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Memorandum: Review of BMT WBM Tamar Lakes Scenarios Update

Dear Robin

Please find attached my review of the above report. If you have any queries please feel free to contact me on 0421 050 864 or at tonychurch@tonychurch.com.au

Kinds regards

Tony

Introduction

This report provides a brief overview of the memorandum entitled Tamar Lake Scenarios Update, including the methodology and sedimentation and water quality results for the proposed Tamar Lakes Scenarios (BMT WBM January 2016). BMT WBM has had a long history of involvement in hydrodynamic and water quality modelling in the Tamar River and estuary and this work represents the latest in ongoing investigations. This BMT WBM memorandum on sediment nutrient fluxes follows the development of a hydrodynamic and water quality model of the Tamar catchment, river and estuary which involved the compilation and analysis of existing water quality data, assessment of catchment landuse, calibration and verification of a suite of coupled catchment, hydrodynamic and water quality models. The scenarios outlined in the memorandum simulate water column water quality responses to two sediment nutrient flux rates at 17 sites in the Tamar River estuary. The objective was to examine water quality responses upstream and downstream of a proposed barrage in the estuary to a "base case" sediment nutrient flux and a "developed" sediment nutrient flux which can possibly be considered the "worst case" scenario.

It should be noted here that the scope of this report does not allow a comprehensive review of the model simulations although recommendations for future work are provided where uncertainty around model parameterisation and model results exist. Furthermore, I have not had access to the original model calibration and verification report and as such it is not possible to comment with any certainty on model calibration and verification both of which are fundamental to further simulations made by the model by way of scenarios. It is understood however that the model is well calibrated and verified against extensive existing water quality data (pers comm. M. Barry, C. Voss BMT WBM).

Background

The Tamar River estuary is located in north eastern Tasmania extending for approximately 70km from Launceston to Bass Strait on Tasmania's north coast. The river comprises the North Esk and South Esk Rivers. The South Esk River is the longest river in Tasmania and is the main source of freshwater and sediments to the Tamar. The Tamar and its tributaries drain a catchment area of approximately 10 000km^2 some 15% of the state of Tasmania (NRM North 2015).

The Tamar River estuary is a drowned river valley and is tidal for its whole length to the South Esk and North Esk Rivers. The Tamar River estuary gradually becomes less saline with distance upstream and is generally well mixed vertically (NRM North 2015). In periods of high river flows the lower salinity zone moves downstream creating conditions which are conducive to flocculation and settling of suspended sediments. In periods of low flow, the salinity zones extend further upstream and transport sediments in an upstream direction where it settles. Thus the upper reaches have been gradually infilling with fine silt and clay which has accumulated to a thickness of up to nine metres in some areas (GHD, 2009ain NRM North 2015).It has been estimated that an annual average of 30,000m^{3}of sediment has been deposited in the upper estuary. GHD, 2009b (in NRM North 2015) have reported that over the past 20years, nearly 1,000,000m^{3}has been dredged from the river. A proposed barrage is being investigated as a means of minimising the upstream tidal movement of sediment thus mitigating upstream sedimentation process and the need for the associated dredging works.

Catchment landuse includes green space, grazing, dairy, broadacre cropping, intense cropping, horticulture, rural residential, hardwood and softwood plantations, native production forests and urban areas. Pollutant inputs to the Tamar River estuary comprise both diffuse and point-source, including high levels of turbidity, nutrients, bacteria and metals. There are 26 Sewage Treatment Plants (STPs) within the greater catchment, 13 of which are located near the Tamar River, discharging effluent into the estuary or its tributaries. Four STPs are located in and around Launceston (NRM North 2015). It is understood that effluent quality emanating from these STPs is poor (pers comm. M. Barry).

There has been extensive water quality monitoring of the river and estuary, 17 sites of which have been used in the calibration of the BMT WBM water quality model. Overall water quality is rated poor in the upper catchments apparently rarely meeting water quality objectives and water quality guidelines (pers comm. M. Barry). Urban and rural landuses contribute to this poor water quality. Water quality then improves with distance downstream of the estuary towards the mouth where water quality is rated good primarily due to oceanic exchange.

Discussion of the Tamar Lakes Scenario Update

The following section provides a brief overview of water quality information provided in the memorandum entitled Tamar Lake Scenarios Update (BMT WBM 2016).

Total Suspended Solids

Figure 2-1 from the memorandum shows model results for Total Suspended Solids (TSS) at 17 sites and the top and bottom of the water column. The barrage simulation shows negligible TSS through the longitudinal profile compared to the Base Case which has elevated TSS between sites T1 and T7. This simulation demonstrates the effect of the barrage on TSS concentrations in the estuary.

Sediment Nutrient Flux Rates

Sediment flux parameter values are provided from the Aquatic Eco Dynamics (AED) Manual and various studies in SA, NSW and Nova Scotia. It would seem appropriate to consider studies closer to the Tamar that are more reflective of the local conditions. For example, a number of flux studies have been undertaken in Port Phillip Bay commencing with CSIRO in the 1990's by Professor Graham Harris and then more recently associated with channel dredging for the Port Phillip Bay channel deepening project. Of the studies cited in the memorandum none would appear clearly indicative of the Tamar estuary environment per se. Two studies were undertaken in Intermittently Closed and Open Lakes and Lagoons in NSW namely Smiths Lake and Lake Illawarra, Port Waterways in SA and a study in Nova Scotia.

The sediment flux values indicated in Table 4-3 of the memorandum appear to be relatively high. The base case sediment flux rate for ammonia is 6.23 mmol $m^{-2}d^{-1}$ and 2.32 mmol $m^{-2}d^{-1}$ for nitrogen. For the developed case ammonia and nitrogen sediment flux rates are 63.12 and 7.44mmol $m^{-2}d^{-1}$ respectively. In a study undertaken by Macreadie et al (2006) on denitrification measurements of sediments using cores and chambers in Port Phillip Bay indicates mean nitrogen fluxes in the range of approximately 250 – 800 µmol.m^{-2}.d^{-1} (0.25 to 0.8 mmol N m^{-2}.d^{-1}) and mean ammonium in the range of approximately 280 – 900 µmol.m^{-2}.d^{-1} (0.28 to 0.9 mmol N m^{-2}.d^{-1}). Heggie et al (1999) report dentrification rates in Port Phillip Bay of approximately 1.3 mmol N_2 $m^{-2}d^{-1}$ at organic carbon loadings of approximately 15-25 mmol $m^{-2}d^{-1}$. Seitzinger (1988) states that denitrification rates in coastal and marine sediments are generally greater than those measured in lakes or river systems and reports nitrogen flux rates in estuarine and coastal marine sediments from 1.2 to 6 mmol N m^{-2}.d^{-1} with extremes of 25.6 mmol N m^{-2}.d^{-1}. Seitzinger (1988) reports denitrification rates in lake sediments from 0.05 to 4.1 mmol N m^{-2}.d^{-1} and rivers and streams from 0 to 8.28 mmol N m^{-2}.d^{-1}.

Mass Balance

Table 4-3 of the report shows the mass balance for Total Nitrogen (TN) and Total Phosphorus (TP) given the parameters used for sediment nutrient fluxes. These results suggest upwards of 13,000 tonnes of nitrogen to the system from sediments during both summer and winter following construction of the barrage. While is it likely there will be an increase in nutrient flux from sediments caused by the barrage and due to higher concentrations of particulate and dissolved organic carbon and nutrient accumulation upstream of the barrage which would otherwise be flushed to the estuary, the scale of these increases remains uncertain.

Also noteworthy here is that the STP loads for TP are greater in summer than winter whereas TN loads are greater in winter than summer. Also TN loads are only 1.6 times TP loads in summer and 2.3 times TP loads in winter. In my experience TN loads tend to be at least 3 to 4 times greater than TP loads due to the relative concentrations in raw sewage and the primary treatment technology. With higher levels of treatment technology then TN loads can be up to 2 orders of magnitude greater than TP loads.

Overview of Water Quality Simulation Results

In order to better understand the results of the various simulations, the following overview is provided.

Sediment Nutrient Flux Comparison

Figures 4-1 to 4-20 show the results of the Base Case scenario compared to the Developed Case scenario.

In summary:

- Bottom layer dissolved oxygen is depleted upstream of the barrage at sites T8 to T11. Oxygen depletion is most severe for the Developed Case with anoxic conditions simulated at times at sites T10 and T11.
- Ammonium concentrations are elevated throughout the water column for both the BaseCase and the Developed Case while the highest concentrations occur at the bottom at sites T1 to T11 for the Developed Case.

- Similarly nitrate concentrations are elevated at all sites for both the Base and Developed Cases. The highest concentrations occur during summer at the surface and bottom for the Developed Case.
- TN shows similar trends to ammonium and nitrate with the highest concentrations at the bottom upstream of site T11 for the Developed Case.
- Filterable Reactive Phosphorous (FRP) concentrations are highest in the upper estuary at sites T1 to T5 suggesting urban and STP inputs. While longitudinal trends in FRP are very similar for the Base Case and Developed Case the exception to this is at the bottom during summer at sites T8 to T11 where Developed Case concentrations are clearly higher than those for the Base Case suggesting greater sediment flux of dissolved inorganic phosphorus at these sites.
- TP is elevated at all sites particularly for the Base Case with the exception of sites T10 and T11 at the bottom in summer for the Developed Case reflecting greater sediment flux of dissolved inorganic phosphorus at these sites. The cause of the generally high TP concentrations for the Base Case is unclear.
- Chlorophyll a concentrations are generally elevated at the surface at most sites for both the Base and Developed Cases. Chlorophyll a concentrations are particularly elevated for the Developed Case at the surface (and to a lesser extent the bottom) upstream of site T11 during summer.

Figures 4.21 to 4.40 show Scenario 1 with currents STPs, flows to top 2 m of barrage, Base Case flux compared to the Developed Case.

In summary:

- Dissolved oxygen (DO) simulations are similar to those for the sediment nutrient flux comparisons although Base Case simulations show higher DO concentrations at sites T10 and T11 at the bottom in summer. The reason for this is unclear.
- Ammonium is particularly elevated for the Developed Case at site T8 to T11 at the bottom in summer. It is also elevated at most sites at the surface in winter and at the bottom in winter at sites T1 to T11. The 2m surface discharge appears to reduce ammonium concentrations in summer for the Developed Case at the surface at all sites and at the bottom during summer at sites T1 to T7.
- Nitrate simulations are similar to those for sediment nutrient flux comparisons in winter, however, surface and bottom nitrate concentrations are lower in summer for scenario 1 than the sediment nutrient flux comparisons suggesting a response to the 2m discharge.
- TN simulations show similar trends to those shown for nitrate.
- FRP simulations are similar to those for the sediment nutrient flux comparisons showing a slight response to the 2m discharge.
- TP simulations are similar to those for the sediment nutrient flux comparisons showing no significant response to the 2m discharge.
- Chlorophyll a simulations are similar to those for the sediment nutrient flux comparisons showing no significant response to the 2m discharge.

Figures 4.41 to 4.60 show Scenario 2 which is Scenario 1 with LSIP. In summary:

- DO simulations are the same as Scenario 1
- Ammonium simulations are essentially the same as Scenario 1 except concentrations in the upper reaches are slightly lower in winter at both the surface and at the bottom than those shown in Scenario 1demonstrating the effects of the Launceston Sewage Improvement Project (LSIP).
- Nitrate simulations are essentially the same as Scenario 1 except median concentrations in the upper reaches at sites T1 and T2 are slightly lower in winter at both the surface and at the bottom for the Developed Case than those shown in Scenario 1.
- TN simulations are essentially the same as in Scenario 1.
- Trends for FRP are essentially the same as those of Scenario 1 with the exception of lower overall median concentrations at the surface and bottom at upstream sites for the Developed Case during both summer and winter demonstrating the effects of the LSIP.
- Trends for TP are similar to those for FRP.
- Slightly lower Chlorophyll a concentrations at the upstream sites T1 and T2 during summer demonstrate the minor water quality improvements associated with the LSIP.

Figures 4.61 to 4.80 show Scenario 3 which is Scenario 1 with current STPs with flows applied to the bottom 2 meters.

In summary:

- DO simulations are the same as Scenarios 1 & 2 with a distinct DO sag for the Developed Case at the bottom during summer at sites T8 to T11. The effects of the bottom discharge can be seen downstream of the barrage at sites T12 and T13 where DO concentrations are slightly higher at the bottom in summer (and to a lesser extent winter) for the Developed Case than those seen in Scenarios 1 & 2.
- Ammonium concentrations are similar to those seen in Scenarios 1 & 2 with a slight reduction at sites T12 to T15 at the surface and bottom in winter along with very minor reductions at the surface in summer for the Developed Case.
- Nitrate concentrations are similar to those in Scenarios 1 & 2 with the exception of generally lower median concentrations at the surface at sites immediately downstream of the barrage.
- TN concentrations show similar trends to ammonium and nitrate with lower median concentrations immediately downstream of the barrage particularly at the surface for the Developed Case during both summer and winter.
- Median FRP concentrations show very little response to the bottom 2m discharge with a slight decrease in variability at the surface during both summer and winter immediately downstream of the barrage for the Developed Case.
- TP concentrations are similar to those for the previous scenarios with the exception of slightly lower median concentrations at the surface at sites T12 and T13 during summer for the Developed Case.
- Median Chlorophyll a concentrations show variable responses to the bottom 2m discharge. During summer (and to a lesser extent winter) median surface Chlorophyll a concentrations are lower downstream of site T11 than for Scenario 2. At the bottom, median summer

Chlorophyll a concentrations at sites T10 and T11 are slightly higher than those shown for Scenario 2 suggesting mixing of surface water due to the bottom discharge.

Figures 4.81 to 4.100 show Scenario 4 which is Scenario 3 with LSIP.

In summary:

- DO simulations are the same as those for Scenario 3.
- Ammonium simulations are the same as those for Scenario 3 with the exception of a reduction in median ammonium concentrations during winter at the most upstream sites (T1 & T2) at both the surface and bottom for the Developed Case.
- Median nitrate concentrations show similar trends to ammonium with a reduction in median ammonium concentrations during winter at the most upstream sites (T1 & T2) at both the surface and bottom for the Developed Case.
- Median TN concentrations show very little response to the LSIP. This seems unusual given both ammonium and nitrate show reductions at the most upstream sites.
- Median FRP concentrations demonstrate a marked response to the LSIP with lower concentrations in both surface and bottom waters in summer and winter at sites T1 and T2 with reduced variability at the surface and bottom during winter at sites T1 to T9. Elevated median concentrations at the bottom during summer at sites T8 to T11 remain evident in the Developed Case.
- Median TP concentrations also demonstrate a marked response to the LSIP with lower concentrations in both surface and bottom waters in summer and winter at sites T1 and T2 together with reduced variability at the surface and bottom during winter at sites T1 to T9. Elevated median concentrations at the surface and bottom during summer at sites T8 to T11 remain evident in the Developed Case. Elevated median TP concentrations at sites T8 to T11 at the surface in summer in Scenarios 1-4 seems unusual given correspondingly low FRP concentrations in these surface waters suggesting other factors are at play such as additional catchment sources of TP.
- Median Chlorophyll a concentrations are lower at the surface and bottom at the upstream sites (T1 and T2) during summer than in Scenario 3 demonstrating a local response to the LSIP.

Scenario 5 shows the transfer time from a salt water estuary to a freshwater lake.

Summary of Findings

While it is considered that relatively high sediment nutrient flux rates have been used in this investigation, the trends in water quality observed during this study are, in general, those I would expect to see in an estuary where a barrage has been constructed. For example, there is likely to be depletion of dissolved oxygen concentrations upstream of the barrage, particularly at the bottom in summer, which may result in sediment nutrient flux and associated deterioration in water quality. Thus while the model appears to be simulating water quality outcomes of the various scenarios, the question remains as to the severity of the observed impacts given the relatively high sediment nutrient flux rates used here. In addition, the relative benefits of the top and bottom discharges may be masked somewhat by the magnitude of the flux rates and simulated water quality outcomes along with the benefits associated with LSIP.

It would appear that the sediment nutrient flux rates have been applied as an average across the entire model domain. Given the high degree of spatial variability in flux rates coupled with the relatively high rates that have been used in this study the overall flux of sediment nitrogen simulated by the model is potentially overstated. This may also apply to soluble phosphorus fluxes. Furthermore, the Tamar Estuary SeaMap Habitat Map (provided by R. Firth) indicates that in the vicinity (including upstream) of the proposed barrage the estuary floor comprises largely cobble and reef. It would appear therefore that there is unlikely to be significant sediment nutrient flux in this area until such time as sufficient sediment has been deposited on the estuary floor post barrage construction. This then raises the question as to what is the anticipated sedimentation rate upstream of the barrage and at what point in time would sediment nutrient fluxes likely commence. The net result of high flux rates is high bioavailable nutrient concentrations in the water column with the potential to stimulate algal blooms. Thus the assessment of likely sediment nutrient flux rates and the estimation of the temporal and spatial scales associated with sedimentary processes in the estuary upstream of the proposed barrage are critical to inform further debate.

Recommendations

In order to allow more informed debate on the potential water quality impacts of the construction and operation of a barrage in Tamar River estuary, it is recommended that:

- A literature review is undertaken of sediment nutrient flux rates (for both N and P) focussing on mild temperate maritime climates including but not limited to Port Phillip Bay.
    - Sediment nutrient flux rates for mild temperate lakes should also be investigated. Spatial and temporal variability in flux rates should also be documented where possible.
    - The review should examine published literature as a priority.
    - The review should then inform debate on the most suitable flux rates to be used in future scenario modelling.
- In the event that suitable flux rates cannot be found in the published literature for an estuarine system similar to Tamar, stakeholders should consider undertaking a replicated sediment nutrient flux investigation in the non-tidal, freshwater tidal and saline-tidal waters of Tamar Estuary.
    - This should be undertaken in both summer and winter. These data would then form the basis of flux rates for use in future scenario modelling.
- The sedimentation rate in the area upstream of the barrage is estimated to allow an assessment of the potential temporal scales associated with the onset of sediment nutrient fluxes with distance upstream of the barrage.

Heggie et al (1999) note that at low organic carbon loadings, high denitrifying efficiencies return most N to the overlying water body as generally unavailable nitrogen. At high organic loadings (> 100 mmol $m^{-2}d^{-1}$) most N is returned as biologically available ammonium. This suggests that ammonification (producing NH_4), nitrification (NO_3) and denitrification (N_2) are tightly coupled and respond to organic carbon loads.

- Given that the model is currently using literature values for Dissolved and Particulate Organic Carbon (DOC/POC) it is recommended that both DOC and POC be included in the routine monitoring of Tamar estuary.

References

BMT WBM (2016). Tamar Lake Scenarios Update Memorandum. 27 January 2016. Pp 1-72.

GHD (2009a). Draft Water Quality Improvement Plan for Tamar Estuary and Esk River Catchments. Final Version 1.2.

Heggie DT, Skyring GW, Orchardo J, Longmore AR, Nicholson GJ & Berelson WM. (1999).and denitrifying efficiencies in sediments of Port Phillip Bay: direct determinations of biogenic N2 and N-metabolite fluxes with implications for water quality. *Marine and Freshwater Research* 50(6) 589-596.

Macreadie PI, Ross DJ, Longmore AR, &Keough M J. (2006). Denitrification measurements of sediments using cores and chambers. *Mar Ecol Prog Ser* Vol 326: 49-59.

NRM North (2015). Draft Water Quality Improvement Plan for Tamar Estuary and Esk River Catchments. Final Version 1.2.

Seitzinger SP. (1988). Denitrification in freshwater and coastal marine ecosystems: Ecological and geochemical significance. *Limnol. Oceanogr*., 33 (4, part 2), 702-724.