A part of BMT in Energy and Environment

Tamar Lake Preliminary Technical Assessment

R.B18703.001.02.TamarLake.doc
February 2012

Tamar Lake Preliminary Technical Assessment

Offices

Brisbane
Denver
Mackay
Melbourne
Newcastle
Perth
Sydney
Vancouver

Prepared For:	Tamar Lake Inc
Prepared By:	BMT WBM Pty Ltd (Member of the BMT group of companies)

DOCUMENT CONTROL SHEET

BMT WBM Pty Ltd

BMT WBM Pty Ltd
Level 8, 200 Creek Street
Brisbane 4000
Queensland Australia
PO Box 203 Spring Hill 4004

Tel: +61 7 3831 6744
Fax: + 61 7 3832 3627

ABN 54 010 830 421

www.bmtwbm.com.au

Document :	R.B18703.001.02.TamarLake.doc
Project Manager :	Ian Teakle
Client :	Tamar Lake Inc
Client Contact:	Robin Frith
Client Reference	

Title :	Tamar Lake Preliminary Technical Assessment
Author :	Ian Teakle
Synopsis :	This report presents a preliminary technical assessment of hydrodynamic, water quality, siltation and flooding implications associated with the proposed Tamar Lake concept.

REVISION/CHECKING HISTORY

REVISION NUMBER	DATE OF ISSUE	CHECKED BY	ISSUED BY
0	25/11/2011	MAJ	IAT
1	01/12/2011	MAJ	IAT
2	10/02/2012	MAJ	IAT

DISTRIBUTION

DESTINATION	REVISION			
	0	1	2	3
Tamar Lake Inc	PDF	PDF	PDF	
BMT WBM File	PDF		PDF	
BMT WBM Library	PDF		PDF	

CONTENTS

	Contents		**i**
	List of Figures		**ii**
	List of Tables		**ii**
1	**INTRODUCTION**		**1-1**
	1.1	**Tamar Lake Concept**	**1-1**
	1.1.1	Barrage Description	1-1
	1.1.2	Proposal Benefits	1-1
	1.2	**Scope of Assessments**	**1-2**
2	**HYDRODYNAMICS**		**2-1**
	2.1	**Tidal Dynamics**	**2-1**
	2.2	**Salinity**	**2-3**
	2.3	**Flushing**	**2-4**
	2.4	**Stratification**	**2-5**
3	**WATER QUALITY**		**3-1**
	3.1	**Introduction**	**3-1**
	3.2	**Catchment Flows/Loads**	**3-1**
	3.3	**Point Sources**	**3-3**
	3.4	**Nutrient Cycles and System Transformation**	**3-4**
	3.5	**Summary of Water Quality Considerations**	**3-4**
4	**SILTATION**		**4-1**
	4.1	**Existing Situation**	**4-1**
	4.2	**Tamar Lake Concept**	**4-1**
	4.2.1	Upstream of Barrage	4-2
	4.2.2	Downstream of Barrage	4-2
	4.3	**Summary of Siltation Considerations**	**4-4**
5	**FLOODING**		**5-1**
	5.1	**Existing Conditions**	**5-1**
	5.2	**With Barrage**	**5-1**
	5.2.1	Benefit of Lake Drawdown and Non-tidal Regime	5-2
	5.2.2	Barrage Control Structure Requirements	5-2

5.2.2.1 Flood Flows 5-3
5.2.2.2 Drawdown 5-4
5.2.2.3 Daily Flows 5-5
5.3 Summary of Flooding Considerations 5-5

6 ASSESSMENT SUMMARY 6-1

7 REFERENCES 7-1

APPENDIX A: HYDRODYNAMIC MODEL RESULTS A-1

LIST OF FIGURES

Figure 1-1 Location Plan 1-3
Figure 2-1 Tamar Estuary Tidal Gradients – March/April 1985 2-2
Figure 2-2 Longitudinal Profiles of Salinity Measurements from DPIWE 2002-2004 2-4
Figure 3-1 Proportion of Sediment Generation in the Tamar Catchment 3-2
Figure 4-1 Regime Equilibrium Relationship for Tidal Estuaries 4-3

LIST OF TABLES

Table 3-1 Sewage Treatment Plant Loads (from BMT WBM 2010) 3-3
Table 5-1 Preliminary Estimate of Spillway Widths 5-4

1 INTRODUCTION

This report provides a preliminary technical assessment of the environmental feasibility of the Tamar Lake proposal as outlined in the document "The Tamar Valley – A Strategic Plan and Vision for its Development" (Frith, 2011). This assessment has been commissioned by the not-for-profit organisation "Tamar Lake Inc." in order to further investigate the potential environmental benefits, environmental impacts and constraints associated with the proposal. The assessment was undertaken by engineering and environmental consultancy, BMT WBM.

1.1 Tamar Lake Concept

Frith (2011) provides a concept plan for the Tamar Lake proposal.

In summary the Tamar Lake proposal is for the construction of a barrage across the Tamar River at the Eastern End of Moriarty Reach, in the approximate location shown in Figure 1-1. At this location the Tamar Estuary is approximately 650 m wide, with maximum depths of 25 to 35 m.

The barrage would separate the Tamar River into a tidal section on the downstream side and a freshwater lake on the upstream side. During non-flood conditions the barrage would be required to maintain an upstream lake level of approximately 1.0 m below current high tide level at Launceston. Accordingly a lake level of 0.6 m above Australian Height Datum (AHD) has been adopted in this assessment.

1.1.1 Barrage Description

The barrage would require a crest level above high tide level plus an allowance for future sea level rise. To meet these objectives the lowest feasible crest level would be approximately 2.2 m above AHD. A gated spillway would be required to pass catchment inflows when downstream tide levels permitted (i.e. downstream tide levels were below lake level). It is further proposed in Frith (2011) that power could be generated by passing normal barrage flows through screw turbines.

The gated spillway could also be used to drawdown the lake level preceding a peak flood inflow from the South Esk and North Esk catchments. Preliminary flood impact investigations detailed in Section 5 indicate that the gated spillway would be required to pass the full design flood in order to ensure no increase in flood level impacts at Launceston. The gated spillway would need to be of the order 300 to 500 m long to satisfy this requirement.

1.1.2 Proposal Benefits

The Tamar Lake proposal as described in Frith (2011) is directed at providing significant net benefits in terms of the following items:

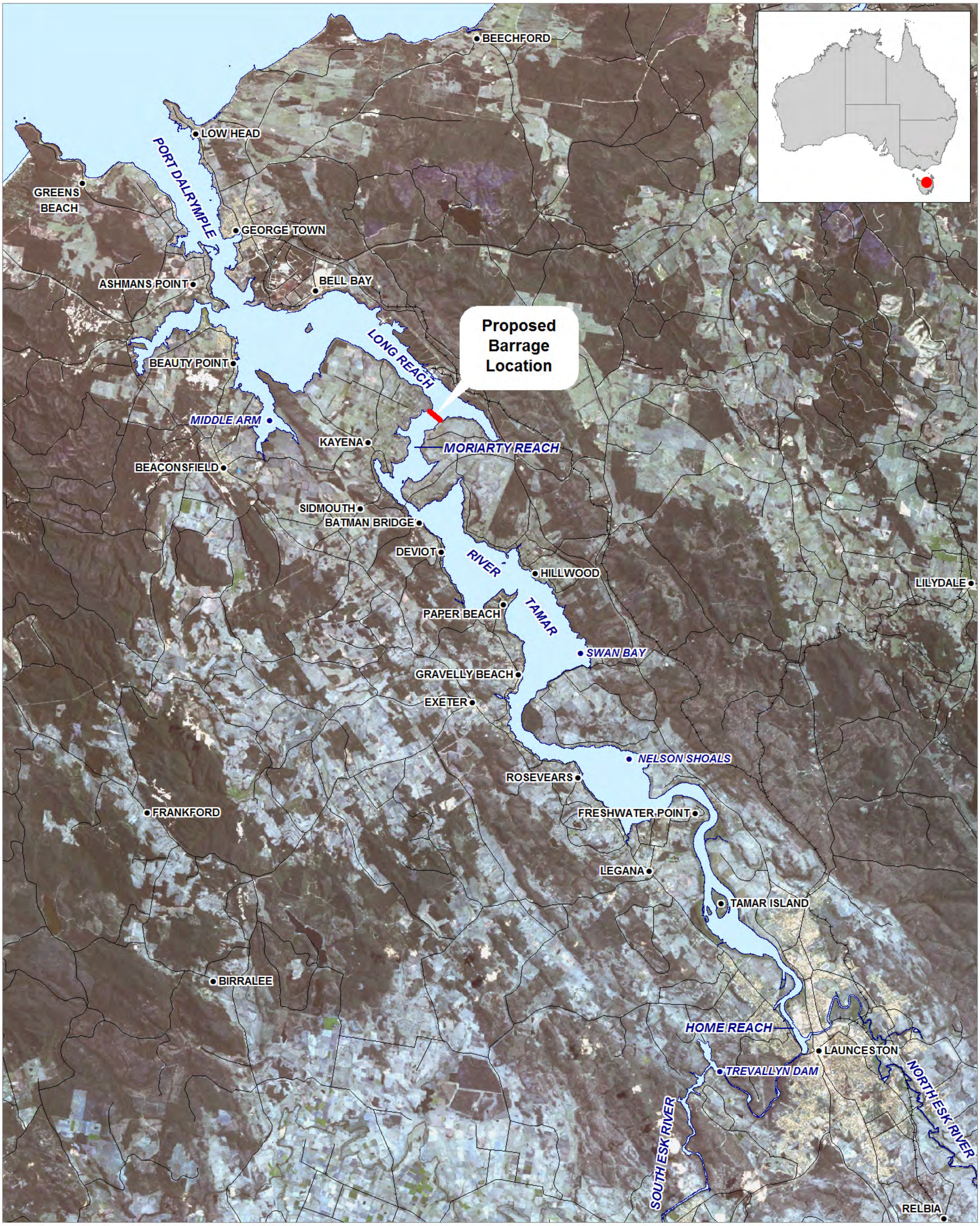
- Silt Management;
- Flood Mitigation;
- Freshwater storage and irrigation;
- Power Generation; and
- River amenity and tourism.

The purpose of this assessment is to undertake some pre-feasibility considerations of the potential benefits and other potential impacts associated with the Tamar Lake proposal. The scope of the particular pre-feasibility assessments included in this document are outlined below.

1.2 Scope of Assessments

The scope of the preliminary assessments reported herein are outlined in the points below:

- Changes to the hydrodynamic regime, upstream and downstream of the proposed barrage;
- Changes to the Water Quality regime, including qualitative assessments of:
  - Changes to the flushing regime; and
  - Changes to the nutrient cycle and potential for algal blooms.
- Changes to siltation regime, including qualitative assessments of:
  - Potential for suspended sediment bypassing of the freshwater lake;
  - Likely zones of reduced/increased sediment deposition; and
  - Likely downstream effects and the influence of discharge timing on sedimentation.
- Changes to the flooding regime, including qualitative assessments of the flood mitigation potential of the scheme.



Title:

Location Plan

Figure: 1-1

Rev: A

BMT WBM
www.bmtwbm.com.au

Filepath : I:\B18703_I_JLB Tamar Lake Constraints Assessment IAT\DRG\COA_001_111123_Location Plan.WOR

2 HYDRODYNAMICS

The Tamar Lake concept represents a significant proposed change to the hydrodynamics of the Tamar River system. The system hydrodynamics in turn drive water quality (Section 3), siltation (Section 4), and flood response (Section 5).

Assessments of the Tamar Lake proposal hydrodynamic changes have been split into the following sections:

- Tidal dynamics;
- Salinity; and
- Flushing.

Hydrodynamic modelling has been used to inform some of the assessments described in this report. The hydrodynamic models used in this study are based on the models described in the reports by BMT WBM (2008b; 2009) undertaken for Launceston City Council. Appendix A includes some model comparisons between existing case and developed case simulations.

A more detailed summary of the existing hydrodynamic, siltation and water quality processes associated with the Tamar Estuary can be found in the following sources:

- "Tamar River Siltation Study", Foster et al. (1986);
- "Review of Foster (1986) Report on Sedimentation Processes", BMT WBM (2008a); and
- "Hydrodynamic Modelling of the Tamar Estuary Final Report", BMT WBM (2009).

2.1 Tidal Dynamics

The Tamar Estuary is a body of water approximately 55 km long from its entrance into Bass Strait to the upstream tidal limit on the North Esk River, covering a total area of around 90 km^2. The total volume of the Tamar Estuary is approximately 740 gigalitres (below Mean Sea Level).

The dominant process affecting the regular (tidal) hydrodynamics of the Tamar estuary is the entry and passage along the estuary of tides from Bass Strait. These tides are predominantly semi-diurnal. There is considerable amplification of tides as they propagate along the estuary to the tidal limits upstream of Launceston. This amplification is illustrated in Figure 2-1.

The tidal prism at a section in an estuary is the average volume of water that enters and leaves during tidal water level oscillations. With mean tidal range for the system of around 3 m the tidal prism of the entire Tamar Estuary is around $2x10^8$ m^3 or 200 gigalitres.

In the Tamar River, as is common in such estuaries, the tidal wave becomes progressively more asymmetrical as it propagates upstream. That is, its shape in terms of variation of both the water surface level and the tidal current speed becomes more peaked but of shorter duration during the flooding tide and smaller but of longer duration during the ebbing tide. This provides a mechanism for the differential transport of sediments, with dominant tide-induced transport in the upstream direction. As such during naturally occurring dry weather conditions tidal flows can lead to movement of sediments to the upstream parts of the estuary where they can settle out in areas where currents are too weak to keep them mobilised.

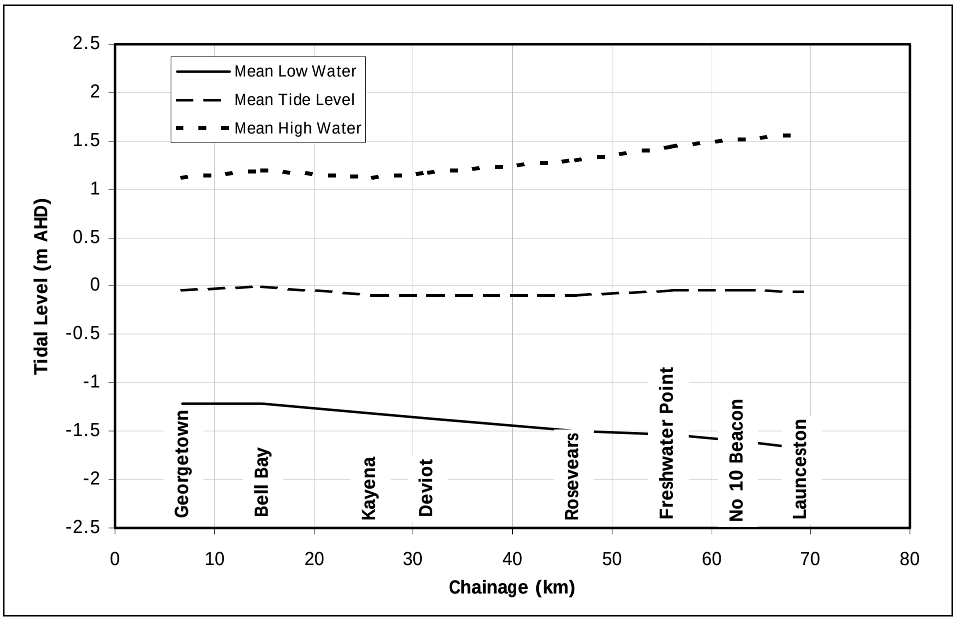


Figure 2-1 Tamar Estuary Tidal Gradients – March/April 1985

The Tamar Lake proposal would construct a barrage on the Moriarty Reach, creating a freshwater lake upstream and reducing the tidal exchange downstream of this point. The tidal prism at the proposed barrage location is currently $1.1x10^8$ m^3 or 110 gigalitres. With the barrage in place the tidal prism would be reduced by approximately half at Low Head (from around $2.0x10^8$ m^3 to around $1.0x10^8$ m^3) and would be reduced to zero immediately downstream of the barrage. This has implications for the flushing of the system as described below and for changing siltation patterns as described in Section 4.

The changes to water level variations both upstream and downstream of the barrage are illustrated in Figure A-1, which compares both maximum and minimum predicted water levels for the existing and developed cases. The model results indicate that spring tidal ranges would be increased by up to 0.3 m downstream of the barrage and this may have implications for existing infrastructure.

Upstream of the barrage, water levels would be held at around 0.6 m AHD, which is around 1 m below current high tide level at Launceston. A majority of the Rosevears and Tamar Island mudflats would be inundated at this level, but with significant areas with depths of less than 1 m. The Yacht Basin mudflats, which are currently only exposed at low tide would be inundated by water depths of around 2 m.

Due to the tidal prism reductions current patterns would be changed significantly both upstream and downstream of the barrage. Figure A-2 a) shows the maximum modelled current speeds during dry weather conditions for the existing case, while A-2 c) shows the equivalent result for the developed case. Main channel current speeds are approximately halved at Low Head and reduce to less than 10% of the existing case in Long Reach immediately downstream of the barrage wall.

It has been proposed that discharging from the barrage only during the ebb tide would assist with transporting the freshwater and its suspended sediment load out into Bass Strait. There would be some minor reduction in retention times with an ebb tide discharge, however it is unlikely that such an approach would significantly reduce the extent of mixing between the freshwater discharge and the water in the estuary downstream of the barrage. This is a consequence of the relatively small freshwater flow rates and the major reductions in tidal prism and consequently tidal flushing immediately downstream of the barrage.

As would be expected for the lake upstream of the dam wall, current speeds will be relatively quiescent during dry weather conditions. For instance at Batman Bridge the peak current speeds during would reduce from in excess of 1.5 m/s to less than 0.05 m/s during catchment inflows of around 50 m^3/s.

Current directions in the channel upstream of the barrage would be uniformly downstream in contrast to the oscillating tidal flows that characterise the existing situation. Flow patterns on the shallow mudflats would be driven predominantly by wind driven circulations.

Figure A-2 b) shows the maximum modelled current speeds during 100 year ARI flood conditions for the existing case, while A-2 d) shows the equivalent developed case. Maximum velocities are reduced in the downstream portion of the lake system (relative to the current tidal system) as the tidal flow component is of the same order (or larger) than the freshwater flow. This illustrates that the downstream portion of the lake system would be a more quiescent regime under the full range of expected flow conditions.

2.2 Salinity

Salinity in the Tamar Estuary varies from oceanic conditions (35 parts per thousand, ppt) at Low Head to generally less than 2 ppt in the Home Reach. There are variations in the longitudinal salinity profile depending on the current level of catchment inflows.

Significant horizontal gradients of depth-averaged salinity occur between Blackwall and Ti-Tree Bend. Within this mixing region vertical gradients of salinity are also evident, particularly during flooding stages of the tide.

DPIWE (2003) undertook comprehensive monitoring of water quality parameters along the entire Tamar Estuary between late-2002 and mid-2004. The longitudinal salinity variations observed during this period are shown in Figure 2-2.

Salinity is an important parameter for a range of physical, chemical and biological processes. For instance it is likely that sediment flocculation induced by the salinity mixing around Freshwater Point is an important component of the siltation process that results in upstream sediment migration into the Home Reach during dry weather conditions.

With the Tamar Lake proposal the system upstream of the barrage would be converted to a freshwater environment. The estuarine mixing zone would be forced to move downstream of the barrage. Partial mixing of the ocean water and freshwater discharged from the barrage would occur in the lower Tamar Estuary downstream of the barrage. Depending on how the barrage flows were discharged, the freshwater might form a stably-stratified surface layer that might inhibit complete mixing. However it is considered likely that significant mixing of the salt and freshwater would occur within the confines of the lower Tamar Estuary under tidal flow conditions. This would need to be investigated with more detailed three-dimensional hydrodynamic modelling than has been undertaken as part of this pre-feasibility assessment.

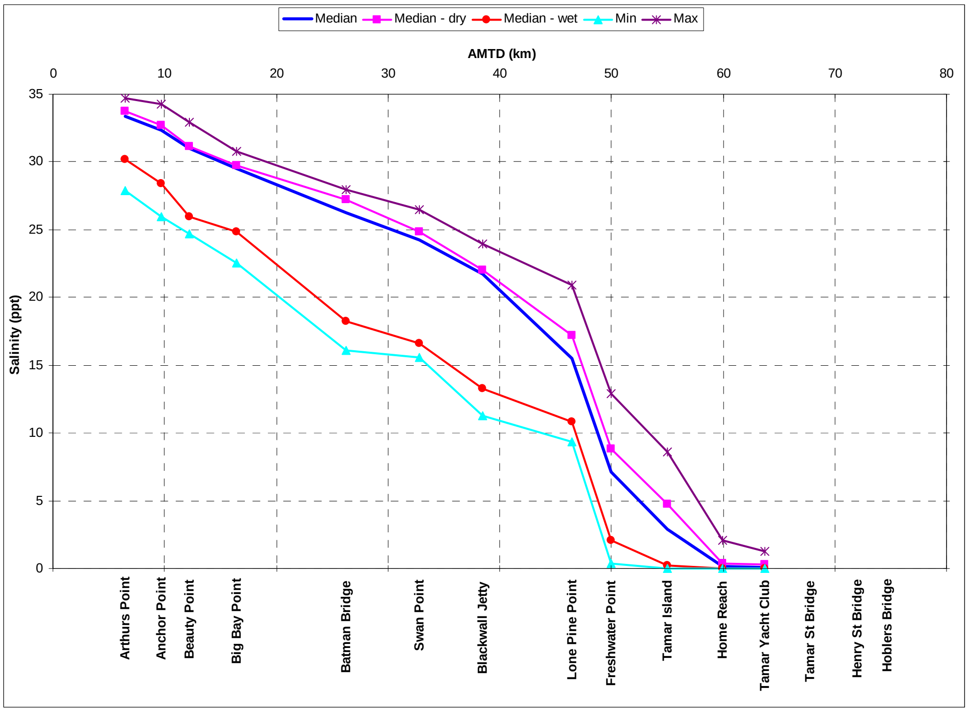


Figure 2-2 Longitudinal Profiles of Salinity Measurements from DPIWE 2002-2004

2.3 Flushing

The Tamar Estuary is currently flushed by two mechanisms:

- Catchment inflows; and
- Tidal exchange with Bass Strait.

In order to assess how the Tamar Lake proposal would affect residence times within the estuary a tracer flushing assessment was undertaken. This assessment involved initialising the hydrodynamic model with a unit conservative tracer upstream of the barrage location and modelling the gradual dispersion of this tracer from the system for typical dry weather catchment inflows of around 50 m^3/s. Flushing times are reported as the time it takes for the initial unit concentration to reduce by a factor 1/e, and this is usually referred to as the "efolding" time.

This assessment was undertaken for the existing state of the estuary and for the proposed developed case and the results are shown in Figure A-3.

Under the existing conditions the slowest flushing occurred in the vicinity of Deviot, with efolding times of around 40 days. Flushing times for the Tamar Lake scenario increased upstream of the barrage due to the absence of the tidal flushing mechanism. The slowest flushing occurred immediately upstream of the barrage, with predicted efolding times of around 105 days.

Decreases in the system flushing (increasing efold times) can increase the systems vulnerability to water quality problems as discussed in Section 3.

It should be noted that the simple relative flushing assessment undertaken here was performed for “dry weather” rather than “average” catchment runoff conditions. Under more “average” catchment flows of around 80-100 m^3/s the lake flushing times would be likely to reduce by around 60% while the existing tidally dominated flushing at Deviot would be unlikely to reduce as significantly. The freshwater system will inevitably flush less efficiently than the tidal regime across all catchment runoff conditions.

An important qualification on the first-pass flushing assessment detailed above is that it has been performed with a two-dimensional depth-averaged model, which is unsuited to simulating vertically stratified systems as described in Section 2.4 below. A more comprehensive assessment of flushing potential of the proposed lake system would require the application of a three-dimensional hydrodynamic model with the capacity to reproduce thermal stratification dynamics.

2.4 Stratification

Stratification is driven by density differences, which may result from vertical salinity and temperature variations in the estuary. Moderate to strong stratification can inhibit vertical mixing when flow conditions are relatively quiescent. Tidal flow conditions have a tendency to mix the flow and inhibit the development of both temperature and salinity stratification.

Due to the highly energetic macro-tidal flow regime, the Tamar Estuary is generally fully mixed with only localised and generally weak stratification typically observed. For instance some transient salinity driven stratification associated with the salt wedge dynamics has been observed in the vicinity of Freshwater Point (Foster, 1986).

The freshwater lake, due to its relatively quiescent nature and absence of ocean water exchange, will be more prone to the development of temperature induced stratification during summer months. This can have implications for system flushing and water quality as discussed in Section 3.

3 WATER QUALITY

3.1 Introduction

The management of water quality from catchments discharging into freshwater systems is an area of considerable research, especially where discharges into reservoirs are concerned. This research has focussed on the quantification of catchment loads, the role of diffuse and point source contributions, sediment accumulation, nutrient fluxes and the management of eutrophication and algal blooms. Within this chapter, current conditions with regards to water quality issues in the estuary and likely impacts on a freshwater dominated system in the area of the upper estuary are discussed.

3.2 Catchment Flows/Loads

The primary delivery mechanism for sediments into the Tamar Estuary is from flood flows depositing material sourced from the catchment. With several major rivers flowing into the estuary, such loads can be considerable and provide constant replenishment of any material that may be removed from the estuary by tidal processes or dredging. The conversion of the upper part of the estuary to a freshwater lake system will therefore need to take account of these catchment sources in how the system may need to be managed.

Work completed as part of the Tamar Estuary and Esk River catchment modelling study (BMT WBM 2010) identified that between 58,000-80,000 t/yr of sediment characterised as total suspended solids was estimated as being generated within the catchment, of which a proportion may be transported into the estuary. Reservoirs such as Trevallyn Dam would have the capacity to trap a proportion of this sediment from catchments upstream of it, however in flood flows it would be expected that a considerable amount would be moved into the estuary. In addition, approximately 26% of the Tamar Estuary sediment load would be generated in the North Esk River and in those smaller catchments immediately adjacent to the estuary, and these flows would not be mitigated by any reservoir trapping as shown in the figure below.

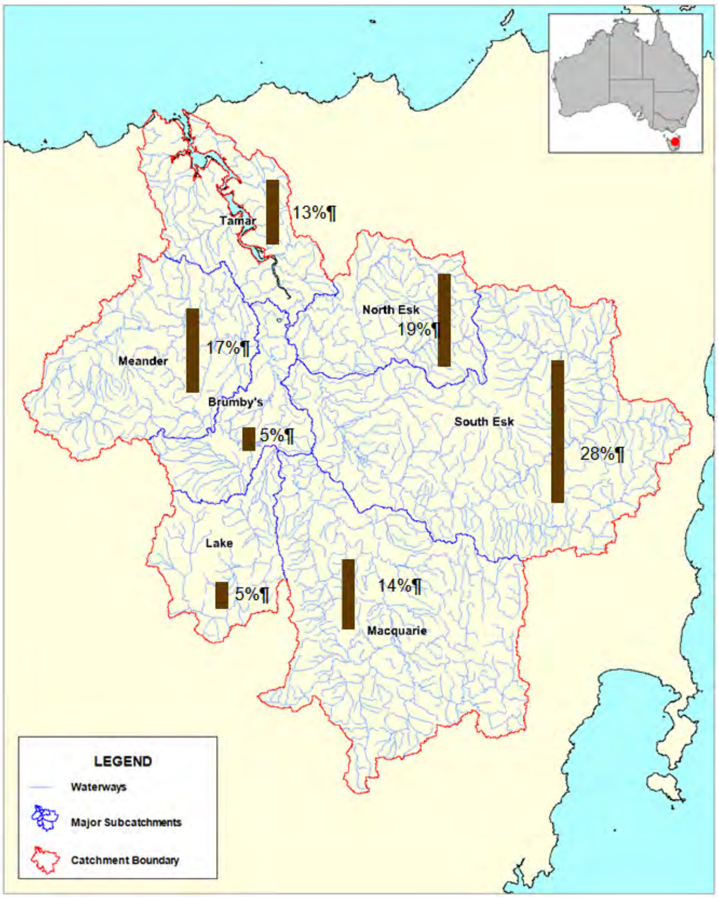


Figure 3-1 Proportion of Sediment Generation in the Tamar Catchment

As such, there is the potential for 15,000-20,000 t/yr of sediment to enter into the estuary if all that is likely to be generated in the catchment was to enter the estuary from these two catchments alone. There will be some degree of in-channel storage of this material, and that the area of the lake itself will not encompass the whole estuary, however this demonstrates that a significant quantity of sediment would be likely to flow into the proposed freshwater lake system. The fate of this sediment once it has entered the lake system is discussed in Section 4.

With regards to diffuse source loads, it is also expected that significant nutrient contributions from the catchment are likely as predicted by the previous catchment modelling. Mass loads in the order of 1,800-2,200 t/yr of nitrogen and 170-260 t/yr of phosphorus are generated in the catchment. The degree of trapping in reservoirs is likely to be less than that of sediment, hence a larger proportion of the catchment loads are likely to enter the estuary, and hence the proposed lake system would also receive this. It is expected that the majority of the phosphorus would be particulate bound, but some transformation both within channels and reservoirs would see that become soluble, and therefore readily bioavailable. Any remaining particulate bound nutrients may also settle out within the freshwater system and through further sediment/nutrient fluxes also be transferred into the water column and be bioavailable. This then may cause eutrophication (excessive plant growth) in a freshwater system and also be available for any phytoplankton (algae) or cyanobacteria (blue-green algae). If water temperatures and light climate become suitable, this could also lead to blooms of these species, some of which may be toxic. Again, given the flushing times predicted of greater than 100 days, this would be sufficient to allow blooms to occur, as periods in excess of 5 days (when conditions are suitable) can provide sufficient time for a bloom to propagate, though in the climate of the region, longer residence times would usually be necessary. From previous assessments (WBM 2009), it was noted that climatic conditions would basically prevent algal growth during winter due to low water column temperatures, though during summer periods it would be possible for those temperatures to be conducive to algal growth

Also of concern with regards to diffuse loads is the close proximity of urban runoff sources at the current head of the system. Given that runoff events from urban catchments can sometimes be up to 100 times more frequent than the runoff from non-urban areas and that there would be little lag between the time of the rainfall event and commencement of discharge into the lake, it may be that the urban runoff would have a greater influence on lake water quality than the proportion of that land use in the catchment would suggest. The urban areas within the catchment occupy approximately only 2% of the catchment area however are attributed to 10% of the sediment load generated.

3.3 Point Sources

Frith (2011) identifies that upon conversion, the lake system will not benefit from the tidal flushing and that a barrage could not be constructed until upstream waste water discharges meet the relevant Australian Standards. BMT WBM agrees with this in principle, although further analysis would be required to determine which standards are applicable to the particular eco-system that will evolve and if discharges were mitigated to that level could the desired water quality objectives for the Lake be achieved. This would only be possible with further detailed analysis including catchment and receiving water quality modelling.

To further explain, there were at least 12 sewage treatment plants within the Tamar Estuary and Esk River catchments when the BMT WBM (2010) assessment was undertaken, the majority of which were in close proximity to the head of the estuary where the lake system is proposed. as shown in the table below.

Table 3-1 Sewage Treatment Plant Loads (from BMT WBM 2010)

STP Name	Average Daily Flow (ML/day)	Total Suspended Solids (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Beaconsfield	0.40	14	9.5	6.0
Prospect Vale	1.35	59	13.0	8.9
Carrick	0.46	47	13.5	8.7
Deloraine	0.57	27	12.9	5.8
Hoblers	2.16	12	17.0	11.0
Norwood	3.95	18	24.0	11.0
Westbury	0.41	44	12.3	4.4
Fingal	0.13	60	17.8	6.3
Longford	1.54	28	13.9	11.7
Riverside	1.13	22	44.4	10.0
Newnham Drive	5.14	18	31.4	8.7
Ti Tree Bend	37.50	11	18.8	5.4
Total Flow (ML/yr) / Load (t/yr)	**19980 ML/yr**	**299 t/yr**	**406 t/yr**	**134 t/yr**

In some cases, discharges may occur directly into the lake system if not modified. As such, the amount of nutrients, which would be mostly in a bioavailable form, would provide sufficient resources to facilitate algal growth without significant improvements in treatment (again dependent on climatic conditions). The proportion of the nutrient load from these sources is relatively high in comparison to the diffuse source loads, representing 20% of the total nitrogen load and 40% of the total phosphorus load which could potentially reach the lake system. Given their form, it would be necessary to minimise these loads wherever possible, through redirection of any direct point source discharges to the estuarine part of the estuary, in combination with upgrades to treatment infrastructure to improve nutrient reduction performance.

It is understood (Robin Frith – pers. comm.) that Ben Lomond Water have undertaken to substantially upgrade their sewage treatment facilities discharging into the Tamar Estuary over a 5-year timeframe. The associated substantial reductions in point source nutrient loads should improve the water quality health of the Tamar Estuary and would significantly improve the water quality prospects for the Tamar Lake proposal.

3.4 Nutrient Cycles and System Transformation

The conversion of the current estuarine system into a freshwater lake raises several potential issues with regards to latent material in that part of the system. It is likely that in the transformation to a freshwater system, large changes in the sediment/nutrient fluxes would occur. The new conditions would be expected to cause a change in equilibrium such that those nutrients currently bound in the sediment in saline conditions would potentially be released into the water column when the system becomes freshwater dominated. In addition, other elements, especially sulfur, may also be released and have the potential to cause noxious odours (hydrogen sulfide) if conditions in the sediment are anoxic. The buffering capacity of a saline system can limit these processes, however as buffering capacity is lowered as the system moves to freshwater, changes in pH due to changes in nutrients and other elements are also likely.

3.5 Summary of Water Quality Considerations

The literature on changing long-term saline dominated systems to a long term freshwater system is limited. Therefore some of the impacts and effects may not be understood, although it is inevitable that this transformation will significantly alter the water quality characteristics and hence impact on the saline ecosystem. Examination of the ecological impacts of these changes would be required.

It is expected that given the diffuse and point source loads currently being discharged into the estuarine system, similar loads would be expected in the proposed freshwater system if these weren't improved. The expected loads still result in the requirement to actively manage sediment deposition within the lake system and may actually result in poorer water quality outcomes if eutrophication or algal blooms occurred. If both diffuse and point source discharges into the system can be appropriately managed, it is expected that the water quality in the freshwater system could achieve relevant water quality objectives, however no assessment of the cost and feasibility of the management actions has been determined in this assessment

Before further consideration of the freshwater conversion of the upper estuarine areas of the Tamar Estuary, detailed modelling and further research would need to occur to examine the likely fate of catchment derived material, possible improvements in point source discharge concentrations and the process of transforming a saline dominated system into a freshwater one would need to be carefully considered.

4 SILTATION

One of the principal benefits associated with the Tamar Lake proposal is the potential solution it poses to the Home Reach silt management problem as outlined in Frith (2011).

4.1 Existing Situation

Siltation of the Home Reach occurs due to the following physical processes:

1 Fine sediments are brought to the estuary during flood events. Even without fresh deposits there are essentially inexhaustible supplies of silt stored in the estuary bed, particularly in the Tamar Island and Rosevear mudflats.

2 Flood events scour sediment from the Tamar River Home Reach and Lower North Esk River.

3 Some of the flood borne sediment load transported downstream as ‘wash load’ and a significant proportion either remains in suspension locally or settles out in quiescent areas. The settling process is aided by flocculation of the sediment as the freshwater mixes with saline water.

4 The deposited sediment is subject to resuspension by spring tide currents in the main channel and wave action on the shallow embankments.

5 The asymmetry in the tidal currents, with the upstream flood tide current speed greater than the ebb current, leads to a differential in the sediment transport, with a net upstream movement.

Ongoing siltation of the Home Reach is essentially driven by natural processes as detailed above. However, anthropogenic influences have contributed to the siltation “problem”.

Catchment modifications have increased the sediment load entering the estuary. The potential source of sediment from the catchment is discussed in further detail in Section 3. However, the vast quantities of sediment already stored in the estuary dictate that substantial reductions in catchment sediment loads would be unlikely to substantially reduce the rate of Home Reach siltation.

Historic dredging during the 20th century imposed changes on the estuary that nature has been trying to drive towards a new equilibrium. Allowing this equilibrium to be attained would involve further siltation of the Home Reach, with various implications for river amenity as well as increasing Launceston’s vulnerability to flooding.

A recent study into the silt management options for the Upper Tamar Estuary (GHD, 2009) determined that ongoing dredging of the Home Reach and lower North Esk River was the best available option. Frith (2011) proposes the Tamar Lake as an alternative to an ongoing dredging program.

4.2 Tamar Lake Concept

The Tamar Lake concept would impose major changes to the siltation dynamics of the Tamar River both upstream and downstream of the barrage.

4.2.1 Upstream of Barrage

The mechanisms for upstream silt migration into the Home Reach would be effectively removed by halting the tidal flows with the barrage. Sediment would continue to be scoured from the Home Reach during flood events but the upstream silt transport during dry weather conditions would no longer occur. Therefore it would be expected that the Home Reach would become a net exporter of sediment under the Tamar Lake proposal.

Mixing of fresh and saline water would be moved downstream of the barrage and the accelerated flocculation and siltation that is believed to occur in waters where salinity exceeds around 3 ppt would be reduced. However, the lower energy hydrodynamic environment in the lake upstream of the barrage would probably experience substantial deposition from the silt entering the lake from the catchment. While it is considered likely that the rate of sediment accumulation upstream of the barrage would be substantially reduced under the Tamar Lake proposal, it is possible that this part of the system would remain a net accumulator of the sediment load entering from the catchment. Sediment would tend to deposit further downstream under the Tamar Lake proposal, with the Home Reach likely to be a net exporter of sediment.

Upstream of the barrage there would no longer be a tidal mechanism re-suspending sediment from the channels. There would continue to be a wave re-suspension mechanism acting on the shallow mudflats. It is possible that these changes would result in a gradual transfer of silt from the mudflats into the channel, with the system slowly attaining a more uniform depth.

It is difficult to determine the rate and extent of sediment removal from the Home Reach and to ascertain the implications of this removal. There is potentially some risk that, while removing the need for dredging, this process may introduce some new problems such as bank stability for instance.

Benefits from reducing or eliminating future net siltation in the Home Reach include minimising the requirement for future dredging and some benefit in terms of flood mitigation due to larger channel cross-section and hence flood conveyance capacity.

More definite quantification of the morphological response of the system upstream of the barrage would require more detailed numerical modelling assessments taking into account the processes and responses described above. In particular a more thorough understanding of the existing sediment flocculation processes and how these would be different under a Tamar Lake scenario would probably require scientific investigation in order to derive some of the fundamental input parameters to the numerical modelling exercise.

4.2.2 Downstream of Barrage

The sediment dynamics downstream of the barrage would be expected to change substantially as a result of the barrage construction. The primary reason for these changes is the large reduction in tidal prism imposed by the barrage.

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

Where the channel is out of equilibrium for some reason (e.g. due to dredging or change in tidal dynamics), there will be a tendency to re-establish equilibrium through either deposition or erosion provided additional sediment is available and/or the bed is erodible respectively. Thus (for example), previous extensive dredging of the upper Tamar River estuary has been followed by subsequent siltation in order to restore regime equilibrium.

Using numerical models of various tidal streams in Eastern Australia, BMT WBM has developed an equilibrium relationship that applies to a wide range of stream sizes from minor creeks to large rivers, as illustrated in Figure 4-1.

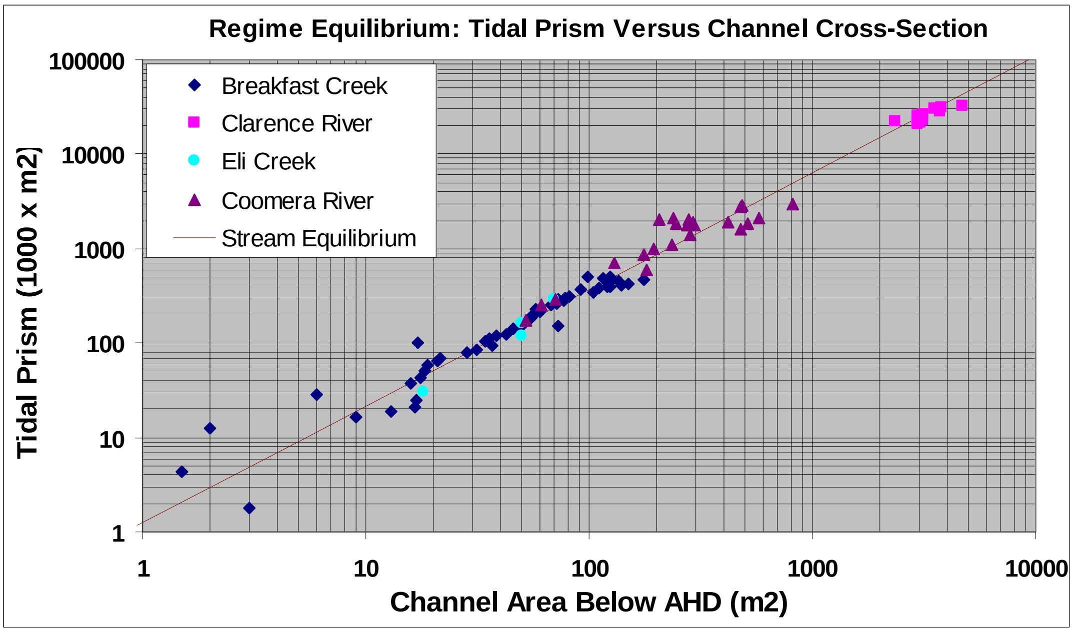


Figure 4-1 Regime Equilibrium Relationship for Tidal Estuaries

With an imposed reduction in tidal prism due to the barrage construction the downstream system would have a tendency to accumulate available sediment in order to develop a channel cross-section that is in regime equilibrium. The rate of any associated changes will depend on the rate of sediment supply. In the case of the lower Tamar Estuary, this sediment could be imported from Bass Strait or it could be delivered from the upstream catchment flows.

There are a number of reasons to believe that the rate of channel siltation downstream of the barrage would be much slower than the siltation currently experienced in the upper estuary. Firstly the channels are much deeper and will therefore accommodate a much greater volume of sediment deposition. Secondly, there may be a degree of “bypassing” of the catchment sediment load into Bass Strait due to limited mixing of the fresh and saline waters. Thirdly the mechanism for upstream transport of sediment into the lower estuary from Bass Strait may be slower than the transport generated by the highly asymmetric tide in the upper estuary.

More definite quantification of the expected rate and pattern of sediment accumulation downstream of the barrage would require more detailed numerical modelling of the hydrodynamics and sediment transport processes. A three-dimensional numerical model would be required in order to describe the process of fresh and saline water mixing, sediment flocculation and settling.

4.3 Summary of Siltation Considerations

In summary, the Tamar Lake concept is likely to:

- Stop ongoing siltation and result in net export of sediment from the Home Reach;
- Inhibit but not eliminate deposition in the freshwater portion of the system such that the lake would be likely to remain a net accumulator of catchment derived sediment;
- Experience greater rates of sedimentation than currently occurs in the more downstream parts of the lake; and
- Significantly change the morphodynamic regime downstream of the barrage such that a slow net accumulation of catchment derived sediment and sediment from Bass Strait would be likely to occur.

5 FLOODING

5.1 Existing Conditions

The South and North Esk Rivers combine at Launceston to form the River Tamar. Together the two rivers drain approximately 9,550 km^2 or some 14% of the state of Tasmania. The larger of the catchments is the South Esk River and significant flooding in the River Tamar is predominantly a result of rainfall events in the South Esk. Small catchments along the Tamar Valley do not contribute significantly to flooding in the River Tamar.

A number of flood studies of the River Tamar have been undertaken. One of the early studies was in the late 1950's and early 1960's by the University of New South Wales. A physical model of the Upper Tamar River was developed for this study. This study recommended the construction of a levee system to protect the low lying areas of Launceston, which were devastated by flooding in 1929. The levee system was constructed, but is now undergoing significant maintenance and upgrade works. In preparation for these works the Launceston City Council commissioned BMT WBM to undertake detailed numerical flood modelling of the River Tamar. Findings from this study are presented in the River Tamar & North Esk River Flood Study (BMT WBM, 2008). This work was undertaken in parallel with the Tamar Estuary Hydrodynamics Modelling Study (BMT WBM, 2009), which presented preliminary flood modelling results that lead to the more detailed work in BMT WBM (2008). For the 2008 study BMT WBM developed and calibrated a two-dimensional (2D) TUFLOW model of the full length of the River Tamar and the lower reaches of the North and South Esk Rivers. The model calibration was in the upper reaches only, but is considered to be the best available information at the location of the proposed barrage. Launceston City Council designated flood levels are derived from BMT WBM (2008).

In flood assessments the severity or magnitude of the flood is usually expressed in terms of an event's Average Recurrence Interval (ARI). The larger or more severe the flood event the less frequently it would be expected to recur on average and the higher it's ARI.

Flooding at the site of the barrage is significantly influenced by the tidal regime, the latter of which has a peak flow rate in a spring tide of the order of 8000 m^3/s. The peak 100 year ARI flow rate is approximately 3000 m^3/s. The modelling undertaken to date has not considered timing of the tide and flood wave at this location, but on reviewing the model results it is expected that the peak flood 100 year ARI flood level would be about 1.5 to 1.6 m AHD, i.e., 0.3 to 0.4 m above the peak tide level of 1.2 m AHD.

5.2 With Barrage

The construction of a barrage will result in increases in upstream flood levels. The magnitude and extent of any increases will be predominantly influenced by the degree of the blockage and the design of the hydraulic control structures associated with the barrage. Therefore this overview has focussed on a preliminary assessment of the size of such control structures. This analysis was done using desktop assessments informed by results from the TUFLOW model. A detailed assessment of barrage structure configurations in the TUFLOW model was not undertaken.

With regards to the configuration and operation of the barrage and lake, it was previously noted that Frith (2011) proposes the following:

- That the flood waters and water releases pass through gated spillways, locks and in larger events over the barrage crest;
- That the barrage crest would be about 1 m above high tide level (to accommodate for increased tide levels as a result of climate change) - a crest level of 2.2 m AHD is assumed;
- That the lake water level be maintained at about 1 m below the normal high tide level in Launceston - a lake level of 0.6 m AHD is assumed; and
- That the lake level be drawn down prior to arrival of a flood to provide a reduction in flood level in the river at Launceston over current conditions.

5.2.1 Benefit of Lake Drawdown and Non-tidal Regime

To assess the sensitivity of flood levels to a non-tidal regime and a lowered lake level the TUFLOW model was altered and rerun to determine a theoretical upper bound benefit (maximum decrease) to flood levels in the river at Launceston, assuming no barrage in place. A starting water level of 0.0 m AHD (the assumed drawdown level) was adopted and the ocean boundary was fixed at 0.0 m AHD so as to represent a non-tidal regime. There was no barrage structure in the model so that the effects of the lowered lake level and non-tidal regime could be isolated. The 100 and 200 year ARI events were assessed. In the 100 year ARI event there was a reduction in peak flood level of 0.18 m at Launceston and in the 200 year ARI event there was a 0.08 m reduction, again noting that this is without a barrage in place. As will be demonstrated in the following section the potential for a reduction in flood level at Launceston is in a sense theoretical only, and from a practical view point the benefit of the additional storage would most likely be realised through a reduction in the gated spillway requirement rather than a reduction in flood level.

Some further modest reduction in Launceston flood levels may be realised over time due to increases in the Home Reach channel cross-sectional area (and flood conveyance capacity) as a result of the changed siltation dynamics (refer Section 4).

5.2.2 Barrage Control Structure Requirements

The hydraulic control structures will be required to:

- Convey flood flows without causing increased flood levels in the river at Launceston and at other flood level sensitive locations along the river;
- Allow drawdown of the lake to occur prior to the commencement of the flood hydrograph; and
- Convey daily inflows to maintain the lake level at desired lake level - assumed to be 0.6 m AHD for the purposes of this analysis.

A desktop analysis (informed by TUFLOW model results) was undertaken to determine the hydraulic structure size for each of the above flow requirements as described below, with the exception that only flood impacts at Launceston were considered.

5.2.2.1 Flood Flows

The barrage will mostly likely be required to be designed such that there is no significant increase in flood level in the river at Launceston and possibly at some other low-lying communities. For the purposes of this preliminary analysis the flood level at Launceston was the only consideration. The TUFLOW model was used to determine the maximum water level that could occur at the site of the barrage without increasing the flood level at Launceston under a non-tidal regime and a lake level of 0.0 m AHD. This flood level was derived by iteratively adding energy loss in the TUFLOW model at the location of the barrage until an increase in the flood level at Launceston occurred. To account for the lowered lake level and non-tidal regime initial water level in the model was set at 0 m AHD and the ocean boundary was fixed at 0 m AHD.

The maximum allowable flood level at the barrage was then used in the desktop analysis to size the spillway requirements. The maximum level was found to be lower than the barrage crest level of 2.2 m AHD and so all flow was assumed to be passing over a gated spillway. In undertaking the desktop analysis, the follow assumptions were made:

- Weirs were ogee crests with discharge coefficient of 2.18 (The Design of Small Dams, BR(1977)) up to a submergence factor of 0.85 - the submergence factor is the tailwater depth above the spillway divided by the headwater depth above the spillway;
- When the submergence factor was between 0.85 and 1.0, the weir coefficient was linearly interpolated between 2.18 and 0 - this is not strictly correct but was considered to be a reasonable assumption for the purposes of this assessment;
- It was assumed that the spillway gates could be lifted above the flood level such that there would only be spillway flow;
- Lake area of 45 km2 (Frith, 2011);
- Vertical walls on lake above low tide (for the purposes of volume calculations);
- Change in water level in response to inflow/outflow occurs instantaneously across lake;
- A spring tidal cycle was assumed downstream of the barrage; and
- The flood flow hydrograph was adopted from the TUFLOW run with no tidal influence.

The width of gated spillway was sensitive to the spillway crest level, as would be expected. Therefore a range of crest levels were assessed - the practical limits on the spillway crest level were not taken into consideration. The preliminary estimate of spillway widths required so that there would be no increase in flood level in the 100 and 200 year ARI design events are summarised inTable 5-1. The 95% 200 year ARI flow hydrograph was used in this analysis as was adopted for the design of the levee system in Launceston (BMT WBM, 2008).

Table 5-1 Preliminary Estimate of Spillway Widths

Spillway Crest Level (m AHD)	Required Spillway Width (m)	
	100 year ARI	200 Year ARI
-3.0	210	300
-2.0	300	460
-1.0	460	700

With a crest level of -1.0 m AHD there would need to be 700 m of gated spillway. This is wider than the river and so is not practical. If the a crest level in the range of -3.0 m to -2.0 m AHD is adopted, the spillway gates would need to lift 3.5 to 4.5 m to be above the flood level. The practicalities of this have not been investigated as part of this report.

It is likely that using the spillway widths in Table 5-1 would result in a small reduction in flood level in the Launceston area because of the non-tidal regime and lower water level at the commencement of the flood. The magnitude of such reductions could only be calculated by modelling, which is beyond the scope of this study.

A consideration in the design will be increased ocean levels and flow rates due to climate change. The influence of climate change on flood levels at Launceston is yet to be analysed by Council and so flood levels in Launceston were not available for such an analysis. Nonetheless a theoretical desktop analysis with ocean levels increased by 0.8 m but assuming the current flood flow rates was undertaken. This analysis found that a barrage could not be constructed, even with increased spillway width, without increasing flood levels above existing in Launceston: an increased spillway width would not compensate for the significant reduction in outflow from the gated spillway that would occur with increased downstream tide levels. This is an unfair test because flood levels will increase at Launceston under a climate change scenario, but the analysis does serve to demonstrate that the barrage will not assist in keeping flood levels at the current levels under a climate change scenario. However, it would protect Launceston against increased tide levels associated with sea level rise on the assumption the crest is set above the future high tide level.

5.2.2.2 Drawdown

As previously noted it is proposed to drawdown the lake level prior to the arrival of a flood. A desktop analysis was undertaken to determine the gated spillway width required to achieve a drawdown from 0.6 to 0 m AHD within a 24 hour period. For gated spillway crest levels of -3.0, -2.0 and -1.0 m AHD, spillway widths of 70, 120 and 280 m would be required respectively. In this analysis a spring tide was assumed. The width requirements for flood flows are greater than these and so a drawdown requirement would not control the design.

5.2.2.3 Daily Flows

With regards to daily flows, BMT WBM (2009) provides a dry weather inflow rate into the estuary of approximately 50 m^3/s. A gated spillway width of approximately 10 m (assuming a crest level of -2.0 m AHD) depending on the crest level) would be required to pass this flow and keep the lake level in the range 0.6 to 0.7 m. If the average non-flood inflow over a 12 month period were to be 155 m^3/s (Frith, 2011), then a 25 m width would be required to pass this flow and keep the lake level in the range 0.6 to 0.7 m (assuming a crest level of -2.0 m AHD).

5.3 Summary of Flooding Considerations

A preliminary analysis has determined that a barrage could be constructed and not result in increased 100 and 200 year ARI flood levels at Launceston. Depending on the crest level of the gated spillway and subject to a detailed analysis, a spillway width in the range 300 m to 500 m is likely to be required. There is currently insufficient information available on future flood levels under a climate change scenario to allow a preliminary analysis. However, simply increasing tide levels in the desktop analysis demonstrated that the barrage would not be a means of keeping flood levels at current levels under a climate change scenario. It is recommended that further preliminary analysis under a climate change scenario be undertaken when data becomes available to ascertain the long-term viability of the barrage.

6 ASSESSMENT SUMMARY

This preliminary assessment has focussed on the potential impacts (both beneficial and detrimental) associated with the proposed Tamar Lake concept as described in Frith (2011). The scope of this particular assessment is limited to Hydrodynamic, Siltation, Water Quality and Flooding impacts and is not a comprehensive assessment of the entire range of potential constraints associated with the proposed development.

In summary the following benefits and constraints have been identified through this preliminary assessment of the Tamar Lake concept:

Hydrodynamics

- The Tamar Lake concept principally involves truncation of the tidal portion of the Tamar Estuary to downstream of Moriarty Reach, with the Freshwater lake;
- Relatively quiescent freshwater hydrodynamic regime upstream of the barrage;
- Flushing of the freshwater lake system is not as efficient as the tidal system; and
- Truncation of the tidal prism downstream reduces tidal velocities and flushing downstream of the barrage.

Siltation

- Home Reach is likely to be a net exporter of sediment under the Tamar Lake concept due to removal of tidal transport mechanism coupled with future flood scouring events;
- The above change in siltation regime has potentially significant benefits in terms of minimising Home Reach dredging requirements and providing some additional flood mitigation to Launceston;
- The downstream section of the lake is expected to continue to experience net sediment accretion, in some locations at a higher rate than is currently the case; and
- There is likely to be net accretion downstream of the barrage, however this evolution may occur relatively slowly.

Water Quality

- Catchment and point source loads of sediment and nutrients would continue to require management under a Tamar Lake concept;
- Freshwater system may be more prone to water quality problems such as eutrophication, due to poorer flushing and loss of buffering capacity relative to saline system; and
- There is considerable uncertainty about the implications of the transition of the system from estuarine to a freshwater lake and this would need to be a priority for further investigations.

Flooding

- A barrage could be constructed without impacting on flood levels in Launceston, but further investigation of impacts on intermediate locations would be required;

- To ensure no impacts in Launceston the flood flow would need to pass over a gated spillway rather than over the barrage crest;
- The length of gated spillway would be 300 m to 500 m to ensure no increase in the 100 and 200 year ARI flood level in Launceston, the length being strongly dependent on the invert of the spillway;
- The construction of the barrage in combination with a non-tidal regime and lower water level at the commencement of a flood may result in small reductions to the flood level at Launceston in floods smaller than the 100 year ARI event; and
- The barrage may assist with reducing the increase in flood risk of future sea level rise but is unlikely to fully mitigate the potential impacts of a future sea level rise of around 0.8 m.

Due to the relatively high level of assessment performed in this report, the likely changes and impacts associated with the Tamar Lake proposal have mostly been described in a qualitative sense. Undertaking more quantitative predictions is necessarily a much more involved process involving a number of stages;

- Developing suitable predictive tools for simulating the proposed changes;
- Demonstrating the validity of these tools at answering the questions they are being asked to answer;
- Applying these tools to quantify the expected changes;
- Quantifying the uncertainty associated with the predictions; and
- Assessing the quantified risk to determine the feasibility.

A detailed assessment of the physical and ecological impacts associated with the Tamar Lake concept would require the application of a three-dimensional hydrodynamic model that is capable of simulating thermal stratification dynamics. The model would also need to be capable of simulating the process of fresh/ocean water mixing as it would occur downstream of the proposed barrage.

Due to the substantial system changes that are to be considered the model would need to be suitably validated for a representative freshwater environment. For example it could first be demonstrated to adequately simulate the dynamics of the Trevallyn Dam reservoir. The suitably validated hydrodynamic model would then be used to quantify the transport behaviour within the Tamar Lake system and would underpin the modelling of water quality and sediment transport in the new regime. Due to the very substantial changes associated with the transition to a freshwater environment, the water quality modelling task would be a complex exercise that would have to address some significant uncertainties. It is likely that some scientific research would be needed to support the attempts to model water quality processes during the regime transition and for the proposed future freshwater lake environment. A good understanding of the flocculation behaviour of Tamar Estuary sediments in the existing and proposed future regime would be an essential underpinning of the sediment transport predictions associated with the Tamar Lake concept. It is likely that additional new scientific research specific to the Tamar Estuary would be required in order to derive this understanding.

Based on this preliminary assessment it is considered that the following items should be addressed as priorities for future more extensive or detailed assessments of the Tamar Lake concept:

1. Preliminary ecological assessment of values potentially lost and gained under the Tamar Lake proposal;
2. More detailed hydrodynamic, water quality and sediment transport numerical modelling in order to provide more quantitative prediction of the changes and impacts considered in this report; and
3. Detailed design of the barrage concept and operations with particular focus on flood risk and further demonstrating the feasibility of meeting the risk mitigation requirements of stakeholders.

The preliminary assessments undertaken here have analysed some of the potential benefits and constraints associated with the Tamar Lake concept. The concept involves imposing a major change on the Tamar Estuary in order to realise a series of benefits as outlined in Section 1.1.2. The assessment has not identified any major constraints that would invalidate the concept as proposed in Frith (2011). However, there are inevitably a number of trade-offs and potential for new management problems associated with a major change such as being considered here. Potential issues requiring further investigation and more detailed analysis have been canvassed in this report. Finally, this report has not attempted to apply a cost-benefit analysis to the project and is therefore not providing the necessary background for determining whether the Tamar Lake concept is altogether feasible. Such an assessment would ultimately need to be undertaken on the back of more detailed and comprehensive assessments of the environmental, social and economic impacts of the proposal.

7 REFERENCES

BMT WBM (2008), *River Tamar & North Esk River Flood Study*, Report for Launceston City Council, Report No. R.M7246.002.01, November 2008.

BMT WBM (2009), *Tamar Estuary Hydrodynamics Modelling Study*, Report for Launceston City Council, Report No. R.B15279.007.02.final_report, August 2009.

BMT WBM (2010), *Tamar Estuary and Esk Rivers Catchment WaterCAST Model*, Report for Launceston City Council, Report No. R.B17155.001.02, March 2010.

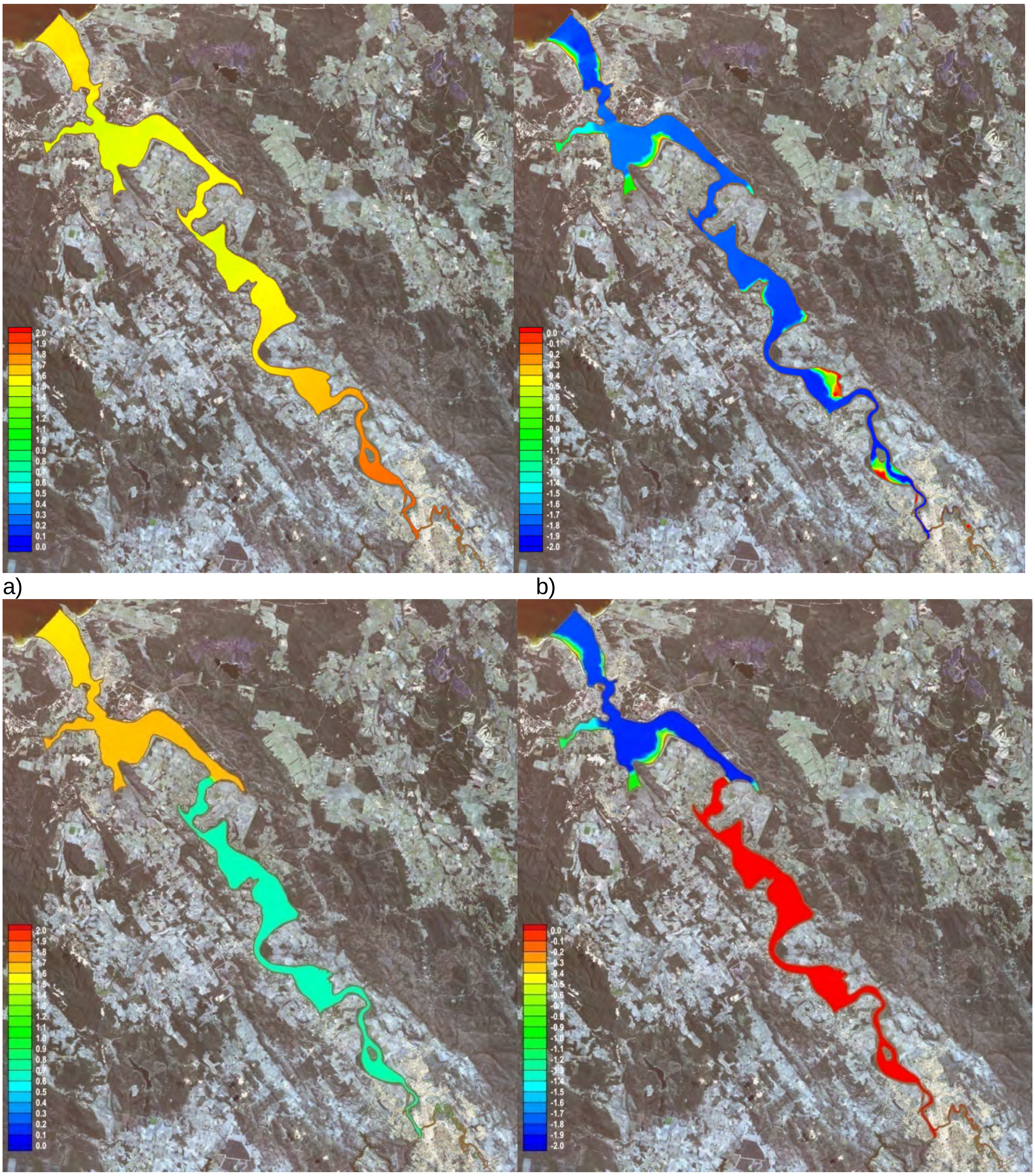
Bureau of Reclamation (1977), *Design of Small Dams,* Bureau of Reclamation, United States Department of the Interior, 1977.

DPIWE (2003), *State of the River Report for the North Esk Catchment.* Water Assessment and Planning Branch, Department of Primary Industries, Water and Environment, Hobart, Technical Report No. WAP 03/06.

Foster D. N., Nittim R. and Walker J. (1986) *Tamar River Siltation Study*. WRL Techical Report No 85/07.

Frith, R. (2011), *The Tamar Valley - A Strategic Plan and Vision for its Development*, Robin Smith, 11 June 2011.

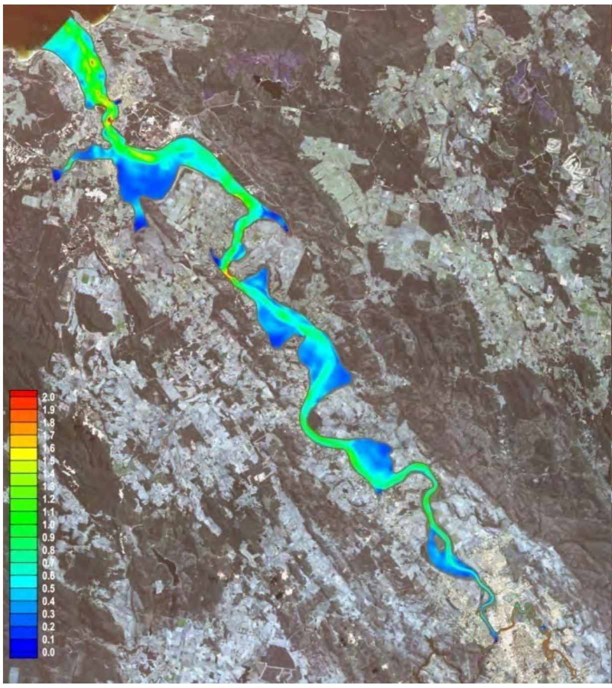
APPENDIX A: HYDRODYNAMIC MODEL RESULTS



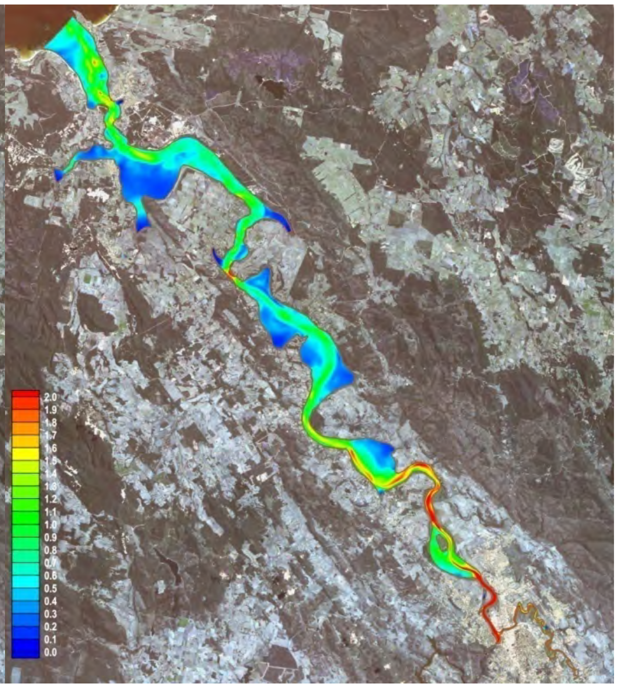
a) b)

c) d)

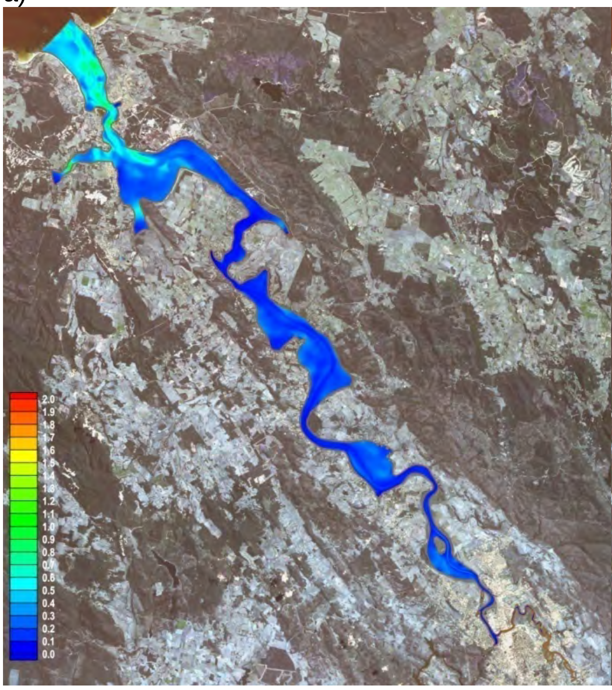
Figure A-1: Modelled tide levels for period from 01/01/2005 to 01/03/2005
a) Existing case maximum water level
b) Existing case minimum water level
c) Tamar Lake case maximum water level
d) Tamar Lake case minimum water level



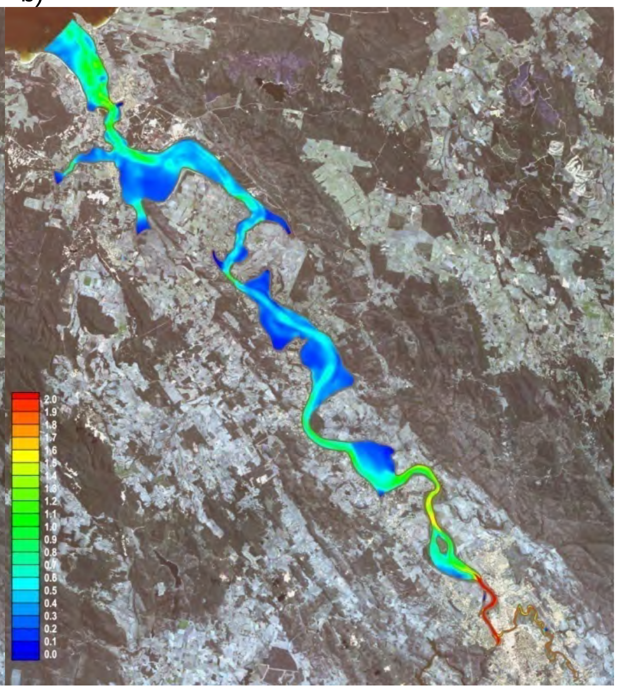
a)



b)

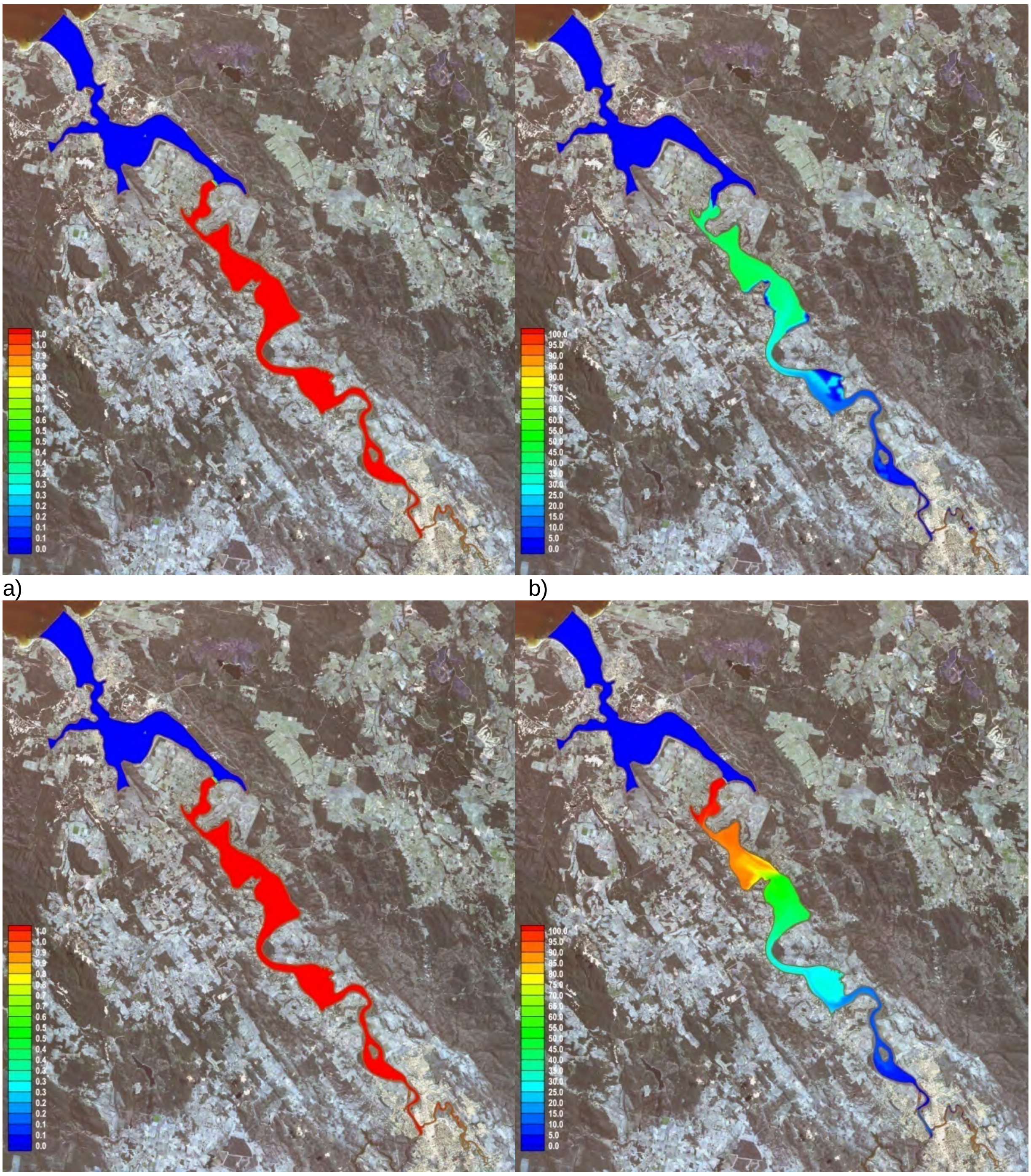


c)



d)

Figure A-2: Modelled maximum current speeds (m/s)
a) Existing case tidal simulation
b) Existing case Q100 flood scenario
c) Tamar Lake case tidal simulation
d) Tamar Lake case Q100 flood scenario



a) b) c) d)

Figure A-3: Model flushing assessment
a) Existing case initial tracer concentration
b) Existing case efold time (days)
c) Tamar Lake case initial tracer concentration
d) Tamar Lake case efold time (days)

BMT WBM Brisbane	Level 8, 200 Creek Street Brisbane 4000 PO Box 203 Spring Hill QLD 4004 Tel +61 7 3831 6744 Fax +61 7 3832 3627 Email bmtwbm@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Denver	8200 S. Akron Street, Unit 120 Centennial Denver Colorado 80112 USA Tel +1 303 792 9814 Fax +1 303 792 9742 Email denver@bmtwbm.com Web www.bmtwbm.com.au
BMT WBM Mackay	Suite 1, 138 Wood Street Mackay 4740 PO Box 4447 Mackay QLD 4740 Tel +61 7 4953 5144 Fax +61 7 4953 5132 Email mackay@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Melbourne	Level 5, 99 King Street Melbourne 3000 PO Box 604 Collins Street West VIC 8007 Tel +61 3 8620 6100 Fax +61 3 8620 6105 Email melbourne@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Newcastle	126 Belford Street Broadmeadow 2292 PO Box 266 Broadmeadow NSW 2292 Tel +61 2 4940 8882 Fax +61 2 4940 8887 Email newcastle@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Perth	Unit 6, 29 Hood Street, Subiaco 6008 Tel +61 8 9322 1577 Fax +61 8 9226 0832 Email perth@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Sydney	Level 1, 256-258 Norton Street Leichhardt 2040 PO Box 194 Leichhardt NSW 2040 Tel +61 2 9713 4836 Fax +61 2 9713 4890 Email sydney@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Vancouver	401 611 Alexander Street Vancouver British Columbia V6A 1E1 Canada Tel +1 604 683 5777 Fax +1 604 608 3232 Email vancouver@bmtwbm.com Web www.bmtwbm.com.au