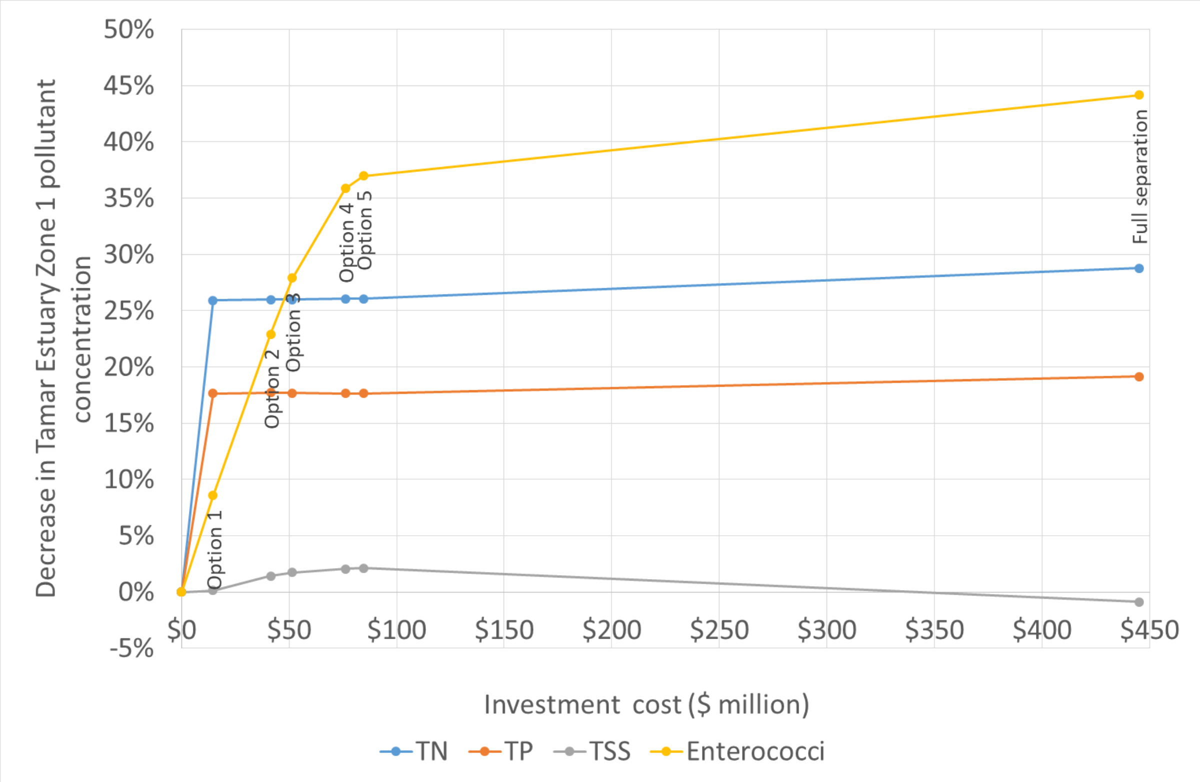

Figure 21. Cost versus estimated decrease in Greater TEER catchment diffuse and point source loads

6 Recommendations

This report provides a detailed analysis of the effects of a series of potential investment options for reducing CSOs which have been developed by City of Launceston. This analysis has been undertaken using an improved version of the TEER CAPER DSS that was originally developed to support the TEER Water Quality Improvement Plan. In order to be used for analysis of these CSO options significant changes have been made to the DSS to allow results from the CoL hydraulic model to be incorporated and to better represent connections between the combined system and Ti Tree Bend STP. This analysis first looked at the benefits of individual projects before developing a recommended pathway of preferred options. The potential for avoided CSOs to put additional pressures on treatment at TTB has also been explored. Based on this analysis:

- There is a clear pathway of investments in reduced CSOs that has the potential to provide large improvements in enterococci (and other pathogen) concentrations in Zone 1. These investments could be undertaken using a staged approach, progressively capturing the benefits of full investment. Decreasing returns to the scale of investment mean that this approach captures most of the benefits in the early stages of the investment pathway. Investment in Option 5 is expected to lead to a 37% decrease in Tamar Estuary Zone 1 enterococci concentrations for a total cost of roughly $75 million. This represents 85% of the total benefit that could be achieved by fully separating sewage and stormwater in the combined system at 17% of the cost. Full separation is considered to be infeasible given the enormous disruption that would be caused over many years to businesses and residents in the combined system. These results demonstrate that this option is not needed to effect very large decreases in pathogen concentrations in the upper estuary.
- Increased influent volumes to Ti Tree Bend STP from avoided CSOs have the potential to increase nutrient concentrations in the upper estuary. Very little data is available to

accurately estimate this impact but significant trends in treatment effectiveness with increased influent volume are observed in the data that is available. Ti Tree Bend was not designed to effectively reduce nutrient concentrations. It is recommended that nutrient treatment upgrades at Ti Tree Bend are considered as part of the investment pathway to reduce CSOs. TasWater already have some preliminary investigations of upgrade options which could be further developed in the design phase of any investment in CSOs. The analysis here shows this type of upgrade in conjunction with the CSO investment options could lead to significant water quality benefits in the upper estuary with concentrations of TN and TP decreasing by 26% and 18% respectively.

- More data on influent and effluent volumes and pollutant concentrations at Ti Tree Bend would significantly reduce the uncertainty of estimates of the impacts of increased influent volumes on treatment effectiveness. TasWater should continue to add to their understanding through continuation and refinement of their monitoring program.

7 References

Jessup, C. (2015). Launceston’s Combined Sewage System – Investigation and Strategy Development, Dissertation towards completion of Bachelor of Engineering (Honours), University of Southern Queensland.

Kelly, R.A. (2017). An investment plan for improving water quality in the Tamar estuary: Diffuse source management, Technical Report, NRM North, Tasmania.

City of Launceston (2017).

Tamar Estuary and Esk Rivers Program. (2015). Tamar Estuary and Esk Rivers Catchment Water Quality Improvement Plan. NRM North, Tasmania.

Appendix 1. Approach to modelling Combined System Overflows

The TEER CAPER DSS was originally developed to support the TEER Water Quality Improvement Plan. Combined system overflows in this model were estimated using a fairly simple relationship between total flow and a threshold. A fixed volume of sewage was assumed to be present in the system every day with flow duration curves for urban land use areas in the combined system used to estimate frequency of various volumes of stormwater in the system. A fixed flow threshold was then used to simulate CSOs. There was no relationship in the original model between CSOs and effluent discharged at Ti Tree Bend, which was estimated based on historical flow and pollutant concentration data at this STP.

In order to properly account for the effect of CSOs on water quality in the Tamar estuary and to allow for analysis of various investment options in the combined system on catchment pollutant loads and estuary concentrations, the TEER CAPER DSS has been redeveloped. The new version of the DSS contains a significantly improved representation of CSOs based on the hydraulic modelling undertaken by City of Launceston as well as a new module for estimating discharges from Ti Tree Bend STP that represents the linkages between combined system flows and the STP. This Appendix describes the new CSO and TTB modules in the TEER CAPER DSS. Appendix 2 provides a detailed description of the analysis undertaken to determine the impacts of influent volume on treatment effectiveness at TTB.

A1.1. Modelling CSOs

City of Launceston staff provided estimates of CSOs of sewage and total discharge for 5 points around the estuary based on their hydraulic model for 20 different design events corresponding to different total volumes and intensities of rainfall. The location of discharge points used in the modelling is shown in Figure 22.

FIGURE 22. LOCATION OF DISCHARGE POINTS USED IN CSO MODELLING IN THE DSS (SOURCE: CITY OF LAUNCESTON)

For CSO component of the DSS, total rainfall associated with each event was used as representative of the likelihood of each event. Ideally rainfall intensity would also have been used to determine this likelihood but long term rainfall intensity data was not available. The CSO component model relates the each event to the total rainfall for the event and maps these against the probability that rainfall is greater than or equal to this amount. These probabilities were based on analysis of the historic rainfall record from 1 January 1951 to 30 June 2017. Separate probabilities were determined for summer (Oct-Mar) and winter (Apr-Sept) in line with other modelling in the TEER CAPER DSS, as shown in Figure 23. Note than markers on this figure correspond to design events in the modelling provided by City of Launceston staff.

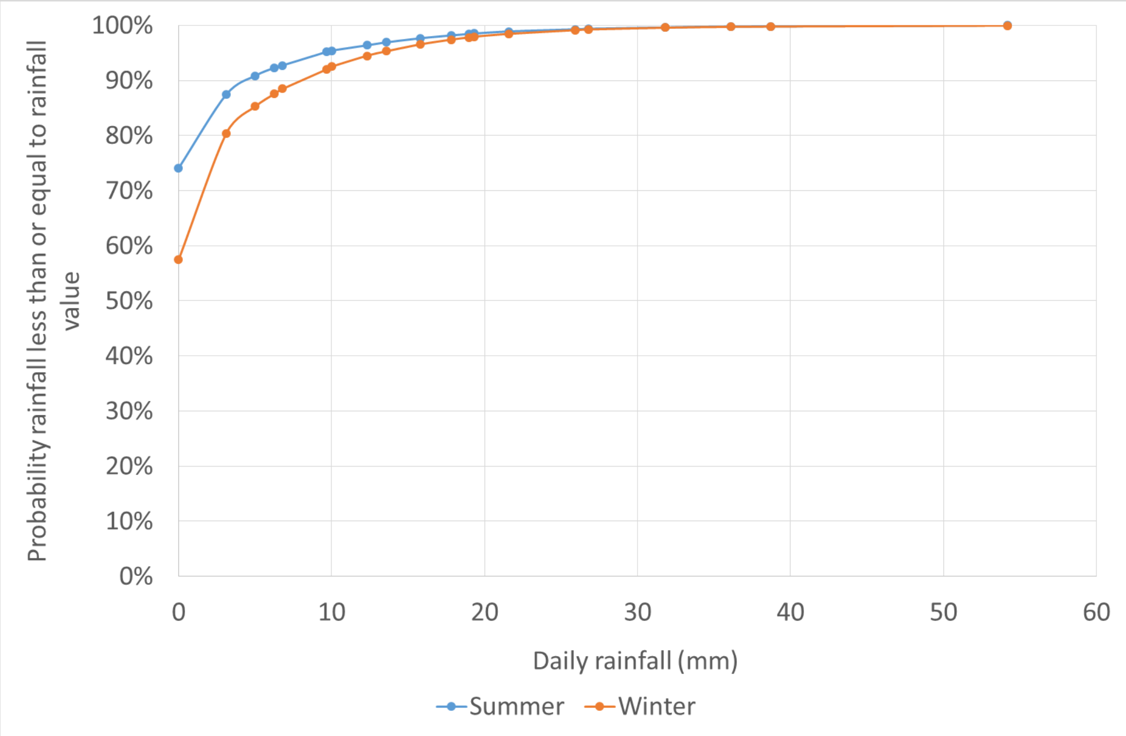

FIGURE 23. PROBABILITY OF DAILY RAINFALL LESS THAN OR EQUAL TO RAINFALL AMOUNT

The pollutant load for each design event is estimated as:

$$L_{p,r} = C_p(D - S) + Q_pS$$

where C_p is the concentration of pollutant *p* in urban stormwater (as calibrated in the Source Catchments model for the TEER catchment which underlies the TEER CAPER DSS), Q_p is the concentration of pollutant *p* in raw sewage, *D* and *S* are the total discharge and sewage discharge associated design event respectively based on the CoL hydraulic model.

Catchment loads were then estimated as the integral of the probability – load curve for each season estimated using the probability associated with each design event at each discharge point, as shown in Figure 24.

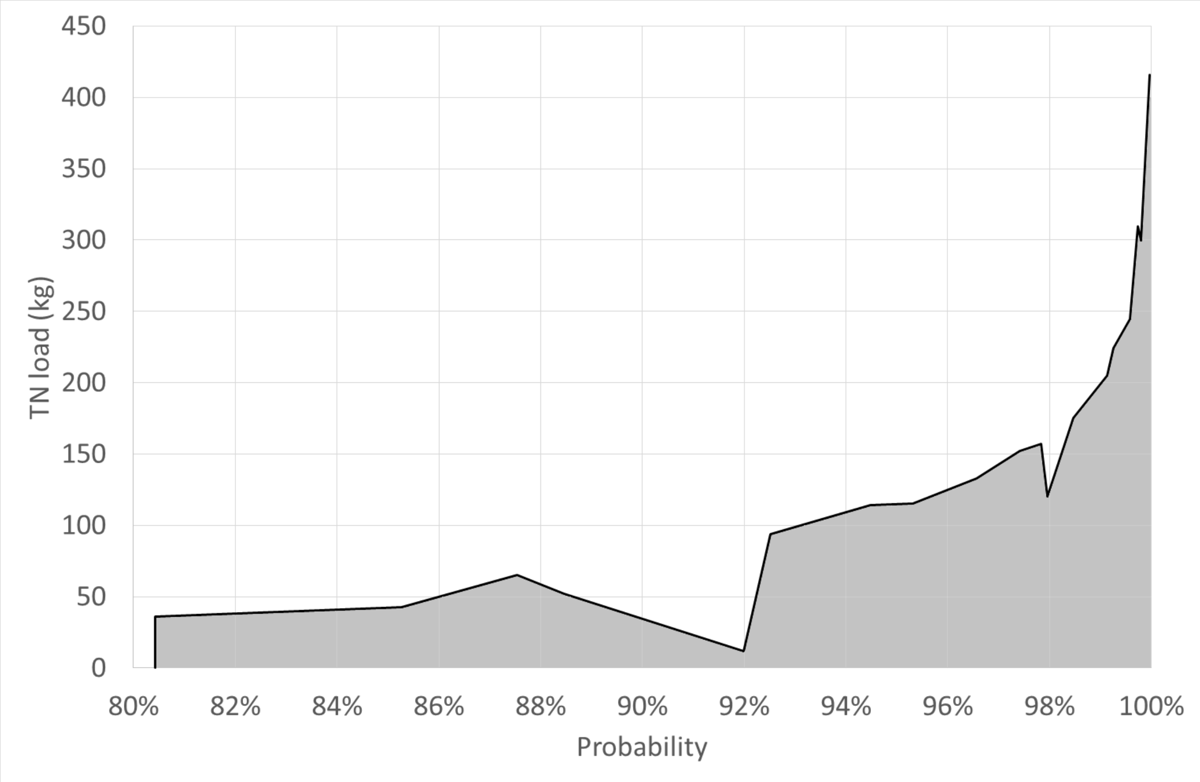

FIGURE 24. EXAMPLE OF CALCULATION OF WINTER TN LOAD DISCHARGED AS CSOS AT MARGARET FOR THE BASE CASE SCENARIO

Loads are effectively weighted by the likelihood of each event to calculate an expected daily average load. This is then multiplied by the number of days in each season. So the total load from the discharge point is:

$$\bar{L} = \sum_{r=1}^{n} \frac{(L_{p,r} + L_{p,r-1}) \times (\alpha_r - \alpha_{r-1})}{2}$$

where α_r is the probability associated with design event *r* and $L_{p,r}$ is as calculated above.

A1.2. Modelling discharges at Ti Tree Bend STP

Discharges at Ti Tree Bend STP are modelled using the same basic approach, although in this case the minimum rainfall is 0mm. Total combined flows and sewage volume to Ti Tree Bend have been provided by CoL staff from the hydraulic model for each of the design events. Analysis of this data showed that the dry weather sewage component is an underestimate. Jessup (2015) estimates that dry weather flows to Ti Tree Bend STP are 12.2ML, consisting of raw sewage. This lines up well with an analysis of influent data measured at Ti Tree Bend that showed the minimum dry weather inflow to TTB STP is 11.1ML with a range of values above this on zero rainfall days. This compares with a weighted average sewage flow to the estuary of 4.5 ML from the CoL hydraulic model. Given the uncertainty it was decided that Jessup's value should be adopted. Sewage and combined inflow was thus set to 12.2ML for periods of zero rainfall. A fixed additional sewage input of 8.5ML was found to provide an average daily sewage input (weighted by probability) of approximately 12.2ML.

Influent to TTB STP is then assumed to be the sum of base case influent and avoided CSOs under the scenario. As was the case with CSOs pollutant loads are estimated using a combination of raw sewage concentrations and stormwater concentrations for each pollutant applied to the raw sewage and estimated stormwater component.

Total effluent for each design event is then:

$$E_{p,r} = e_{p,i} I_{p,r}$$

Where $e_{p,r}$ is a multiplier reflecting treatment efficiency for the pollutant *p* and influent volume *i* for design event *r*, and $I_{p,r}$ is the influent load of pollutant *p* for design event *r*. Derivation of the treatment efficiency multiplier used in the TEER CAPER DSS is described in Appendix 2.

Total effluent discharged from TTB is estimated in the same way as for CSOs as the sum of areas under the probability-load curve:

$$\bar{E} = \sum_{r=1}^{n} \frac{(E_{p,r} + E_{p,r-1}) \times (\alpha_r - \alpha_{r-1})}{2}$$

Note that unlike CSOs this curve extends to 0% probability. The dry weather value is assumed to remain constant while there is no rainfall. Load for events between 0 and the minimum design threshold rainfall (3.12mm) is assumed to remain constant at the base case level given it is assumed that no CSOs occur below this rainfall threshold. Effluent loads are then the sum of the area below this curve as shown in Figure 25.

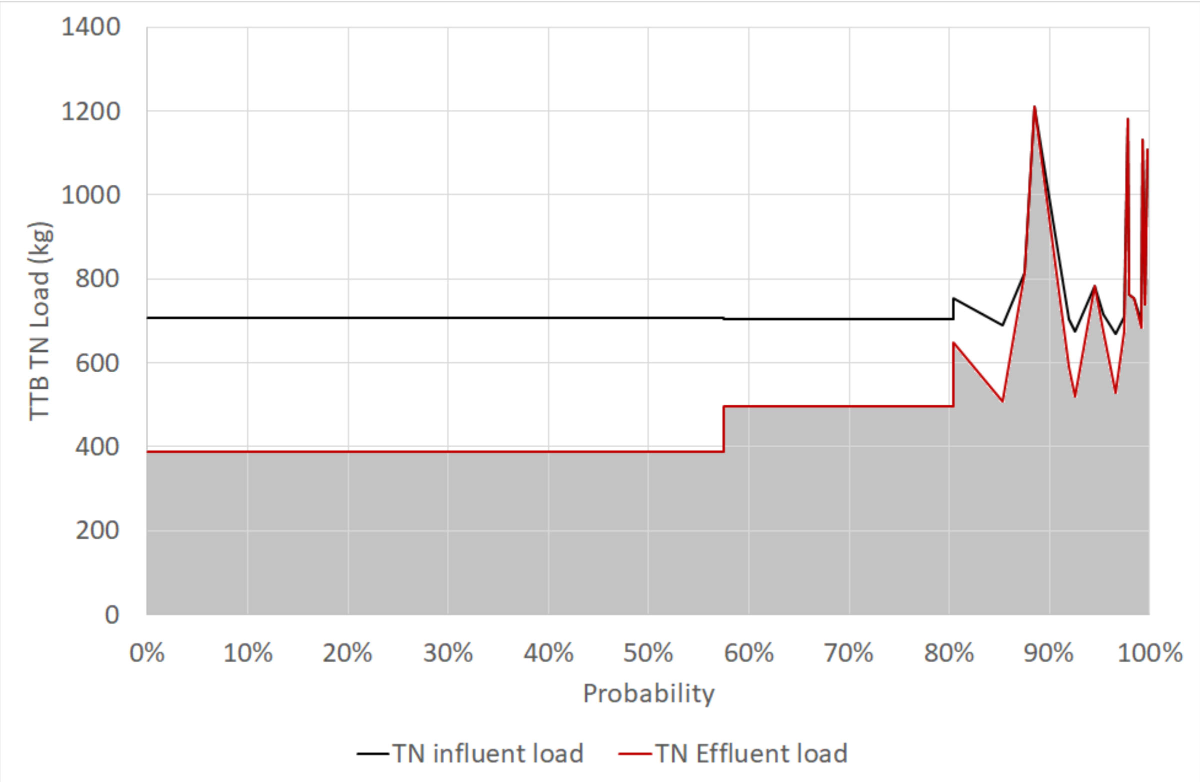

Figure 25. Calculation of effluent loads discharged from TTB STP

Appendix 2. Estimating impacts of increased flow on treatment effectiveness at TTB

As was described in Section X, it is known that treatment efficiency is likely to increase at Ti Tree Bend STP as influent increases. This is in part due to progressive bypasses to parts of the treatment process as influent volumes increase and partly due to less efficient treatment within those processes with increased flows. Given the potential for avoided CSOs to increase influent volumes and pollutant loads arriving at TTB STP for treatment it was felt that the potential effects of this should be tested in scenarios. This Appendix describes the data analysis used to estimate the effects of increasing influent volumes on treatment efficiency at TTB STP.

A2.1. Data

Ideally data would be available measured influent and effluent volumes and concentrations with which to calculate the proportion of influent load discharged to the estuary. Unfortunately sufficient data of this form was not available from TasWater. Data that was available did allow for estimation of influent and effluent loads however. Data sets provided by TasWater were:

- Daily influent volumes calculated as the sum of total flows from the City Rising Main and Hope st for 26/9/2015 to 22/10/2017 with some small gaps.
- Approximately 50 measurements of effluent concentrations of TN, TP, TSS and enterococci measured between July 2016 and June 2017 (approximately weekly).
- Approximately 38 influent concentration measurements for TN and TP from 1/9/2015 to 3/11/2017. These generally do not correspond to effluent concentration measurements.

A2.2. Estimating influent loads

Influent loads were estimated as:

$$I_t = C_p(F - S) + Q_pS$$

where *F* is the influent flow, *S* is the estimated sewage contained in the influent flow, C_p is the concentration of pollutant *p* in urban stormwater and Q_p is the concentration of pollutant *p* in raw sewage. In calculating influent load for these purposes, sewage volume was assumed to be the minimum of the influent flow value and the 12.2ML. Stormwater influent to TTB was then the difference between total influent flow and estimated sewage volume as described above.

The available influent concentration data was able to be used to test the accuracy of this estimate of influent load for TN and TP. Table 3 shows the measured and estimated values of both event mean concentration for days rainfall means stormwater is included in the combined influent and the concentration of raw sewage estimated on dry days (ie. zero rainfall).

TABLE 3. COMPARISON OF ESTIMATED AND MEASURED INFLUENT CONCENTRATION PARAMETERS

Parameter	**TN**			**TP**		
	Based on measured data	Based on modelled data	Difference	Based on measured data	Based on modelled data	Difference
Event mean concentration (mg/L)	44.9	35.3	-21%	6.8	6.8	0%
Raw sewage (mg/L)	56.9	58.0	2%	8.9	11.2	26%

The values in this table show that the approach is reasonably accurate in reproducing key influent concentration parameters. As such, given the paucity of influent concentration data it is deemed that this approach is appropriate for estimating the treatment effectiveness of TTB.

A2.3. Estimating effluent loads

Effluent loads were calculated using the measured effluent concentration data and assuming that effluent volume is equal to influent volume (in line with assumptions made by Jessup, 2015). This is likely to overestimate effluent volume to some degree as there will be some losses within the plant itself such as evaporation.

A2.4. Relationships between the effective treatment and influent volume

Treatment effectiveness was then estimated as the proportion of influent that remains as effluent, that is:

$$e_k = \frac{E_k}{I_k}$$

where E_k is the effluent load for observation k and I_k is the influent load. Note that as e_k increases, treatment effectiveness declines.

Influent volume and treatment effectiveness data were then analysed to look for a relationship for TN, TP, TSS and enterococci. Table 4 provides a summary of the relationships found by this analysis. Figures 26 to 29 show fit of these empirical models.

TABLE 4. STATISTICS OF FIT FOR TREATMENT EFFECTIVENESS VERSUS INFLUENT RELATIONSHIPS AT TI TREE BEND

Parameter	TN	TP	TSS	Enterococci
Constant	0.28865	0.11750	0.00743	0.00077
Coeff Influent (kL)	2.128E-05	9.860E-06	8.070E-07	0
p-value on coeff influent	1.950E-08	3.405E-06	2.419E-08	NA
R^2	0.47	0.35	0.47	NA

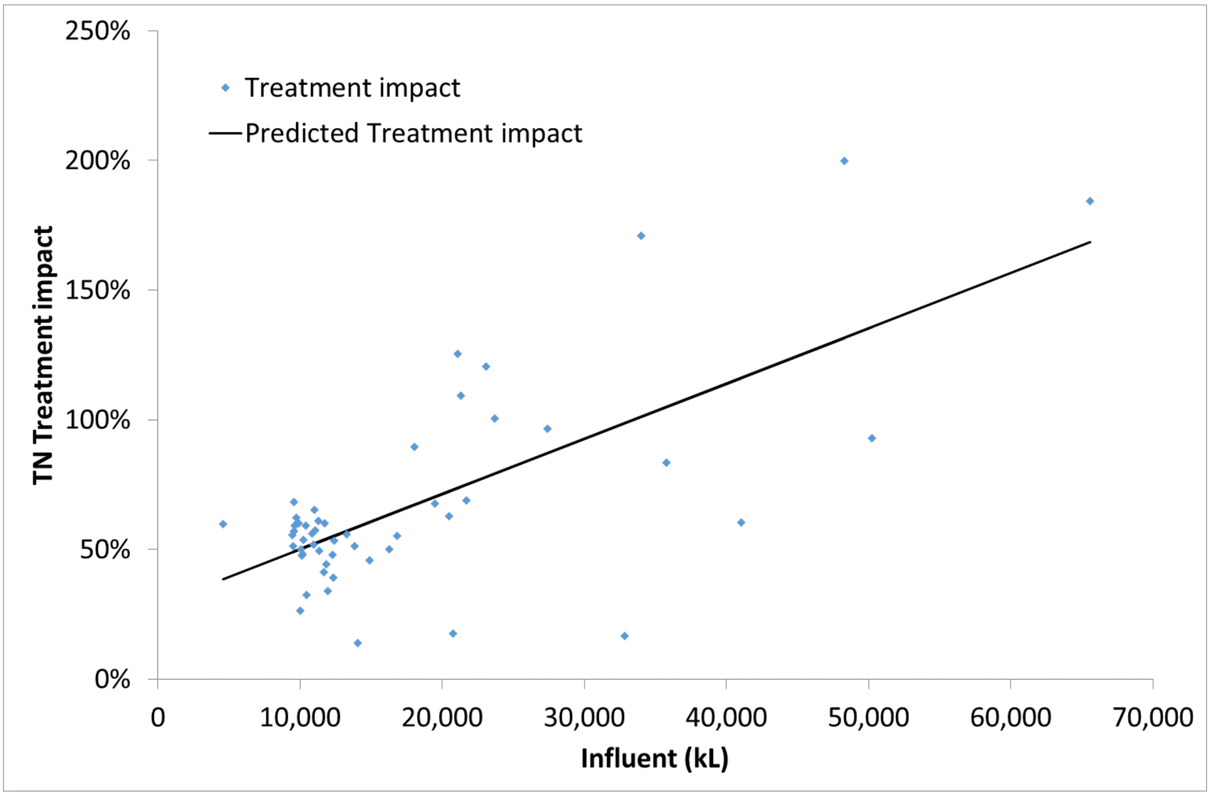

FIGURE 26. FITTED RELATIONSHIP BETWEEN TN TREATMENT IMPACT MULTIPLIER AND INFLUENT VOLUME

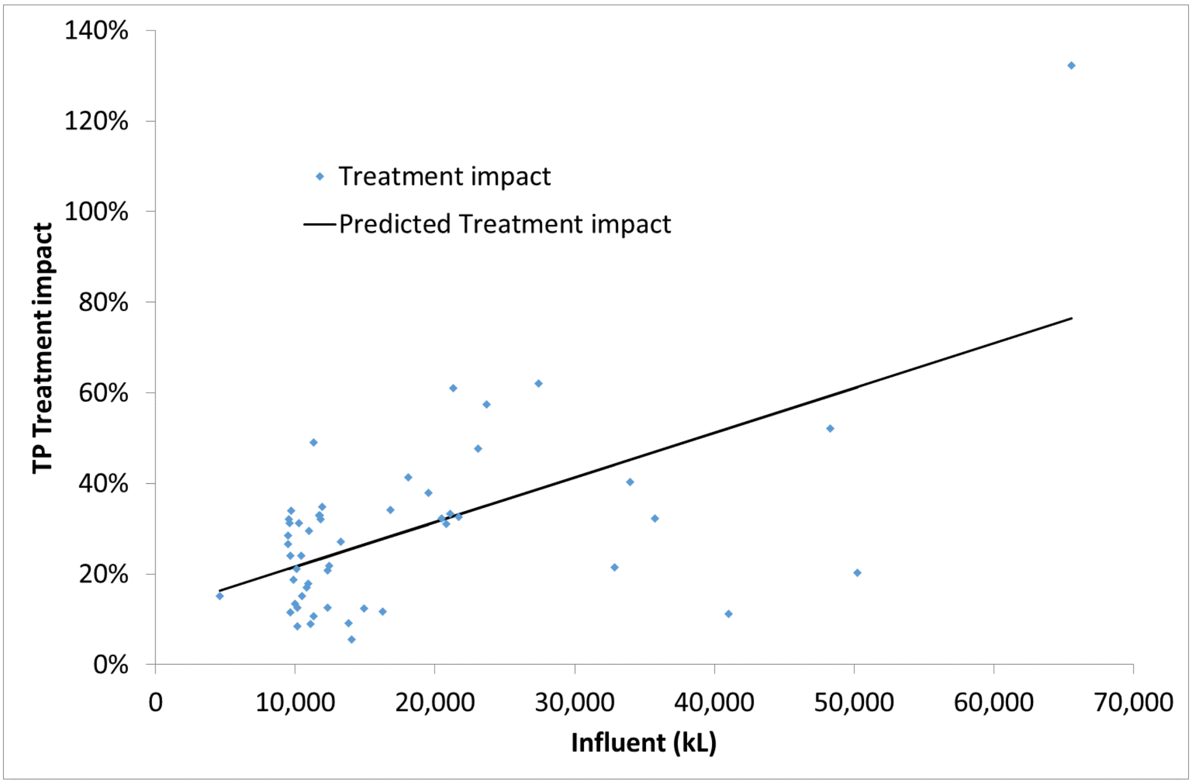

FIGURE 27. FITTED RELATIONSHIP BETWEEN TP TREATMENT IMPACT MULTIPLIER AND INFLUENT VOLUME

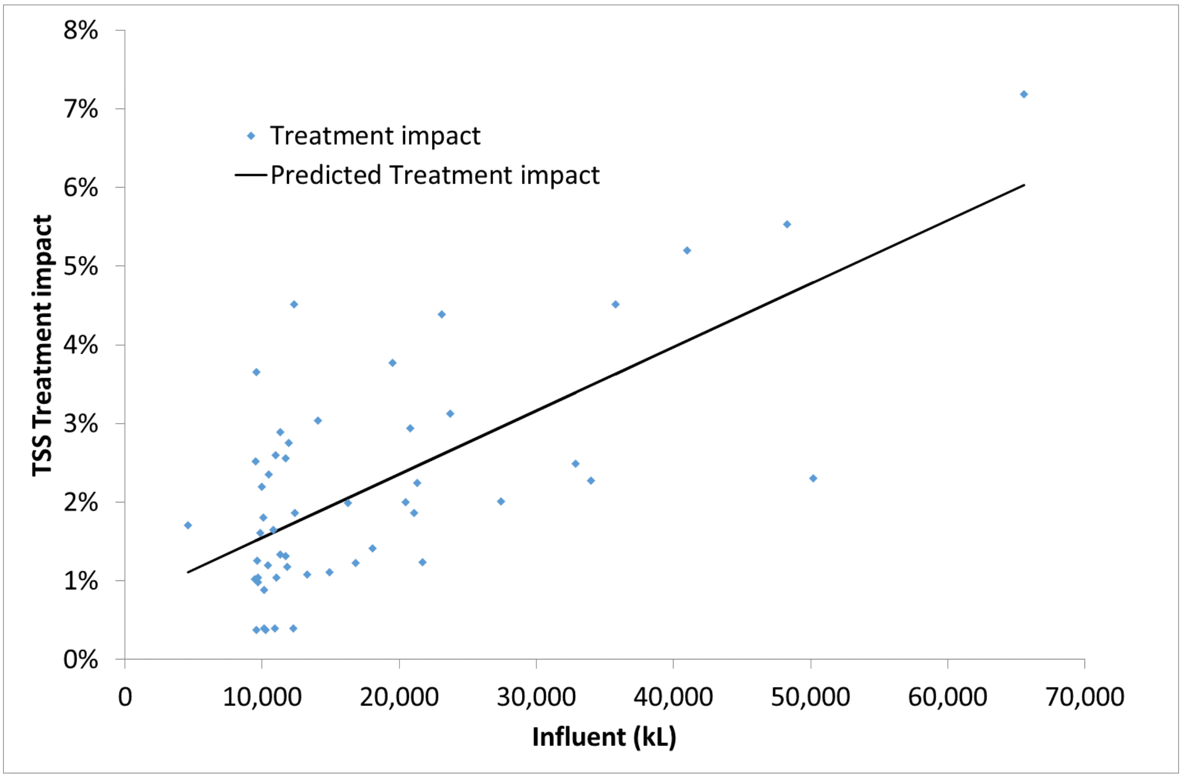

FIGURE 28. FITTED RELATIONSHIP BETWEEN TSS TREATMENT IMPACT MULTIPLIER AND INFLUENT VOLUME

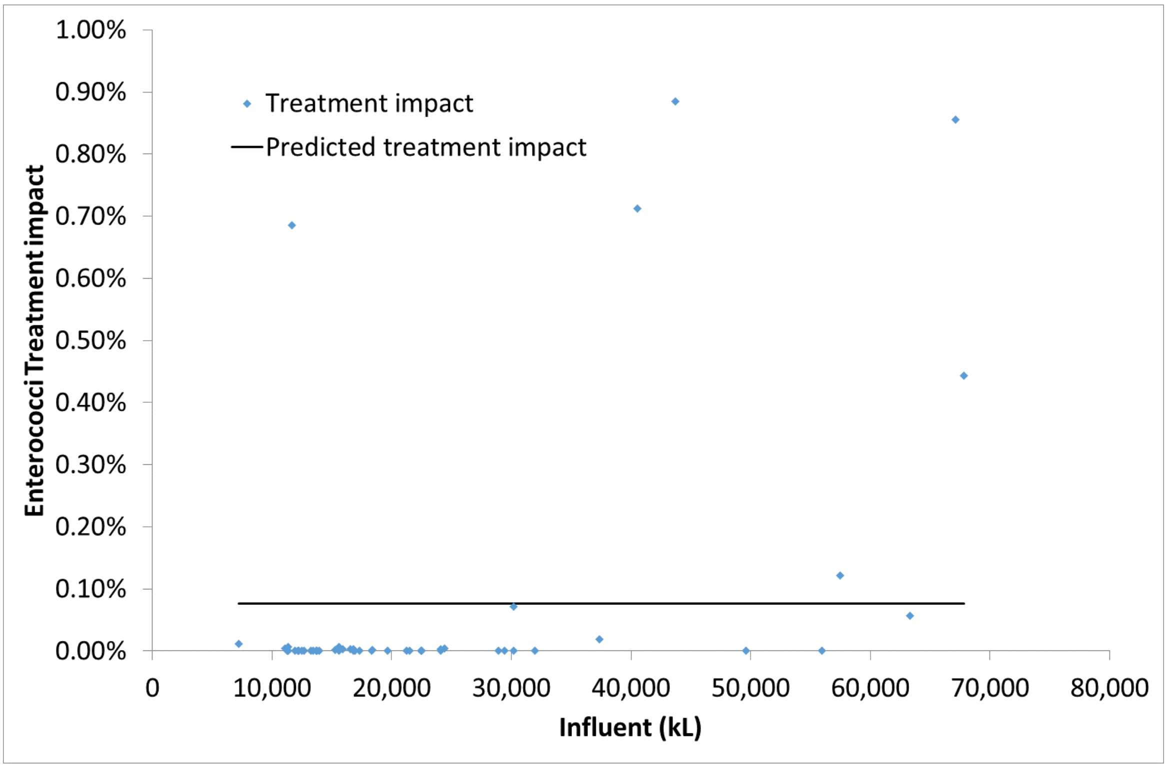

FIGURE 29. FITTED RELATIONSHIP BETWEEN ENTEROCOCCI TREATMENT IMPACT MULTIPLIER AND INFLUENT VOLUME (NOTE AVERAGE VALUE USED)

Table 4 and these figures indicate:

- There is a significant trend between the treatment impact multiplier and influent volume for TN, TP and TSS. In all cases *p*-values are very small (less than 0.00001) indicating a significant trend in the data.

- R^2 values for these relationships are fairly low (0.35 to 0.47). Inspection of the fits shown in the figures confirms that there is a significant variability of observations around the trend line demonstrating a high degree of uncertainty about the specific value of this multiplier.
- No real trend was observed for enterococci. Treatment impact multipliers are generally very low (less than 0.1%) indicating very effective removal of enterococci from influent to Ti Tree Bend. Given the lack of clear relationship with influent and the very low value of this multiplier a fixed average value has been used to model treatment impact of Ti Tree Bend on enterococci loads.