entura Hydro Tasmania | The power of natural thinking

Forth Flood Plan
Hydraulic Modelling Report

ENTURA-663C8
21 February 2014

Prepared by Hydro-Electric Corporation ABN48 072 377 158
t/a Entura 89 Cambridge Park Drive, Cambridge TAS 7170 Australia

Entura in Australia is certified to the latest version of ISO9001, ISO14001, and OHSAS18001.

Document information

Document title	Forth Flood Plan Hydraulic Modelling Report
Client organisation	Central Coast Council
Client contact	Philip Adams
ConsultDM number	ENTURA-663C8
Project Manager	Craig Ludlow
Project number	E302873/P506363

Revision history

Revision 3.0

Revision description	Final report submitted to client		
Prepared by	Craig Ludlow	C Ludlow	20/03/2015
Reviewed by	Michael Wallis	M Wallis	20/3/'15
Approved by	Michael Wallis	M Wallis	20/3/'15
	(name)	(signature)	(date)
Distributed to	Philip Adams (name)	Central Coast Council (organisation)	20/03/2015 (date)

Page left intentionally blank

Executive summary

Introduction

Entura was commissioned by Central Coast Council (CCC) in January 2013 to carry out a flood study for the lower Forth River. The main objectives of the study were to:

- Assess the 1 in 100 annual exceedence probability (AEP) flood levels taking into consideration storm surge for current and future climate conditions and more detailed river survey data.
- Identify the impact on flood levels of the Harvest Moon levee (Levee D) and Leith Road floodstop, which were constructed after the August 2007 flood event.
- Assess the impact of the proposed Levee C which may be constructed in the future.

Background

A number of flood levees have been constructed along the lower Forth River between the Forth Road bridge and the Bass Highway to protect agricultural land and businesses from flooding, with Levee A constructed as protection from tidal influences. The design standard of the levees, in terms of flood immunity, is not known. In addition the level of the southern section of Levee D was based on the measured August 2007 flood event levels and predictions from the original modeling in the Lower Forth Flood Response and Recovery Plan (Central Coast Council, 11 March 2008).

CCC are also considering a new levee (Levee C) to link Levee A to Forth Road.

Survey

River cross sections were commissioned for this study for use in the MIKE FLOOD hydraulic model developed for the study.

Modelling scenarios

A range of modelling scenarios were carried for the study as outlined in the table below.

Scenario	Description	Rainfall	Sea Level
1	August 2007 verification flood event	Measured	Measured
2	August 2011 verification flood event	Not modelled	
3	Existing levee conditions Existing climate conditions 1 in 100 AEP rainfall	1 in 100 AEP	1 in 10 AEP storm surge.
4	Existing levee conditions Existing climate conditions 1 in 100 AEP storm surge	1 in 10 AEP	1 in 100 AEP storm surge
5	Existing levee conditions 2100 climate conditions 1 in 100 AEP rainfall	1 in 100 AEP with % increase in rainfall	1 in 10 AEP storm surge plus 0.8m sea level rise
6	Existing levee conditions	1 in 10 AEP with %	1 in 100 AEP storm surge

Scenario	Description	Rainfall	Sea Level
	2100 climate conditions 1 in 100 AEP storm surge	increase in rainfall	plus 0.8m sea level rise
7	Assessment of Harvest Moon and Leith Road Levees for worst case 1 in 100 AEP flood scenario (i.e. either rainfall or storm surge) Existing climate conditions	1 in 100 AEP or	1 in 10 AEP or
8	Assessment of Harvest Moon and Leith Road Levees for worst case 1 in 100 AEP flood scenario (i.e. either rainfall or storm surge) 2100 climate conditions	1 in 100 AEP or 1 in 10 AEP with % increase in rainfall	1 in 10 AEP or 1 in 100 storm surge plus 0.8m sea level rise
9	Assessment of Levee C for worst case 1 in 100 AEP flood scenario (i.e. either rainfall or storm surge) Existing climate conditions	1 in 100 AEP or 1 in 10 AEP	1 in 10 AEP or 1 in 100 storm surge
10	Assessment of Levee C for worst case 1 in 100 AEP flood scenario (i.e. either rainfall or storm surge) 2100 climate conditions	1 in 100 AEP or 1 in 10 AEP with % increase in rainfall	1 in 10 AEP or 1 in 100 storm surge plus 0.8m sea level rise

Hydrologic analysis

Flood hydrographs were developed for the August 2007 flood event and for the 1 in 10 AEP and 1 in 100 AEP design rainfall events for the existing climate and the 2100 future climate taking into consideration of increased rainfall due to climate change.

Climate Futures for Tasmania (2011) found that precipitation in the period 2070-2099 is anticipated to increase by 15% with an estimated increase in runoff of 65% for the 1 in 10 AEP event. For the 1 in 100 AEP event precipitation is estimated to increase by 20% with an estimated increase in runoff of 52%. This data was used to develop the 2100 climate design flood hydrographs.

The shape of the August 2007 flood hydrograph was used as the basis for the design flood hydrographs.

The peak discharges of the design flood hydrographs were has on flood frequency analysis of records on the Forth River below Paloona Dam and from catchment scaling for the catchments contributing to the lower Forth River.

The August 2007 and design flood hydrographs were used as inputs to the hydraulic model developed for the study.

Hydraulic analysis

A MIKE FLOOD hydraulic model of the lower Forth River was developed by Entura and was calibrated to the August 2007 flood event.

The MIKE FLOOD model was based on a MIKE 11 model previously developed by Entura, LiDAR survey available for the LIST, river cross section survey of the lower Forth River commissioned by CCC for this study, levee culvert details provided by CCC, as built survey of Levee D provided by CCC and design drawings of bridges and floodways sourced from DIER.

The calibrated MIKE FLOOD model was used to model the 1 in 100 AEP rainfall and storm surge events for the existing and 2100 climate conditions and to assess the impact of the existing Levee D and the proposed Levee C on flooding.

Flood extent maps were prepared for all modelled flood events.

For the existing climate 1 in 100 AEP rainfall and storm surge events, with the levees as currently in place, significant flooding is predicted to occur on the western floodplain with the impact of climate change increasing flood levels by approximately 0.7m to 1.0m.

For the existing and 2100 climate 1 in 100 AEP rainfall events and the 2100 climate 1 in 100 AEP storm surge event, with the levees as currently in place, flooding of the Harvest Moon infrastructure is predicted to occur. For the existing climate 1 in 100 AEP storm surge event the Harvest Moon infrastructure is predicted to be protected by Levee D.

In the vicinity of Turners Beach no flooding of properties is predicted to occur for the existing climate condition 1 in 100 AEP rainfall or storm surge events. For the 2100 climate approximately 35 properties along Boyes Street, Susan Street, Arcadia Avenue and Whitegum Way are predicted to be affected primarily due to the 0.8m rise in mean sea level. Properties at the end of Lethborg Avenue and Heather Court may also be affected. Provision of a small levee and one way flow device may prevent flooding of these properties in the climate change scenario.

Other areas where properties may be affected by the modelled flood events, with the levees as currently in place, include:

- Near the intersection of Turners Beach Road and the Bass Highway. For the existing climate condition the dwellings at this location are not predicted to be affected however for the 2100 climate condition 3 to 4 dwellings could potentially be inundated.
- At the bend in Forth Road near Mell Street buildings associated with the sports fields are predicted to be affected for flooding from the 1 in 100 AEP rainfall events (current and 2100 climates) and the 1 in 100 AEP 2100 climate storm surge event. Flooding of a number of residential dwellings in this area is predicted to occur for the 1 in 100 AEP 2100 climate rainfall event.
- Just upstream of the Leith Road floodstop barrier a number of properties are predicted to be affected by flooding for the 1 in 100 AEP 2100 climate rainfall event. No flooding of properties in this area is predicted for the current climate 1 in 100 AEP rainfall event.

Flooding of the low area bounded by Blackburn Drive and the Bass Highway is predicted for all modelled flood events.

Overtopping of the waste water ponds was not predicted to occur for the existing climate flood events however overtopping was predicted for the 2100 climate condition.

Flooding of the western floodplain was found to be initiated by a low section in Levee A. This low section of Levee A would be overtopped by the 1 in 10 AEP 2100 climate surge level.

Levee D was found to reduce the severity of the eastern flooding in the vicinity of the Harvest Moon infrastructure. However the levee also results in an increase in flood levels in the main channel and the western flooding. The maximum increase in flood levels in the river channel as a result of Levee D was estimated to be 0.18m for the existing 1 in 100 AEP current climate rainfall event.

It was found that Levee D has varying levels of flood immunity. The southern section adjacent to the river channel has an immunity approximately equivalent to the 1 in 100 AEP 2100 climate rainfall event while the northern section will be overtopped by a 1 in 50 AEP existing climate rainfall event.

Based on the modelling carried out for this study the Leith Road floodstop barrier is not expected to provide any benefit for the 1 in 100 AEP rainfall event (in terms of prevent flooding of the eastern floodplain) until at least 2100.

It was found that Levee C, with a top level of 2.05m AHD, could be built with minimum impact of surrounding flooding.

Overtopping of the waste water ponds is not predicted to occur for the current climate conditions. The estimated freeboard for the 1 in 100 AEP rainfall event is approximately 0.21m.

Significant overtopping of the waste water ponds is predicted to occur for the 2100 climate conditions 1 in 100 AEP rainfall or storm surge events.

Recommendations

It is recommended that a one way flow device be provided to the DN750mm diameter culvert under the Bass Highway to prevent flooding of the low lying land between Blackburn Drive and the Bass Highway.

It is recommended that a review of the Levee D design be carried out to determine whether it can be optimised to provide a consistent level of flood protection to Harvest Moon infrastructure while minimising the impacts on surrounding flooding.

It is recommended that the relevant authority review the level of freeboard required for the wastewater treatment ponds for the 1 in 100 AEP flood event to determine whether any work is required to provide the facility with the adequate level of flood protection.

It is recommended that the relevant authority put in place plans to, in the future, review the waste water ponds and level of flood protection required, once the potential consequences of climate change on rainfall and sea level rise are better understood.

Once the potential consequences of climate change on rainfall and sea level rise are better understood, it is recommended that CCC review flood mitigation measures that would be required to prevent flooding of properties in Turners Beach.

Additional work completed

On completion of the Draft Forth Flood Plan – Hydraulic Modelling Report, Entura was engaged by Council to carry out the following additional work:

- Update the Part C of the Lower Forth Flood Response and Recovery Plan including:
    - Property/Asset Tables 3 and 4 with the:
        - 1 in 2 AEP and 1 in 5 AEP columns to be deleted.
        - 1 in 10 AEP, 1 in 50 AEP and 1 in 100 AEP columns to be updated with recent modelling results.
        - 1 in 200 AEP column to be replaced with modelling results for the 1 in 100 AEP 2100 climate event.
    - Figures 1, 2 and 3 to be updated to include the latest 1 in 100 AEP existing climate and August 2007 flood event stage hydrographs. The stage hydrographs for the 1 in 1000 AEP and 1 in 2000 AEP flood events are to be retained as these events have not been re-run with the updated model.

    - Update the Forth flood 1:100 AEP flood extent map between Wilmot River and Forth.
- Assess the requirements for Levee A and D to provide a 1 in 50 AEP design flood immunity.
- Provide basic comment on the proposed upgrade work currently being completed for Levee B.

This additional work is documented in the following addendum report:

- Forth Flood Plan – Hydraulic Modelling Report Addendum, Document number: ENUTRA-76A08, 5 December 2013.

Page left intentionally blank

Contents

Appendices

List of figures

List of tables

Page left intentionally blank

1. Introduction

Entura was commissioned by Central Coast Council (CCC) in January 2013 to carry out a flood study for the lower Forth River. The main objectives of the study were to:

- Assess the 1 in 100 annual exceedence probability (AEP) flood levels taking into consideration storm surge for current and future climate conditions and more detailed river survey data.
- Identify the impact on flood levels of the Harvest Moon levee (Levee D) and Leith Road floodstop, which were constructed after the August 2007 flood event.
- Assess the impact of the proposed Levee C which may be constructed in the future.

This report summarises the findings of the investigations carried out for this study and presents flood inundation maps for the calibration and design flood events.

On completion of the Draft Forth Flood Plan – Hydraulic Modelling Report, Entura was engaged by Council to carry out the following additional work:

- Update the Part C of the Lower Forth Flood Response and Recovery Plan including:
    - Property/Asset Tables 3 and 4 with the:
        - 1 in 2 AEP and 1 in 5 AEP columns to be deleted.
        - 1 in 10 AEP, 1 in 50 AEP and 1 in 100 AEP columns to be updated with recent modelling results.
        - 1 in 200 AEP column to be replaced with modelling results for the 1 in 100 AEP 2100 climate event.
    - Figures 1, 2 and 3 to be updated to include the latest 1 in 100 AEP existing climate and August 2007 flood event stage hydrographs. The stage hydrographs for the 1 in 1000 AEP and 1 in 2000 AEP flood events are to be retained as these events have not been re-run with the updated model.
    - Update the Forth flood 1:100 AEP flood extent map between Wilmot River and Forth.
- Assess the requirements for Levee A and D to provide a 1 in 50 AEP design flood immunity.
- Provide basic comment on the proposed upgrade work currently being completed for Levee B.

This additional work is documented in the following addendum report:

- Forth Flood Plan – Hydraulic Modelling Report Addendum, Document number: ENUTRA-76A08, 5 December 2013.

Page left intentionally blank

2. Background

2.1 Forth levees

A number of flood levees have been constructed along the lower Forth River between the Forth Road bridge and the Bass Highway to protect agricultural land and businesses from flooding, with Levee A constructed as protection from tidal influences. The locations of the levees are shown in Figure 2.1 and a description of each levee is provided in Table 2.1. The design standard of the levees, in terms of flood immunity, is not known. In addition, the level of the southern section of Levee D was based on the measured August 2007 flood event levels and predictions from the original modeling in the Lower Forth Flood Response and Recovery Plan (Central Coast Council, 11 March 2008).

Table 2.1: Description of Forth levees

Levee	Description
A	Protects agricultural land on the western side of the river. Built prior to 2007.
B	Protects agricultural land on the western side of the river. Built prior to 2007.
C	Not yet built. Proposed to link Levee A to Forth Road.
D	Protects Harvest Moon infrastructure on the eastern side of the river. Level raised after August 2007 flood event.

A DN 900mm diameter pipe fitted with a tide flap has been provided to drain the agricultural land protected by Levee A back to the Forth River.

A DN750mm diameter pipe, which is not fitted with a tide flap, drains a low point bounded by Blackburn Drive and the Bass Highway south to the agricultural land protected by Levee A. The Turners Beach Berry Patch is located in this low lying area.

The locations of the levee culverts are provided in Figure 2.2.

2.2 August 2007 flood event

In August 2007 a large flood occurred resulting in significant inundation of the lower Forth River and floodplains. A summary of the flooding is provided below:

- The flood discharge passed through the Forth Road bridge and the Forth Road floodway located on the western side of the river.
- The sports fields on the western side of the river downstream of the flood opening were inundated.
- The land to the west of Levee A (Refer to Figure 2.1) was inundated however the waste water ponds were not overtopped.

- A breach of Levee A occurred however it is not known whether this breach occurred before or after the peak of the flood.
- On the eastern side of the river, flow ovetopped the river channel approximately near where Leith Road rejoins the Forth River (Refer to Figure 2.1). This flow inundated Leith Road and infrastructure belonging to Harvest Moon (agribusiness specializing in fresh vegetables).
- The water treatment ponds on the western side of the river were not inundated.
- The Turners Beach Berry Patch was inundated during the flood event.

Photographs of the flood event were taken by CCC and provided to Entura. A selection of the photographs are shown in Figure 2.2.

Peak flood levels, from flood debris marks, were surveyed by CCC after the flood event. These flood levels are shown in Figure 2.1.

2.3 Harvest Moon levee

As a result of the August 2007 flood event the southern section of Levee D was constructed with the aim of protecting Harvest Moon infrastructure from future flooding. Where Levee D crosses Leith Road a floodstop barrier has been provided. When flooding is predicted to occur, the plastic flood barriers are manually installed to fill the gap in the levee. An isometric drawing of the Leith Road floodstop is shown in Figure 2.3.

2.4 Previous flood modelling

Flood modeling of the Forth River has been carried out in the past for the purpose of assessing the impact of a dambreak of the upstream Paloona Dam and to assess the impact of the upgrade of the rail bridge crossing over the river (Jokanovic, August 2012). However a flood study to assess in detail the flood levels in the lower Forth River had not been carried out prior to this study.

Figure 2.1: Forth levees and August 2007 peak flood levels (from CCC with notes by Entura)

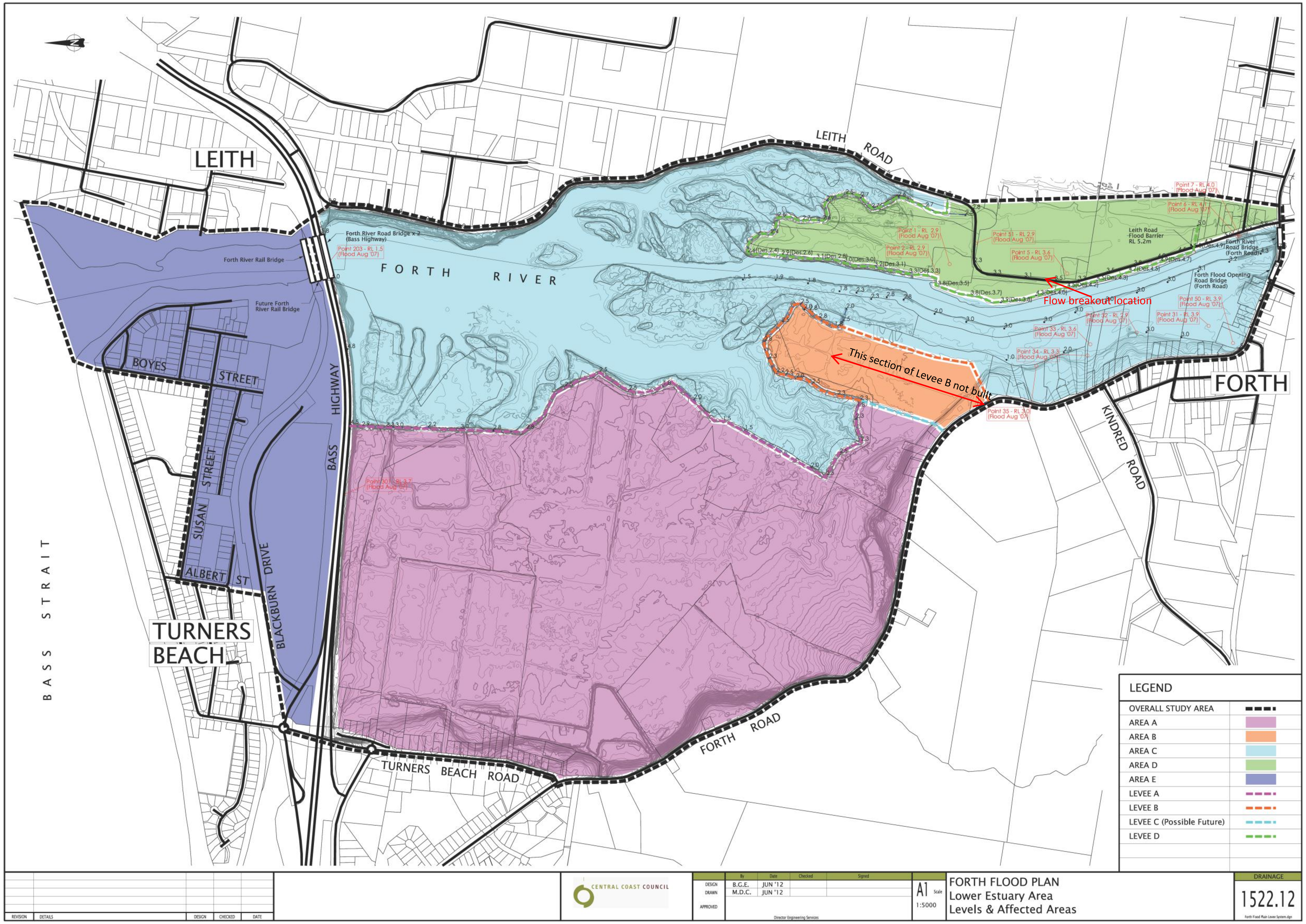
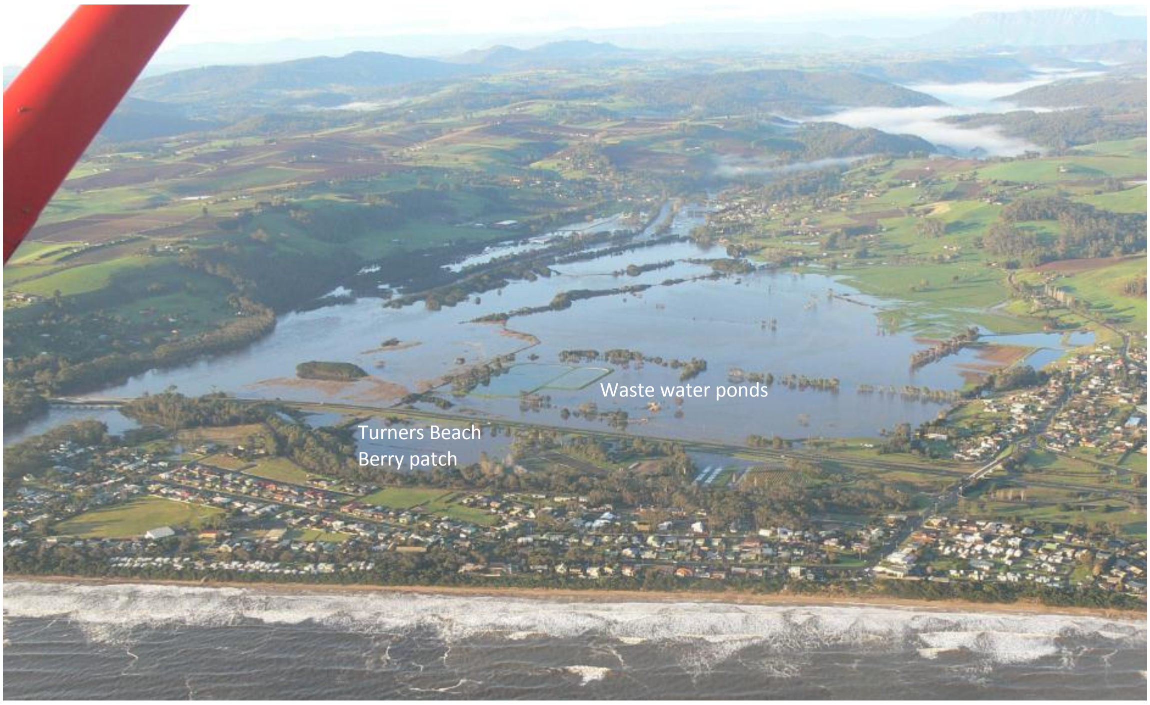


Figure 2.2: Forth levee culverts (image from Google Earth)

Table 2.2: August 2007 flood event – photographs (from CCC)

Photographs of August 2007 flood event

Aerial photograph looking south (11/08/2007)



Forth Road bridge looking downstream (10/08/2007 approx 6:30pm)

Playing fields looking downstream (10/08/2007 approx 6:30pm)

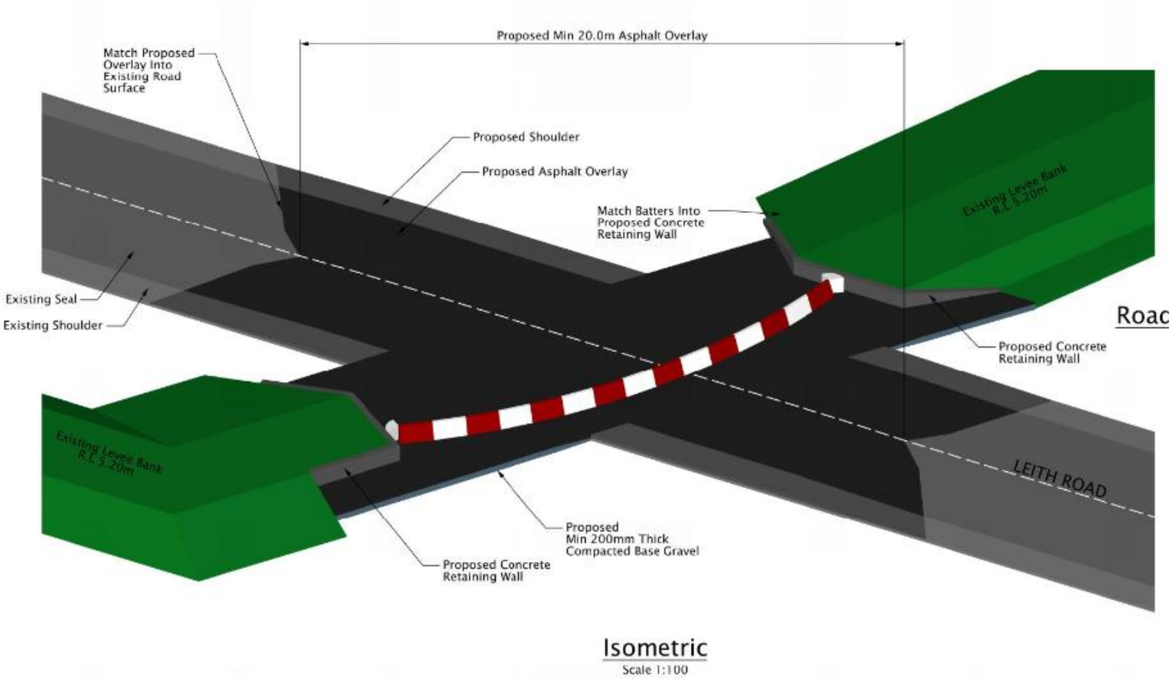
Harvest Moon Factory (11/08/2007)

Leith Road looking north to breakout point (10/08/2007 approx 1:30pm)

Leith Road behind Harvest Moon factory - looking south west (11/08/2007)

Levee A breach

Figure 2.3: Leith Road floodstop (extract from CCC drawing 1522.11)



3. Available data

3.1 Survey

The following survey information was used in the study to develop the hydraulic model:

- LiDAR survey from the Land Information System Tasmania (LIST). This LiDAR was taken post August 2007 when Levee D was partially constructed.
- Surveyed cross sections of the Forth River and detailed survey of the Forth Road bridge commissioned by CCC for the purpose of this study. Refer to Appendix A for a survey plan. Electronic files of the survey have been provided to CCC.
- Traverse survey of Levee D by G. A. Deegan. Refer to Appendix A.
- Measurements of the Forth levee culvert diameters (DN750mm and DN 900mm) by CCC.

All levels present in this study are in m AHD.

3.2 Flood data

The following data for the August 2007 flood event was provided to Entura by CCC:

- Surveyed flood levels.
- Photographs of flooding.

3.3 Hydrologic data

The following hydrologic data was utilised for the study:

- CFEV catchment delineations for the Forth and Wilmot catchments.
- Record of spill from Paloona (regulated) TSM(627.1/130.00/10) PTO(140.00,0).
- Record of water released for power station use at Paloona (regulated) TSM(235.1/156.00/1) PTO(140.00,0).
- Record of flow at the Wilmot River above the confluence with the Forth River (regulated) TSM(524.1/100.00/1) PTO(140.00,0).
- Record of flow at the Forth River below the confluence with the Wilmot River (regulated) TSM(665.1/100.00/1) PTO(140.00,0).
- Record of flow on Forth River upstream of Lemonthyme power station (natural watercourse) TSM 450.1/100.00/1 PTO(140.00,0).
- Record of flow at Clayton's Rivulet U/S Old Bass Highway (natural) DPIPWE Station No. 14237 .
- Percentage change in design rainfall for the 1:10 and 1:100 AEP event (Climate Futures for Tasmania, 2011).

3.4 Tide information

Recorded hourly tide data at Burnie during the period of August 2007 flood event was sourced from the Bureau of Meteorology (BoM) to develop the downstream boundary condition for the hydraulic model.

Storm surge levels for the design flood events were sourced using the "Canute 2" software and is discussed further in Section 6.2.7.

3.5 Design drawings

The following design drawings were sourced for this study:

- Forth River Flood Opening Bass Highway – L72.45 – General Arrangement. Drawing 253 F-1.
- Forth River Bridge Bass Highway – General Arrangement. Drawing 254 F-1.
- KPW 142.2 – Forth River Rail Bridge. Drawing No. 18912-S02
- KPW 142.2 – Forth River Rail Bridge. Drawing No. 18912-S03

3.6 Hydraulic model

The MIKE 11 model developed by Entura to assess the Forth River rail bridge duplication (Jokanovic, August 2012) was used as the basis for developing the 1D/2D integrated hydraulic model for this study. This model contains the details of the Bass Highway and rail bridges (including duplication).

4. Flood scenarios

The flood scenarios provided in Table 4.1 were adopted for the study based on discussion between CCC and Entura and form the basis of the hydrologic and hydraulic analyses carried out for this study.

Table 4.1: Modelling scenario

Scenario	Description	Rainfall	Sea Level	Purpose
Model calibration				
1	August 2007 verification flood event	Measured	Measured	For calibration of the hydraulic model.
2	January 2011 verification flood event	Measured	Measured	For verification of the hydraulic model.
Design floods				
3	Existing levee conditions Existing climate conditions 1 in 100 AEP rainfall	1 in 100 AEP	1 in 10 AEP storm surge.	To assess peak flood levels associated with a 1 in 100AEP rainfall event with co-incident storm surge. All currently constructed levees and rail bridge duplication considered.
4	Existing levee conditions Existing climate conditions 1 in 100 AEP storm surge	1 in 10 AEP	1 in 100 AEP storm surge	To assess peak flood levels associated with a 1 in 100AEP storm surge event with co-incident rainfall. All currently constructed levees and rail bridge duplication considered.
5	Existing levee conditions 2100 climate conditions 1 in 100 AEP rainfall	1 in 100 AEP with % increase in rainfall	1 in 10 AEP storm surge plus 0.8m sea level rise	To assess peak flood levels associated with a 1 in 100AEP rainfall event with co-incident storm surge. All currently constructed levees and rail bridge duplication considered.
6	Existing levee conditions 2100 climate conditions 1 in 100 AEP storm surge	1 in 10 AEP with % increase in rainfall	1 in 100 AEP storm surge plus 0.8m sea level rise	To assess peak flood levels associated with a 1 in 100AEP storm surge event with co-incident rainfall. All currently constructed levees and rail bridge duplication considered.

7	Assessment of Harvest Moon and Leith Road Levees for worst case 1 in 100 AEP flood scenario (i.e. either rainfall or storm surge) Existing climate conditions	1 in 100 AEP or	1 in 10 AEP or	To assess peak flood levels associated with a 1 in 100AEP storm surge event with co-incident rainfall prior to construction of Levee D. Peak flood levels to be compared with Scenario 4 to assess impact of Levee D on flooding. Levees and bridges as per 2007.
8	Assessment of Harvest Moon and Leith Road Levees for worst case 1 in 100 AEP flood scenario (i.e. either rainfall or storm surge) 2100 climate conditions	1 in 100 AEP or 1 in 10 AEP with % increase in rainfall	1 in 10 AEP or 1 in 100 AEP storm surge plus 0.8m sea level rise	To assess peak flood levels associated with a 1 in 100AEP storm surge event with co-incident rainfall prior to construction of Levee D. Peak flood levels to be compared with Scenario 4 to assess impact of Levee D on flooding. Levees and bridges as per 2007.
9	Assessment of Levee C for worst case 1 in 100 AEP flood scenario (i.e. either rainfall or storm surge) Existing climate conditions	1 in 100 AEP or 1 in 10 AEP	1 in 10 AEP or 1 in 100 AEP storm surge	To assess the impact of the prosed Levee C on flooding.
10	Assessment of Levee C for worst case 1 in 100 AEP flood scenario (i.e. either rainfall or storm surge) 2100 climate conditions	1 in 100 AEP or 1 in 10 AEP with % increase in rainfall	1 in 10 AEP or 1 in 100 AEP storm surge plus 0.8m sea level rise	To assess the impact of the prosed Levee C on flooding.

5. Hydrology

5.1 Introduction

A hydrologic analysis was carried out for this study to:

- Develop flood hydrographs for the August 2007 flood event.
- Develop flood hydrographs for the 1 in 10 AEP and 1 in 100 AEP design floods for the existing climate and the 2100 future climate.

5.2 August 2007 flood event

Flood hydrographs were derived for the August 2007 flood event from available flow records and catchment scaling. These hydrographs were used as inputs for the hydraulic modelling calibration.

Recorded flows in the Forth and Wilmot Rivers upstream and downstream of the confluence were used as the basis for the August 2007 flood event hydrographs for input to the top end of the hydraulic model. The flood hydrograph downstream of the confluence is shown in Figure 5.3.

As there are no flow gauging stations on the lower Forth River, catchment scaling was required to estimate the runoff from the catchments downstream of the Wilmot River confluence. The method adopted for the catchment scaling as outlined in Section 5.3.2.

5.3 Design flood events

Flood hydrographs were developed for the 1 in 10 AEP and 1 in 100 AEP design flood events for the current climate and for the 2100 future climate for use as inputs to the hydraulic model of the Forth River.

The development of the design flood hydrographs was based on the following process:

- Flood frequency analysis of recorded flows just downstream of the confluence of the Forth and Wilmot Rivers to determine peak flood discharges at this location for the required flood events. Refer to Section 5.3.1 for details.
- Splitting the peak design flood discharges (from just downstream of the Forth and Wilmot confluence) into the respective contributions from:
  - Outflow from Paloona Power Station.
  - Spill from Paloona Dam.
  - Contribution from Wilmot River.
- Catchment scaling to derive the contribution from the catchment below the Forth and Wilmot confluence. Refer to Section 5.3.2 for details.
- Development of a shape for the design flood hydrographs. The shape of the design flood hydrographs was based on the August 2007 flood hydrograph. The recorded hydrograph was

scaled to match the peak flows estimated by the flood frequency analysis for the 1 in 10 AEP and 1 in 100 AEP design flood events. Refer to Section 5.3.3.

- Assessment of the impact of climate change on the design flood discharges based on outcomes from the Climate Futures for Tasmania (CFT) project.

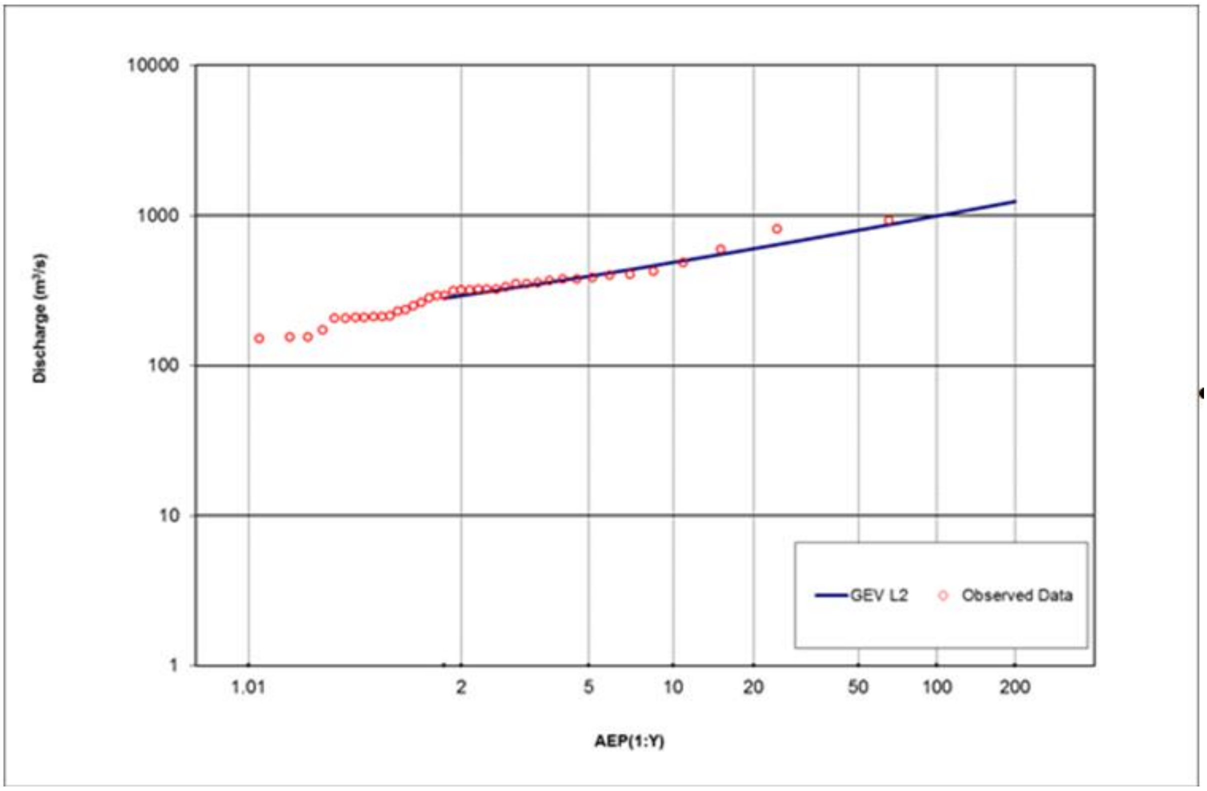
The design hydrographs for existing climate and future climate conditions for the August 2007 flood event and the 1 in 10 AEP and 1 in 100 AEP design flood events are provided in Appendix B.

5.3.1 Flood frequency analysis – Forth River below Wilmot confluence

The flood frequency analysis carried out to estimate peak flows downstream of the confluence between the Forth and Wilmot Rivers was based on the generalised extreme value (GEV) distribution which provided the best fit to the recorded data. The GEV distribution fit is shown in Figure 5.1.

The results of the flood frequency analysis are provided in the Table 5.1 and show the peak flood discharges (at Forth River below Wilmot) that have been adopted for this study under the existing climate.

Figure 5.1: GEV distribution fitted to annual maxima from downstream of the confluence between the Forth and Wilmot Rivers.



entura Hydro Tasmania | The power of natural thinking

Table 5.1: Results of flood frequency analysis downstream of the confluence of the Forth and Wilmot Rivers – existing climate

AEP	Peak Discharge (m^3/s)
1.8	281
2	292
5	394
10	487
20	601
50	798
100	993
200	1239

5.3.2 Estimation of pickup between the confluence of the Wilmot and Forth Rivers and the Bass Highway

Downstream pickup between the confluence of the Forth and Wilmot Rivers and the Bass Highway Bridge needed to be estimated to account for additional flood discharge resulting from rainfall in the lower portion of the catchment for both the August 2007 calibration event and the 1 in 10 AEP and 1 in 100 AEP design rainfall events.

No gauging stations exist on the Forth River below the confluence with the Wilmot River so other gauging stations within the catchment were investigated for use in estimating downstream pickup. Two gauging stations were identified that would be suitable for estimating natural pickup at the Bass Highway bridge site. These two sites were located at Claytons Rivulet and the Forth River upstream of Lemonthyme power station.

It was found that the gauging station at Claytons Rivulet could not be used as the period of record does not extend back as far as 2007 and the Forth River gauge site above Lemonthyme power station was used in the analysis.

A factor was derived so that the recorded August 2007 flood hydrograph at the Forth River above Lemonthyme power station could be scaled to represent the contribution of flow downstream of the Forth River and Wilmot River confluence. The scaling factor was determined based on the areas and mean annual rainfalls of the two catchment using Equation 1. The areas and mean annual rainfalls for the two catchment are shown in Table 5.2.

$$Factor = \left(\frac{Area_{pickup}}{Area_{lemonthyme}}\right)^{0.8} \times \frac{Mean\ annual\ rainfall_{pickup}}{Mean\ annual\ rainfall_{lemonthyme}} \qquad \text{Equation 1}$$

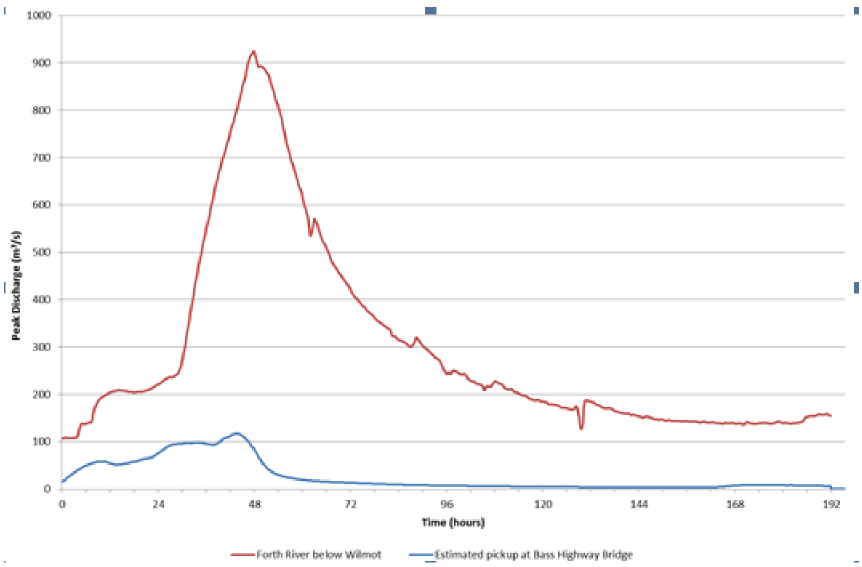
A scaling factor of 0.21 was derived and was used to scale the recorded Lemonthyme flood hydrograph to represent the pickup downstream of the Forth and Wilmot confluence for the August 2007 flood event.

For the 1 in 10 AEP an 1 in 100 AEP flood events, the August 2007 pickup flood hydrograph was scaled again based on the ratio of the design flood discharges estimated from the flood frequency analysis and the peak discharge of the 2007 August flood event to develop the pickup flood hydrographs for the respective design flood events.

Table 5.2: Scaling factors used for estimating downstream pickup

Area	Area (km^2)	Mean annual rainfall (mm)
Southern Forth River	108	1062
Lemonthyme	310.9	2147

Figure 5.2: Estimated hydrograph shape for pickup at the Bass Highway Bridge



5.3.3 Flood hydrograph shape

In order to identify a representative period of flow record at the sites of interest it is important to identify when changes occurred within the catchment. The Forth and Wilmot Rivers have significant hydropower infrastructure constructed across them and as such are heavily regulated. A review of completion dates of hydropower dams in the catchment are shown in Table 5.3. In this case the flow record has only been considered representative from 1974 onwards.

Table 5.3: History of construction of significant hydropower infrastructure along the Forth and Wilmot Rivers

Dam constructed	Year filled	Source
Cethana	1971	HT Dam Summary Information
Devils Gate	1970	HT Dam Summary Information
Mackenzie	1972	HT Dam Summary Information
Paloona	1973	HT Dam Summary Information

Parangana	1969	HT Dam Summary Information
Rowallan	1967	HT Dam Summary Information
Wilmot	1970	HT Dam Summary Information

The four largest flood events that have been recorded at the gauging station located downstream of the confluence between the Forth and Wilmot Rivers have been analysed, details of each of these peak events is summarised in Table 5.4. The hydrographs for these events are shown on Figure 5.3.

Table 5.4: Event selection for the confluence between the Forth and Wilmot Rivers

Year	Peak discharge (m^3/s)	Start date	Finish date	Approximate AEP
1975	594	18-May	20-May	15
1994	481	26-May	31-May	11
2007	927	09-Aug	14-Aug	65
2011	810	11-Jan	20-Jan	25

The shape of the hydrograph for the August 2007 event has been adopted for this study as it is the largest event on record. It also received significant inflows from both the Wilmot and Forth Rivers.

The hydrograph shape extracted from the 2007 flood event was split to reflect the respective contributions from the Wilmot River and discharges from Paloona Dam (spill and power station water). These inputs were cross-checked against those derived from the gauging station downstream of the confluence between the Forth and Wilmot Rivers.

Spill from Paloona Dam and flows from the Wilmot River were scaled until their sum plus the power station water provided an equivalent peak flow to that calculated using flood frequency analysis for the 1:10 and 1:100 AEP events. Power station water was capped at the flows recorded in the 2007 event flood.

In terms of emergency management it should be noted that shorter duration floods with a similar peak flood discharge have the potential to occur such as the January 2011 flood event. This event was almost entirely driven by rainfall in the lower catchment causing a very fast response time.

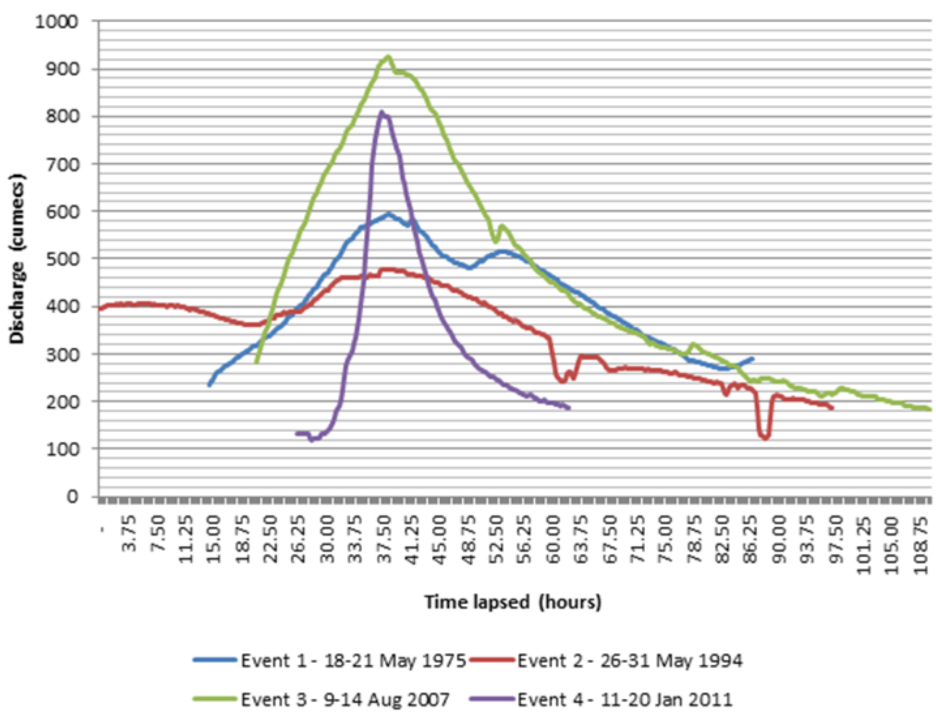
5.3.4 Climate change impact on flood discharge

The impact of climate change on peak flood discharge was estimated using a process developed by CFT (Climate Futures for Tasmania, 2011). Design rainfalls were obtained from Australian Rainfall and Runoff (Climate Futures for Tasmania, 2011). Climate Futures for Tasmania gridded rainfall has been used to derive percentage change in design rainfall depth for the 1 in 10 and 1 in 100 AEP storm event for the critical duration event. Climate change impacts on runoff were derived from linear interpolation between the rainfall intensities at the end of the 21st century (2070-2099) and the baseline period (1961-1990). A relationship was derived between percentage change in rainfall in the Mersey and Forth catchments and percentage change in runoff for the 1 in 10 AEP and the 1 in 100 AEP flood event. This relationship was used to scale the hydrographs to account for climate change impacts at the end of the 21st Century.

Climate Futures for Tasmania (2011) found that precipitation in the period 2070-2099 is anticipated to increase by 15% with an estimated increase in runoff of 65% for the 1 in 10 AEP event. For the 1 in 100 AEP event precipitation is estimated to increase by 20% with an estimated increase in runoff of 52%.

The estimate percentage increases of 65% and 52% were used respectively to factor the flood frequency peak discharges for the 1 in 10 AEP and 1 in 100 AEP design flood events.

Figure 5.3: Hydrographs assessed at the confluence between the Forth and Wilmot Rivers.



5.4 Design flood discharges

The peak discharges for the 1 in 10 and 1 in 100 AEP events adopted for this study are shown in Table 5.5. The design hydrographs for existing climate and future climate conditions for the August 2007 flood event and the 1 in 10 AEP and 1 in 100 AEP design flood events are provided in Appendix B.

Table 5.5: Results of hydrological analysis of peak discharges at key locations along the Forth and Wilmot Rivers for the existing and 2100 future climate 2100

AEP (1 in X)	Peak Discharge at Forth River above Wilmot (m^3/s)	Peak Discharge at Wilmot River above Forth (m^3/s)	Downstream Pickup at Bass Highway Bridge (m^3/s)
10 (existing climate)	354	139	62
10 (2100 future climate)	557	257	103
100 (existing climate)	679	328	127
100 (2100 future climate)	1011	521	193

6. Hydraulic study

6.1 Introduction

An integrated 1D/2D unsteady MIKE FLOOD (developed by DHI) model was developed for the hydraulic study of the lower Forth River. Details of the software can be found at http://www.dhigroup.com.au.

The hydraulic model was initially calibrated to the August 2007 flood event and was then used to assess the flood scenarios outlined in Section 4.

The model set-up, calibration and results from the design flood events are discussed below.

6.2 Model set-up

6.2.1 Model extent

A single MIKE FLOOD model was set-up to represent the study area as shown in Figure 6.1. MIKE FLOOD links a 1 dimensional model (MIKE 11), used to model the river channel, and a 2 dimensional model (MIKE 21) representing the floodplain into a single combined hydraulic model.

The original MIKE 11 model of the Forth River previously developed by Entura (Jokanovic, August 2012) extends from the Paloona Dam to Bass Strait. This original model was used at the basis for the MIKE FLOOD model developed for this study. The full extent of the original MIKE 11 model was retained however the river channel from approximately 1km upstream of the Forth Road bridge to Bass Strait was modified to suit the inclusion of the MIKE 21 model and the new survey of the river channel.

The MIKE 21 model representing the floodplain was set to cover the likely extent of flooding of the agricultural land downstream of the Forth Road bridge. The upstream extent of the MIKE 21 model was set to capture floodplain flow conditions upstream of and through the Forth Road floodway.

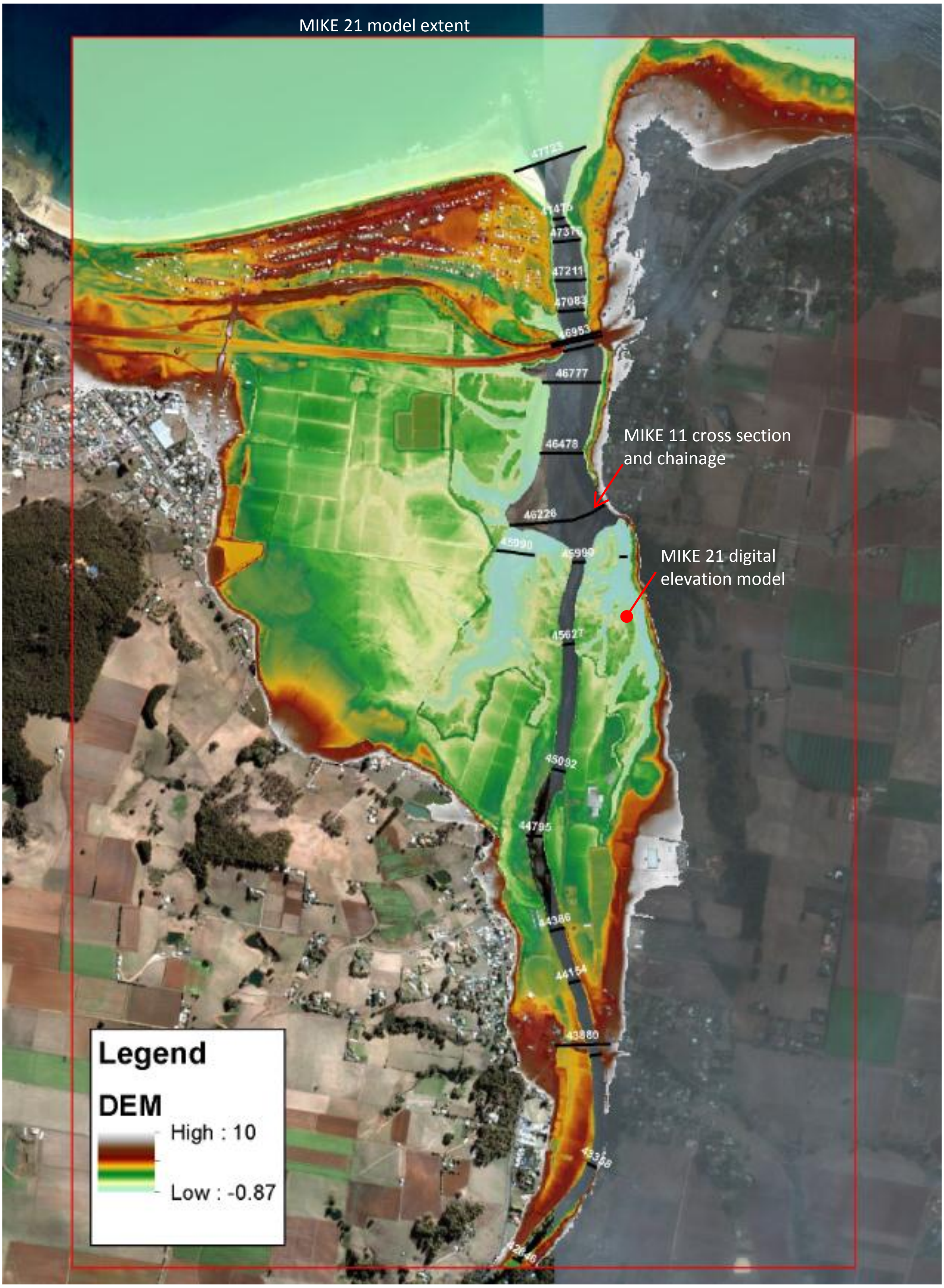
6.2.2 River cross sections and floodplain bathymetry

The river cross sections in the updated section of the MIKE 11 model were based on the bathymetric survey obtained by CCC for this study. Where required the surveyed sections were extended using the LiDAR survey. The locations of the river cross sections are provided in Figure 6.1.

Two gridded digital terrain models were developed for the floodplain areas modelled in MIKE 21 based on the available LiDAR survey from the LIST. A grid cell size of 5m was adopted as this size provided a good balance between the accuracy required for this study and the run times required for the hydraulic model. Based on a 5m grid size the hydraulic model run time was approximately 24 hours.

The first terrain model represented the floodplain pre-construction of Levee D for use in the model calibration scenario. The available LiDAR survey, which was taken after construction of Levee D had

Figure 6.1: MIKE FLOOD model extent for the lower Forth River



commenced, was adjusted (adjacent to the main river channel only) to remove the levee by interpolating between levels either of the levee.

The second terrain model represented the floodplain post-construction of Levee D. The traverse survey of Levee D (refer to Appendix A) was used to set the levels along the top of the levee.

For both terrain models the top levels of Levees A and B were based on the LiDAR survey and were captured in the 5m grid along with key barriers to floodplain flow including roads and the water treatment pond bunds.

6.2.3 Bridges and culverts

The following bridges, weir and culverts were included in the MIKE 11 hydraulic model:

- Paloona Bridge (deck level = 25.44m, soffit level = 23.60m)
- Forth River weir near pumping station
- Forth Bridge at Forth (deck level = 7.35m, soffit level = 6.12m)
- Flood Bypass Bridge (deck level = 6.15m, soffit level = 5.53m)
- Bass Highway Bridges (deck level = 5.40m, soffit level = 3.31m)
- Railway Bridge (deck level = 6.31m, soffit level = 4.02m)
- Pipe culvert across Bass Highway, DN 750mm.
- Pipe culvert across flood protection levee, DN 900mm.

6.2.4 Coupling 1 and 2 dimensional models

The MIKE 11 and MIKE 21 models were coupled together using MIKE FLOOD. Lateral links along the banks of the blocked out river cells were assigned to allow flow from the river channel to the floodplain i.e., transfer of flow between the MIKE 11 cross sections and the MIKE 21 models.

The parameters and values used for the lateral links are summarised in Table 6.1 below.

Table 6.1: Lateral Link Structure Details (Common for all links)

Parameter	Value	Comment
Method	Cell to cell	
Type	Weir 1	$Q = W \cdot C \cdot (H_{us} - H_w)^k \cdot \left[1 - \left(\frac{H_{ds} - H_w}{H_{us} - H_w}\right)^k\right]^{0.385}$ Refer to MIKE 11 reference manual for details.
Source	M21	HGH adopted for model stability.
Depth Tolerance	0.1m	For model stability.
Weir C	1.838	Default discharge coefficient.
Manning's n	0.05	Adopted value.

Standard links were established at the inlet and outlet of the structures on the floodplain. The standard links are at the upstream and downstream side of the following structures:

- Flood Bypass Bridge at Forth
- Levee culvert
- Bass Highway culvert.

6.2.5 Hydraulic roughness

Three different hydraulic roughness values, Manning's n values, were assigned to the river cross sections in the MIKE 11 model based on site observations. For the upper 12km stretch of river (between Paloona Dam and pump station) a Manning's n of 0.035 was adopted as per the original MIKE 11 model.

Downstream of the pump station for approximately 3km a Manning's n of 0.033 was adopted. For the final 2km stretch of river a Manning's n of 0.030 was applied.

The hydraulic roughness values for the floodplain were based on field observations and photographic comparison. The roughness values were set to the same 5m grid as the floodplain DEM. The adopted roughness values in the modelling are shown in Table 6.2.

Table 6.2: Adopted roughness values in the MIKE 21 model

Topography type	Roughness (Manning's "n")
River	0.03
Road	0.017
Rural area, private and public open spaces	0.036
Low density residential	0.1
Closed residential	0.167

6.2.6 Inflow locations

Flow in the Forth River is primarily from the outflow from Paloona Dam and power station and from Wilmot Dam. Inflow in the model is modelled as a point source at the location of Paloona Dam and Wilmot River confluence.

The local pickup between the confluence of Wilmot-Forth downstream of Paloona Dam and Forth River at Bass Highway was modelled as a point source just downstream of the Forth Weir near the pumping station.

6.2.7 Ocean water levels

Bass Strait was adopted as the downstream boundary of the MIKE FLOOD model.

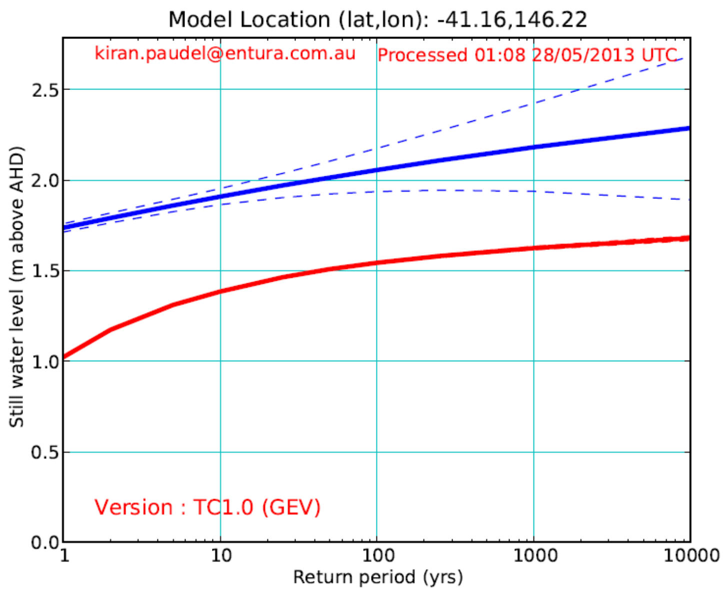
For the August 2007 calibration flood event recorded timeseries of 1 hourly tide levels at Burnie were adopted due to lack of available data at the mouth of the Forth River.

For the design flood events estimates of coincident storm surge were adopted as per the modelling scenarios outlined in Table 4.1.

The storm surge in the Bass Strait at the mouth of Forth River was calculated using a web based software called “Canute”. Developed by Antarctic Climate and Ecosystems Cooperative Research Centre, Canute provides estimates of the likelihood of flooding from the sea during this century, taking into account sea-level rise and the effects of tides and storm surges. More information on Canute can be found at http://canute2.sealevelrise.info/

At the mouth of Forth River, Figure 6.2 shows the storm level plot for extra tropical storm-surge + tide (blue trace) and tropical cyclone storm-surge + tide (red trace). For the worst case scenario, the storm surge levels for the 1 in 10 AEP and 1 in 100 AEP was considered as 1.91 AHD m and 2.06m AHD respectively as indicated by the blue trace.

Figure 6.2: Storm surge level calculation using Canute2.



The required 2100 sea level rise planning allowance for Tasmania is 0.8m (Tasmanian Climate Change Office, August 2012) and was adopted for the climate change scenarios carried out for this study.

The adopted tide levels for the study are summarised in

Table 6.3: Design flood storm surge levels

Storm surge event	Adopted level (m AHD)
1 in 10 AEP existing climate	1.91
1 in 100 AEP existing climate	2.06
1 in 10 AEP 2100 future climate	2.71
1 in 100 AEP 2100 future climate	2.86

6.2.8 Modelling assumptions

The following modelling assumptions were made during the set-up of the hydraulic model:

- The invert levels of the DN 750mm and DN 900 mm flood levee culverts were not surveyed. The invert levels were based on the available LiDAR survey at the inlet and outlet of the culverts.
- As per the original MIKE 11 hydraulic model the dual Bass Highway and rail bridges have each been combined into single hydraulic structures.
- The Leith Road floodstop barrier has been assumed to be in place for all design flood events.

6.3 Model calibration (Scenario 1 and 2)

The August 2007 flood event was used to calibrate the Forth River MIKE FLOOD model.

The flood hydrographs from Paloona Dam and from Wilmot River for the period between 9 August 2007 and 17 August 2007 were obtained from Hydro Tasmania's data record system and were applied to the top end of the MIKE 11 model near Paloona Dam.

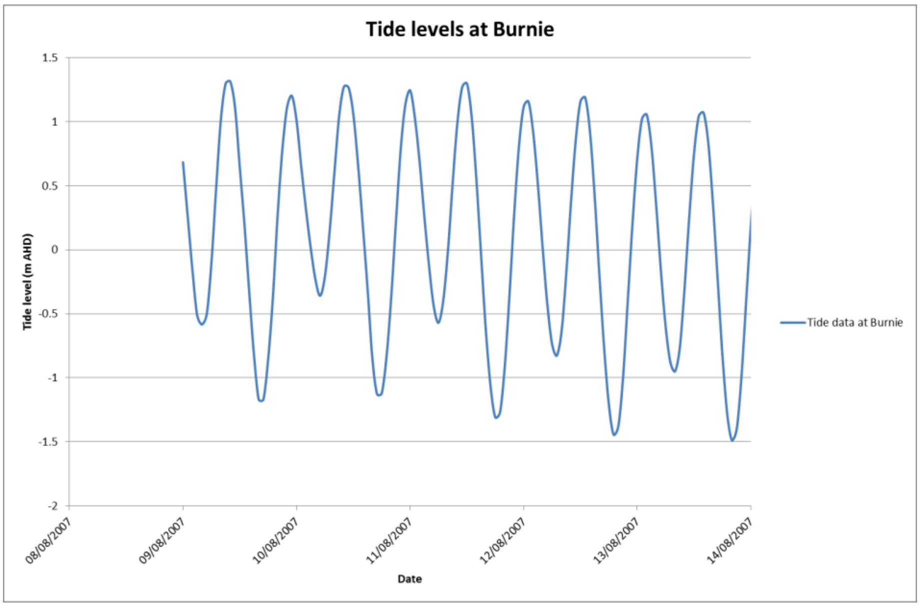
Local pickup between Paloona Dam and the bass Highway was based on catchment scaling as outlined in Section 5.3.2.

As no recorded tide information was available for the Forth River for the August 2007 flood event, the time series of recorded hourly tide levels at Burnie were applied as the downstream boundary condition for the model. The plot of tide level is provided in Figure 6.3.

Levee D, protecting Harvest Moon infrastructure, and the recent rail bridge duplication were not included in the hydraulic model.

The breach that occurred in Levee A was not considered in the calibration of the hydraulic model.

Figure 6.3: Recorded tide levels at Burnie



The hydraulic modelling results for the August 2007 flood event were compared against aerial photographs (Figure 6.4) to check flood extent and the peak surveyed flood levels provided by CCC.

The modelled and observed flood event extents are shown in Figure 6.4. It should be noted that the flood in the lower Forth River peaked at approximately 12am on the 11 August 2007 and the aerial photograph was taken later the same morning. There is a good visual match between the flood extents.

The modelled and surveyed flood levels are shown in Table 6.4, with Figure 6.5 to be used as a reference for the locations of the surveyed flood levels. The peak flood levels predicted by the model are typically within 0.2m of the surveyed flood levels which is considered to be acceptable.

The largest discrepancy between the surveyed and modelled flood levels is at the Bass Highway bridge where the modelled water level is approximately 0.5m above the surveyed level. The highest tide level from the Burnie data is approximately 1.3m AHD. Given the high discharge of the August 2007 flood it is considered unlikely that the water surface would only increase by 0.2m between the ocean and the Bass Highway. This suggests that the surveyed flood level could be too low at this location, which could be due to a local draw down in water level due to high flow velocities in the bridge not picked up by the hydraulic model. Alternatively the difference between absolute tide levels, and timing of the tidal peaks between Burnie and the Forth River could be the cause of the difference between the modelled and surveyed flood level. Due to the uncertainty of the available data, and the reasonable calibration with flood levels near Harvest Moon and the sports fields, Entura did not force the hydraulic model to produce lower water levels at the Bass Highway bridge.

Based on the above analysis the MIKE FLOOD hydraulic model calibration was considered to be acceptable for the design flood modelling.

Due to lack of available data for the 2011 flood event a verification model run was not carried out.

A review of the flood behaviour of the August 2007 flood event was carried out. Plots showing the progress of flooding are provided in Figure 6.6 and show:

- Flooding of the agricultural land on the western side of the river initiated through a low point in Levee A. Flooding of this land progressed via the low point in Levee A until flooding bypassed the southern end of Levee A and B.
- The area protected by Levee B was initially flooded by flow that had broken out of the river just downstream of the sports ovals.
- The breakout of flow on the eastern side of the river upstream of Harvest Moon matched the anecdotal descriptions and flood photographs of the flooding that occurred in this location.
- The model predicted the inundation on the northern side of the Bass Highway which occurred due to high water levels behind Levee A backing up the DN 750mm diameter pipe under the highway.

The calibrated MIKE FLOOD model was adopted for the design flood scenarios.

Figure 6.4: Comparison between observed and modelled flood extents – August 2007

Aerial photograph taken after flood peak had subsided

Modelled peak flood extent (Google Earth image)

Table 6.4: Comparison between observed and modelled flood levels – August 2007

Survey point	Surveyed flood level (m AHD)	Modelled flood level (m AHD)	Difference (m)	Comment
1	2.9	3.04	+0.14	Good match
2	2.9	2.80	-0.1	Good match
5	3.6	3.20	-0.4	Model result low
6	4.1	4.33	+0.23	Reasonable match
7	4.0	4.33	+0.33	Model result slightly high
31	3.9	4.13	+0.3	Reasonable match
32	2.9	N/A	N/A	Surveyed point just outside modelled flood extent
34	3.3	N/A	N/A	Surveyed point just outside modelled flood extent
35	3.0	3.14	+0.14	Good match
50	3.9	4.13	+0.23	Reasonable match
51	2.9	3.06	+0.16	Reasonable match
203	1.5	1.98	+0.48	Model result significantly higher than recorded
301	3.7	N/A	N/A	Surveyed point outside modelled flood extent

Figure 6.5: Locations of surveyed flood levels – calibration flood extent

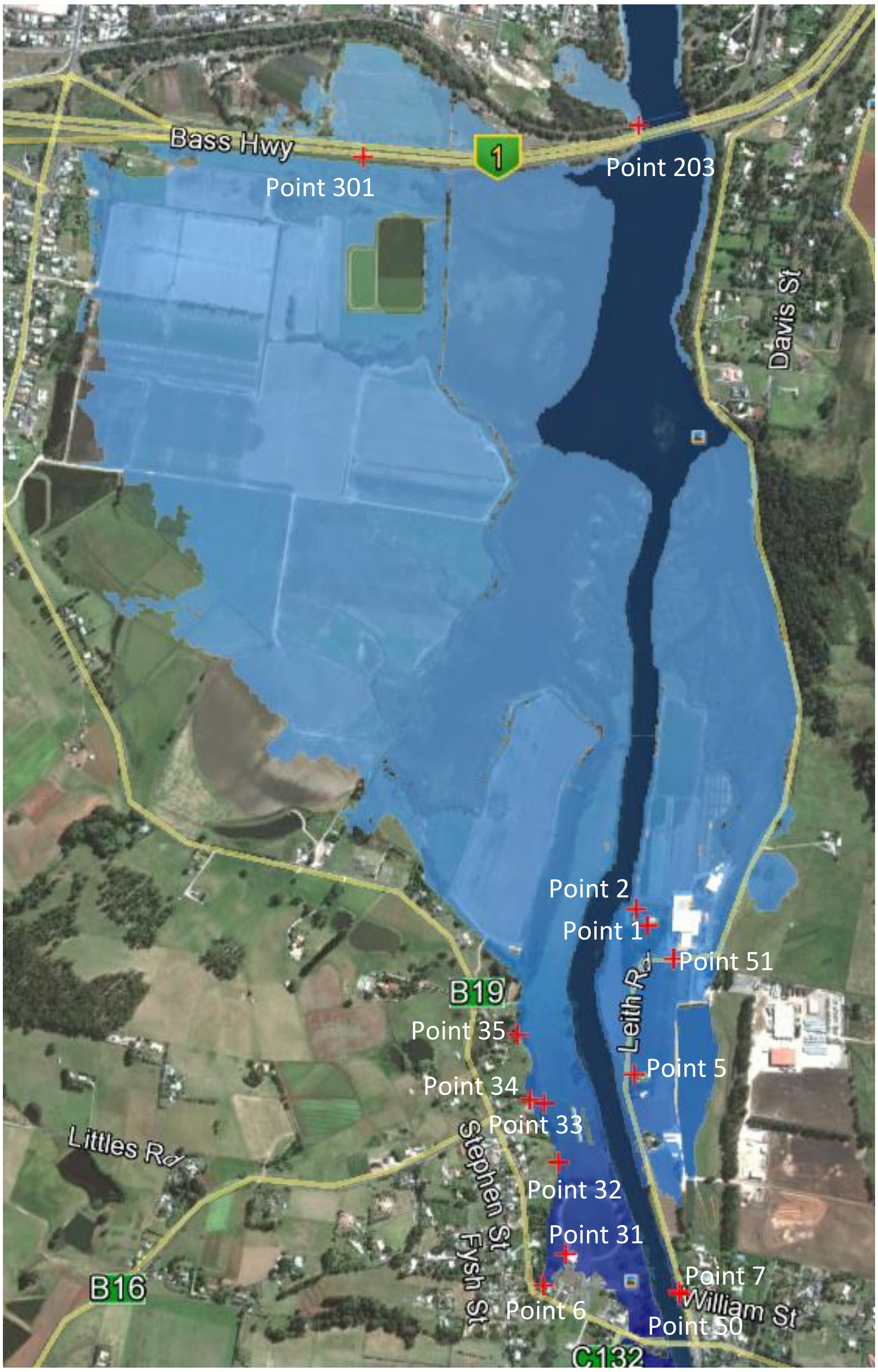
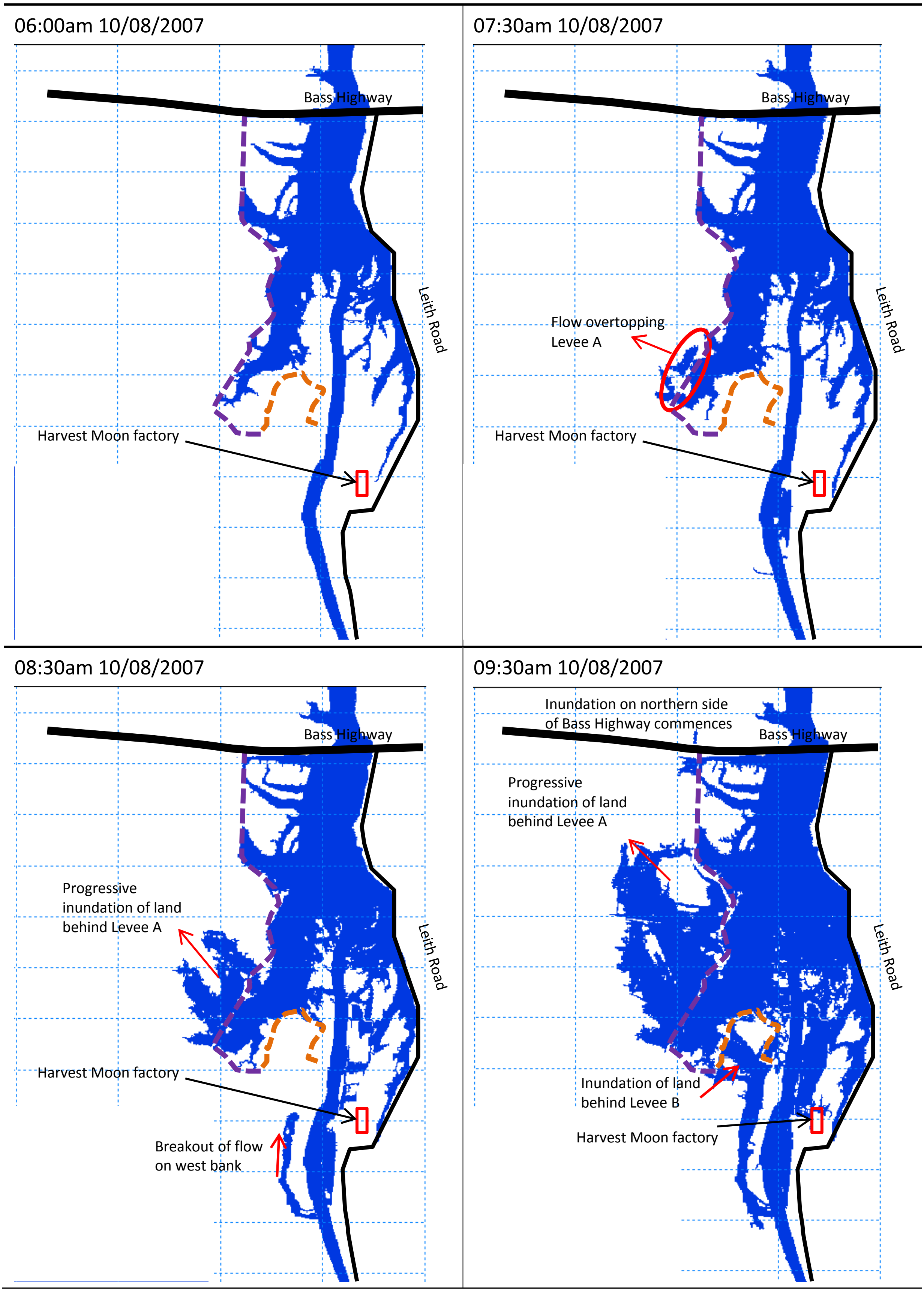
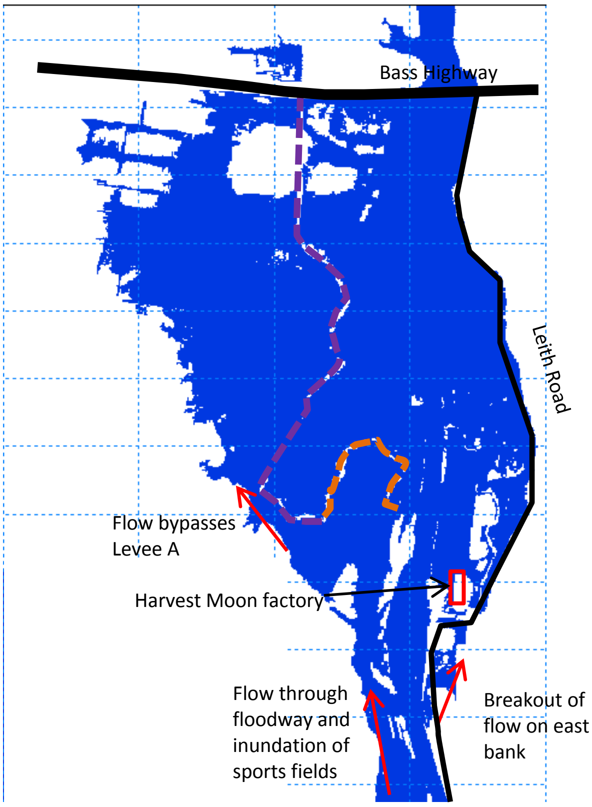


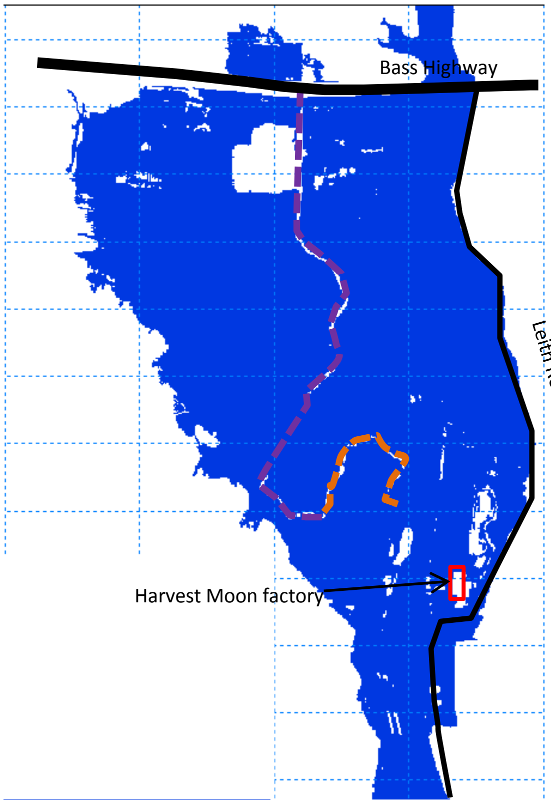
Figure 6.6: August 2007 flood event – modelled flood progress from MIKE 21



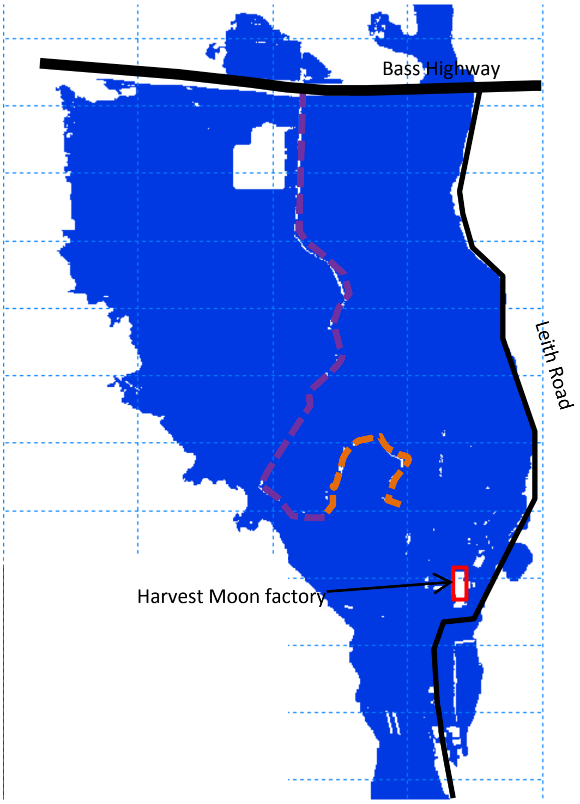
12:00pm 10/08/2007



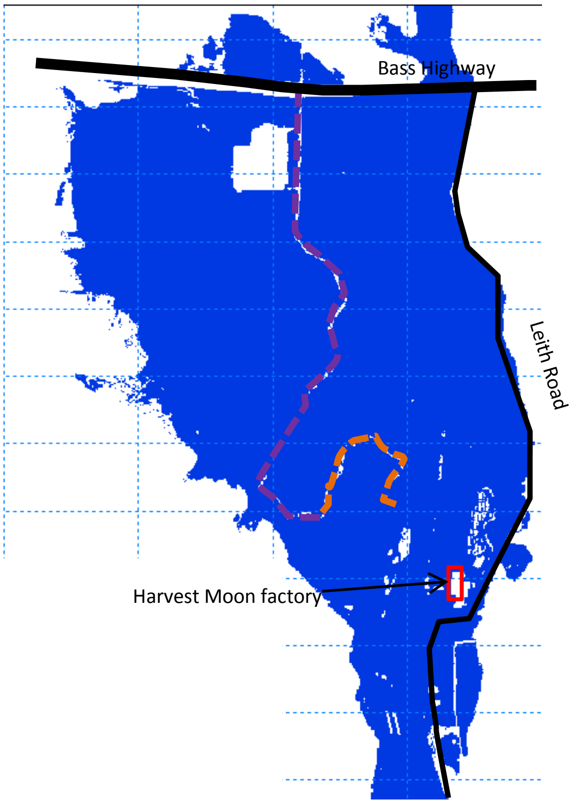
06:00pm 10/08/2007



12:00am 11/08/2007



06:00am 11/08/2007



6.4 Design flood events (Scenarios 3 to 10)

6.4.1 General

A summary the design flood scenarios assessed for the study are provided in Table 6.5. The focus of the design flood events was to assess flooding from the 1 in 100 AEP rainfall and storm surge events.

Scenarios 3 to 6 were run to assess the peak flood levels of the existing catchment conditions for the existing and 2100 future climate conditions.

Scenarios 7 and 8 were run with Levee D removed from the model with the aim of comparing the results against those from Scenarios 3 and 5 to determine the likely impact of the levee on surrounding flooding.

Scenarios 9 and 10 were run to assess the impact of constructing Levee C (for pedestrian access) on flooding. A level of 2.05m AHD was assumed for the top of Levee C to match the top level of Levee A.

The estimated peak flood levels along the main river channel for the existing and 2100 future climates are provided in Table 6.6.

The difference in flood levels between Scenarios 3 and 7 (existing climate 1 in 100 AEP flood event with and without Levee D) and between Scenarios 3 and 9 (existing climate 1 in 100 AEP flood event with and without Levee C) are provided in Table 6.7.

The difference in flood levels between Scenarios 5 and 8 (2100 future climate 1 in 100 AEP flood event with and without Levee D) and between Scenarios 5 and 10 (2100 future climate 1 in 100 AEP flood event with and without Levee C) are provided in Table 6.8.

Flood extent and level difference maps for the design flood events are provided in Appendix C.

Table 6.5: Summary of modelled scenarios

Scenario No.	Description						Mapping remarks
	Climate	Levees		Rainfall AEP	Storm Surge AEP	Storm Surge Level (m AHD)	
		HM & LR*	Levee C				
3	Current	Yes	No	1:100	1:10	1.91	Flood extent plot
4	Current	Yes	No	1:10	1:100	2.06	Flood extent plot
5	2100	Yes	No	1:100	1:10	2.71	Flood extent plot
6	2100	Yes	No	1:10	1:100	2.86	Flood extent plot
7	Current	No	No	1:100	1:10	1.91	Flood extent and level difference with Scenario No. 3
8	2100	No	No	1:100	1:10	2.71	Flood extent and level difference with Scenario No. 5
9	Current	Yes	Yes	1:100	1:10	1.91	Flood extent and level difference with Scenario No. 3
10	2100	Yes	Yes	1:100	1:10	2.71	Flood extent and level difference with Scenario No. 5

* HM & LR: Harvest Moon and Leith Road Levees

Table 6.6: Peak flood levels at different locations along Forth River

Chainage	Description	Peak flood level (m AHD) for Scenario No.							
		3	4	5	6	7	8	9	10
42846	~800m d/s of pump station	7.20	5.83	8.22	6.77	7.19	8.19	7.20	8.22
43358		5.92	4.83	6.73	5.59	5.91	6.66	5.92	6.73
43834		4.90	3.51	5.77	4.44	4.84	5.50	4.90	5.76
43844	Upstream of Forth Bridge	4.98	3.57	5.84	4.53	4.92	5.59	4.98	5.84
43914		4.39	3.24	5.30	4.08	4.30	5.24	4.39	5.30
44154	Near the oval	4.19	3.13	5.07	3.95	4.07	4.79	4.19	5.08
44387		3.80	2.93	4.62	3.68	3.62	4.31	3.80	4.62
44795		3.23	2.67	3.94	3.36	3.06	3.82	3.23	3.94
45092		2.97	2.53	3.72	3.25	2.93	3.79	2.97	3.72
45627		2.71	2.34	3.69	3.18	2.69	3.68	2.71	3.68
45979		2.52	2.24	3.52	3.08	2.54	3.56	2.52	3.52
46226	Widened river section	2.61	2.27	3.61	3.13	2.60	3.62	2.60	3.61
46478		2.53	2.24	3.53	3.09	2.53	3.55	2.53	3.53
46777		2.51	2.23	3.50	3.08	2.51	3.50	2.51	3.49
46922	Upstream of Bass Hwy Bridge	2.45	2.22	3.39	3.05	2.45	3.39	2.45	3.38
46963	Upstream of Railway Bridge	2.37	2.19	3.24	3.02	2.37	3.24	2.38	3.25
47083		2.25	2.14	3.08	2.96	2.25	3.08	2.25	3.07
47211		2.20	2.12	3.03	2.94	2.20	3.03	2.20	3.02
47378		2.14	2.11	2.94	2.92	2.14	2.94	2.14	2.94
47475	Narrowed river section	1.81	2.00	2.67	2.76	1.81	2.67	1.81	2.67
47723	Mouth of the river	1.91	2.06	2.71	2.86	1.91	2.71	1.91	2.71

Note: Peak flood levels and flood level differences will vary on the floodplain.

Table 6.7: Peak flood levels along the Forth River channel and flood level differences for the 1 in 100 AEP rainfall event – existing climate

Chainage	Peak flood level 1 in 100 AEP rainfall with Levee D Scenario 3 (m AHD)	Peak flood level 1 in 100 AEP rainfall without Levee D Scenario 7 (m AHD)	Difference in peak flood level between Scenario 3 and 7 representing impact of Levee D (m)	Peak flood level 1 in 100 AEP rainfall with Levee D and C Scenario 9 (m AHD)	Difference in peak flood level between Scenario 3 and 9 representing impact of Levee C (m)
42846	7.2	7.19	0.01	7.2	0
43358	5.92	5.91	0.01	5.92	0
43834	4.9	4.84	0.06	4.9	0
43844	4.98	4.92	0.06	4.98	0
43914	4.39	4.3	0.09	4.39	0
44154	4.19	4.07	0.12	4.19	0
44387	3.8	3.62	0.18	3.8	0
44795	3.23	3.06	0.17	3.23	0
45092	2.97	2.93	0.04	2.97	0
45627	2.71	2.69	0.02	2.71	0
45979	2.52	2.54	-0.02	2.52	0
46226	2.61	2.6	0.01	2.6	-0.01
46478	2.53	2.53	0	2.53	0
46777	2.51	2.51	0	2.51	0
46922	2.45	2.45	0	2.45	0
46963	2.37	2.37	0	2.38	0.01
47083	2.25	2.25	0	2.25	0
47211	2.2	2.2	0	2.2	0
47378	2.14	2.14	0	2.14	0
47475	1.81	1.81	0	1.81	0
47723	1.91	1.91	0	1.91	0

Note: Peak flood levels and flood level differences will vary on the floodplain.

Table 6.8: Peak flood levels along the Forth River channel and flood level differences for the 1 in 100 AEP rainfall event – 2100 future climate

Chainage	Peak flood level 1 in 100 AEP rainfall with Levee D Scenario 5 (m AHD)	Peak flood level 1 in 100 AEP rainfall without Levee D Scenario 8 (m AHD)	Difference in peak flood level between Scenario 5 and 8 representing impact of Levee D (m)	Peak flood level 1 in 100 AEP rainfall with Levee D and C Scenario 10 (m AHD)	Difference in peak flood level between Scenario 5 and 10 representing impact of Levee C (m)
42846	8.22	8.19	0.03	8.22	0
43358	6.73	6.66	0.07	6.73	0
43834	5.77	5.5	0.27	5.76	-0.01
43844	5.84	5.59	0.25	5.84	0
43914	5.3	5.24	0.06	5.3	0
44154	5.07	4.79	0.28	5.08	0.01
44387	4.62	4.31	0.31	4.62	0
44795	3.94	3.82	0.12	3.94	0
45092	3.72	3.79	-0.07	3.72	0
45627	3.69	3.68	0.01	3.68	-0.01
45979	3.52	3.56	-0.04	3.52	0
46226	3.61	3.62	-0.01	3.61	0
46478	3.53	3.55	-0.02	3.53	0
46777	3.5	3.5	0	3.49	-0.01
46922	3.39	3.39	0	3.38	-0.01
46963	3.24	3.24	0	3.25	0.01
47083	3.08	3.08	0	3.07	-0.01
47211	3.03	3.03	0	3.02	-0.01
47378	2.94	2.94	0	2.94	0
47475	2.67	2.67	0	2.67	0
47723	2.71	2.71	0	2.71	0

Note: Peak flood levels and flood level differences will vary on the floodplain.

Table 6.9: Predicted change in flood levels along the Forth River channel due to climate change – Levee D constructed

Chainage	Difference in peak flood level between Scenario 3 and 5 1 in 100 AEP rainfall event (m)	Difference in peak flood level between Scenario 4 and 6 1 in 100 AEP storm surge event (m)
42846	1.02	0.94
43358	0.81	0.76
43834	0.87	0.93
43844	0.86	0.96
43914	0.91	0.84
44154	0.88	0.82
44387	0.82	0.75
44795	0.71	0.69
45092	0.75	0.72
45627	0.98	0.84
45979	1.00	0.84
46226	1.00	0.86
46478	1.00	0.85
46777	0.99	0.85
46922	0.94	0.83
46963	0.87	0.83
47083	0.83	0.82
47211	0.83	0.82
47378	0.80	0.81
47475	0.86	0.76
47723	0.80	0.80

Note: Peak flood levels and flood level differences will vary on the floodplain.

6.4.2 Assessment of results

A summary of the key outcomes from the hydraulic modelling are provided below. The summary has been structured with comments on the following topics:

- Summary of flooding for existing levee conditions.
- Assessment of existing as built levees.
- Assessment of the potential impact associated with the construction of Levee D.
- Assessment of the impact of Levee C which is currently proposed to be constructed to provide a pedestrian link between Forth and Turners Beach.
- Flood immunity of the waste water treatment ponds.

6.4.2.1 Summary of flooding for existing levee conditions

The 1 in 100 AEP rainfall flood event resulted in higher flood levels upstream of the Bass Highway compared with a 1 in 100 AEP storm surge event. As a result the 1 in 100 AEP rainfall event was used to assess the impact of Levee D and Levee C.

For the existing climate 1 in 100 AEP rainfall and storm surge events, with the levees as currently in place, significant flooding is predicted to occur on the western floodplain with the impact of climate change increasing flood levels by approximately 0.7m to 1.0m as shown in Table 6.9.

For the existing and 2100 climate 1 in 100 AEP rainfall events and the 2100 climate 1 in 100 AEP storm surge event, with the levees as currently in place, flooding of the Harvest Moon infrastructure is predicted to occur. For the existing climate 1 in 100 AEP storm surge event the Harvest Moon infrastructure is predicted to be protected by Levee D.

In the vicinity of Turners Beach no flooding of properties is predicted to occur for the existing climate condition 1 in 100 AEP rainfall of storm surge events. For the 2100 climate approximately 35 properties along Boyce Street, Susan Street, Arcadia Avenue and Whitegum Way are predicted to be affected primarily due to the 0.8m rise in mean sea level. Properties at the end of Lethborg Avenue and Heather Court may also be affected. Provision of a small levee and once way flow device may prevent flooding of these properties in the climate change scenario.

Other areas where properties may be affected by the modelled flood events, with the levees as currently in place, include:

- Near the intersection of Turners Beach Road and the Bass Highway. For the existing climate condition the dwellings at this location are not predicted to be affected however for the 2100 climate condition 3 to 4 dwellings could potentially be inundated.
- At the bend in Forth Road near Mell Street buildings associated with the sports fields are predicted to be affected for flooding from the 1 in 100 AEP rainfall events (current and 2100 climates) and the 1 in 100 AEP 2100 climate storm surge event. Flooding of a number of residential dwellings in this area is predicted to occur for the 1 in 100 AEP 2100 climate rainfall event.
- Just upstream of the Leith Road floodstop barrier a number of properties are predicted to be affected by flooding for the 1 in 100 AEP 2100 climate rainfall event. No flooding of properties in this area is predicted for the current climate 1 in 100 AEP rainfall event.

Flooding of the low area bounded by Blackburn Drive and the Bass Highway is predicted for all modelled flood events.

Overtopping of the waste water ponds is not predicted to occur for the current climate conditions 1 in 100 AEP rainfall or storm surge events.

Overtopping of the waste water ponds is predicted to occur for the 2100 climate conditions 1 in 100 AEP rainfall or storm surge events.

Overtopping of the Bass Highway or the rail bridges is not predicted for the modelled flood events.

Overtopping of Forth Road and Wilmot Road is predicted to occur for the 2100 climate condition 1 in 100 AEP rainfall event.

6.4.2.2 Assessment of existing levees

Levee A

The low point in Levee A, as per the August 2007 calibration flood event, initiates flooding of the agricultural land on the western side of Levee A for the design flood events. Refer to Figure 6.7. It should be noted the low point in the levee would be breached by the 1 in 10 AEP existing climate storm surge level without any flow in the Forth River from a rainfall event.

Levee D

It is considered that Levee D could be optimally designed to minimise the impact on surrounding flooding for the 1 in 100 AEP existing and 2100 climate rainfall events.

For all the modelled flood events in this study where Levee D is in place, flooding of the Harvest Moon infrastructure has been initiated by overtopping of the northern section of the levee as shown in Figure 6.7. It is estimated that northern section of Levee D has a flood immunity approximately equal to a 1 in 50 AEP existing climate flood event.

A plot along the Forth River channel is shown in Figure 6.8 and shows the river invert, the peak flood levels predicted for the August 2007 event and Scenario 3 to 6 and the top levels of Levee D adjacent to the river. It can be seen that the section of Levee D adjacent to the river will only just be overtopped for the 1 in 100 AEP 2100 climate rainfall event. This section of levee has a much higher flood immunity than the northern section.

When the impact of Levee D on flooding is assessed (ie comparing the flood predicted flood levels with and without Levee D), it is observed that the levee will slightly increase surrounding flood levels in the Forth River and on the western floodplain from upstream of the Forth Road bridge to approximately the northern extent of the levee. The levee does however reduce the severity of flooding on the eastern floodplain as intended.

For the 1 in 100 AEP current climate rainfall event:

- The maximum predicted increase in flood levels in the river channel is approximately 0.18m. Refer to Table 6.7.
- Based on the flood difference map provided in Appendix C, the increase in flood levels on the western floodplain may not impact on dwellings located on the eastern side of Forth Road, however infrastructure located on the properties may experience a worsening of flooding.

For the 1 in 100 AEP 2100 future climate rainfall event:

- The maximum predicted increase in flood levels in the river channel is approximately 0.31m. Refer to Table 6.7.
- Based on the flood extent and flood level difference maps provided in Appendix C the increase in flood levels due to Levee D is predicted to result in overtopping of Wilmot Road and Forth Road with a small number of dwellings and buildings in the flow path being affected.

  The increase in flood levels may also slightly worsen flooding for a small number of properties located on the eastern side of the river just upstream of the floodstop barrier.

It is recommended that CCC review the design of the existing Levee D. The review should consider the flood immunity required for the Harvest Moon infrastructure and the varying flood immunity of the various sections of Levee D. It may be possible to redesign Levee D so that it can provide the appropriate level of flood protection for the Harvest Moon infrastructure while minimising the impact of flooding for existing and future climate conditions. The re-design of Levee D could potentially involve a lowering of the levee where it runs adjacent to the river channel and a raising of the northern section.

The lowering of Levee D to the appropriate flood protection level may also allay community concerns in respect to the perceived flood height in the river relative to the Level of Levee D.

Leith Road floodstop barrier

Based on the modelling carried out for this study the Leith Road floodstop barrier is not expected to provide any benefit for the 1 in 100 AEP rainfall event (in terms of prevent flooding of the eastern floodplain) until at least 2100.

6.4.2.3 Impact of constructing Levee C

Construction of Levee C at a level of 2.05m AHD is not predicted to significantly impact flood levels for the 1 in 100 AEP existing or 2100 future climate condition rainfall events. This is based on the current levels of Levee A and B. Should Levees A and B be raised from their current levels then implementing Levee C could have a more significant impact on flood levels.

6.4.2.4 Flood immunity of waste water ponds

The lowest level of the waste water pond bunds is approximately 2.82m AHD. It should be noted that this level is not from design drawings or survey and has been extracted from the LiDAR survey.

The peak flood levels for Scenarios 3 to 6 and the freeboard to the lowest point along the pond bunds is shown in Table 6.10.

It is recommended that the relevant authority review whether the freeboard for the existing climate condition is acceptable.

For the 2100 future climate it is predicted that the ponds will be inundated. If the climate change predictions do eventuate the relevant authority will need to be prepared to raise the pond bunds to provide a 1 in 100 AEP flood immunity for future climate conditions.

It should be noted that the 2040 climate condition has not been assessed for this study. There is potential that work to the pond bunds may be required to provide a 1 in 100 AEP flood immunity for this future climate.

Table 6.10: Assessment of waste water ponds

Scenario	Description	Peak flood level (m AHD)	Freeboard to lowest point on bund (m)
3	1 in 100 AEP rainfall and 1 in 10 AEP storm surge – existing climate	2.63	+0.21
4	1 in 10 AEP rainfall and 1 in 100 AEP storm surge – existing climate	2.28	+0.55
5	1 in 100 AEP rainfall and 1 in 10 AEP storm surge – 2100 climate	3.6	-0.83
6	1 in 10 AEP rainfall and 1 in 100 AEP storm surge – 2100 climate	3.14	-0.31

Figure 6.7: Assessment of levees – reference figure

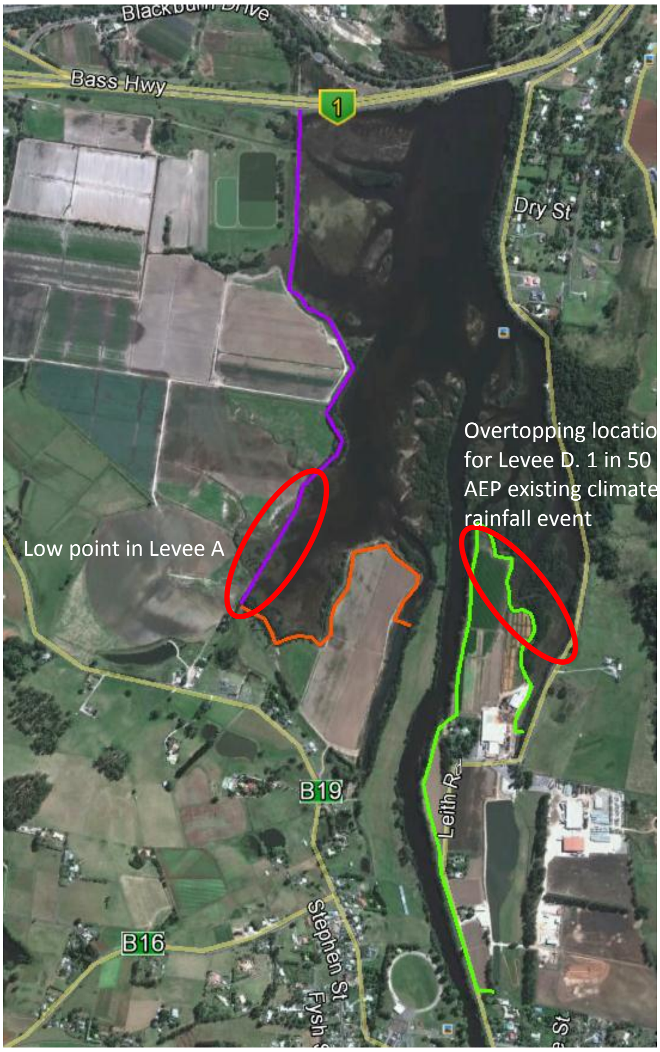
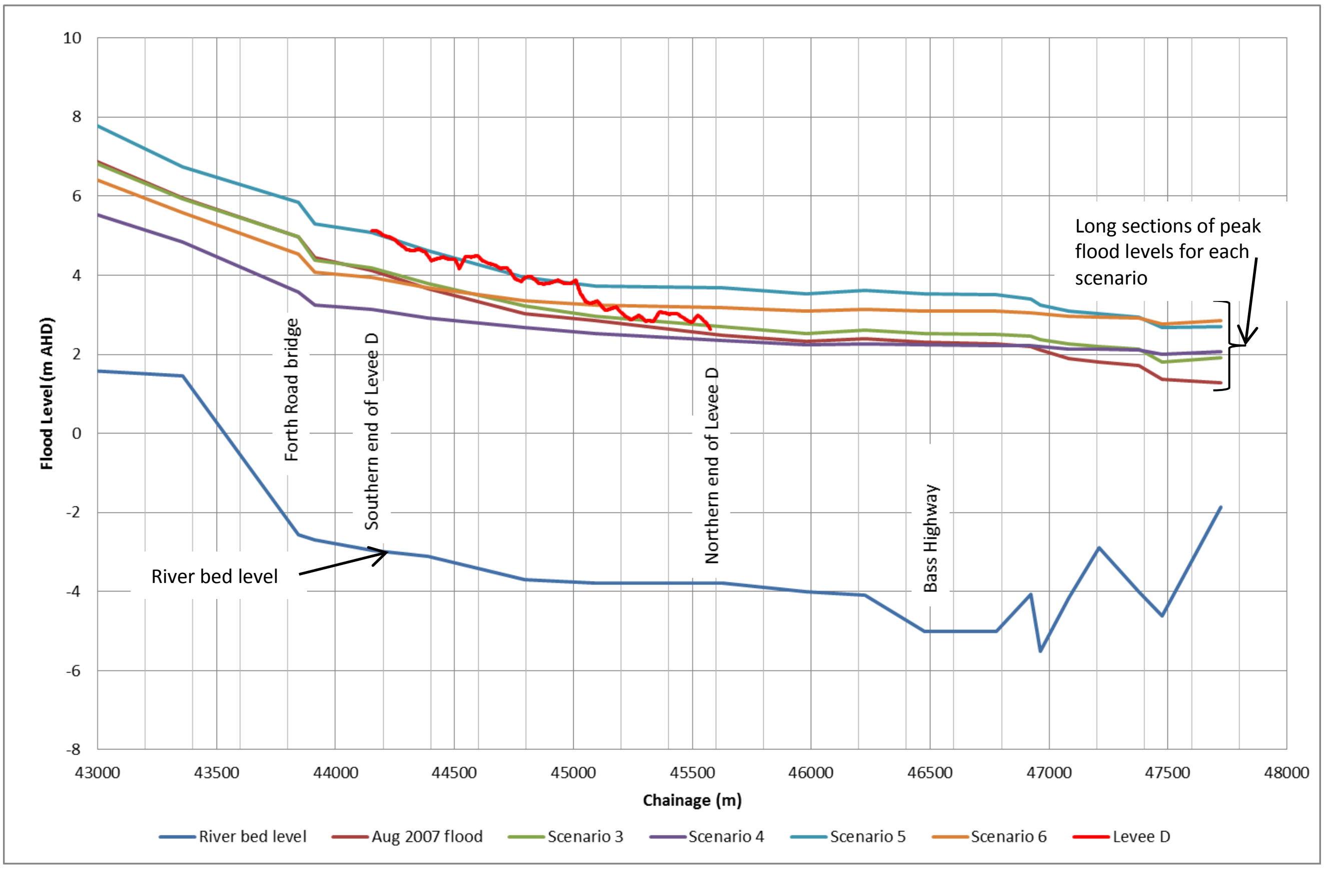


Figure 6.8: Forth River long section



6.4.2.5 Flooding between Blackburn Drive and Bass Highway

Flooding of the low area between Blackburn Drive and the Bass Highway due to water backing up the DN750mm diameter pipe under the Bass Highway could potentially be eliminated through the provision of a one way flow device (such as a tide flap) on the pipe. It is recommended that CCC give consideration to providing such a device on the pipe.

6.5 Mapping

Flood inundation and flood difference maps were prepared for the study and are provided in Appendix C.

It should be noted that the flood difference maps for the 1 in 100 AEP 2100 climate rainfall event assessing the impact of Levee C and D highlight some numerical instabilities in the modelling results near Levee D for these scenarios. However these instabilities do not affect the conclusions and outcomes and recommendations for the study.

7. Conclusions and recommendations

7.1 Conclusions

Flood hydrographs were developed for the August 2007 flood event and for the 1 in 10 AEP and 1 in 100 AEP design rainfall events for the existing climate and the 2100 future climate taking into consideration of increased rainfall due to climate change.

Climate Futures for Tasmania (2011) found that precipitation in the period 2070-2099 is anticipated to increase by 15% with an estimated increase in runoff of 65% for the 1 in 10 AEP event. For the 1 in 100 AEP event precipitation is estimated to increase by 20% with an estimated increase in runoff of 52%. This data was used to develop the 2100 climate design flood hydrographs.

The shape of the August 2007 flood hydrograph was used as the basis for all design flood hydrographs used in this study.

The peak discharges of the design flood hydrographs were based on flood frequency analysis of records on the Forth River below Paloona Dam and from catchment scaling for the catchments contributing to the lower Forth River.

The August 2007 and design flood hydrographs were used as inputs to the hydraulic model developed for the study.

A MIKE FLOOD hydraulic model of the lower Forth River was developed by Entura and was calibrated to the August 2007 flood event.

The MIKE FLOOD model was based on a MIKE 11 model previously developed by Entura, LiDAR survey available for the LIST, river cross section survey of the lower Forth River commissioned by CCC for this study, levee culvert details provided by CCC, as built survey of Levee D provided by CCC and design drawings of bridges and floodways sourced from DIER.

The calibrated MIKE FLOOD model was used to model the 1 in 100 AEP rainfall event with 1 in 10 AEP storm surge and the 1 in 100 AEP and storm surge with 1 in 10 AEP rainfall events for the existing and 2100 climate conditions and to assess the impact of the existing Levee D and the proposed Levee C on flooding.

Flood extent maps were prepared for all modelled flood events.

For the existing climate 1 in 100 AEP rainfall and storm surge events, with the levees as currently in place, significant flooding is predicted to occur on the western floodplain with the impact of climate change increasing flood levels by approximately 0.7m to 1.0m.

For the existing and 2100 climate 1 in 100 AEP rainfall events and the 2100 climate 1 in 100 AEP storm surge event, with the levees as currently in place, flooding of the Harvest Moon infrastructure is predicted to occur. For the existing climate 1 in 100 AEP storm surge event the Harvest Moon infrastructure is predicted to be protected by Levee D.

In the vicinity of Turners Beach no flooding of properties is predicted to occur for the existing climate condition 1 in 100 AEP rainfall or storm surge events. For the 2100 climate approximately 35 properties along Boyes Street, Susan Street, Arcadia Avenue and Whitegum Way are predicted to be affected primarily due to the 0.8m rise in mean sea level. Properties at the end of Lethborg Avenue and Heather Court may also be affected. Provision of a small levee and one way flow device may prevent flooding of these properties in the climate change scenario.

Other areas where properties may be affected by the modelled flood events, with the levees as currently in place, include:

- Near the intersection of Turners Beach Road and the Bass Highway. For the existing climate condition the dwellings at this location are not predicted to be affected however the for the 2100 climate condition 3 to 4 dwellings could potentially be inundated.
- At the bend in Forth Road near Mell Street buildings associated with the sports fields are predicted to be affected for flooding from the 1 in 100 AEP rainfall events (current and 2100 climates) and the 1 in 100 AEP 2100 climate storm surge event. Flooding of a number of residential dwellings in this area is predicted to occur for the 1 in 100 AEP 2100 climate rainfall event.
- Just upstream of the Leith Road floodstop barrier a number of properties are predicted to be affected by flooding for the 1 in 100 AEP 2100 climate rainfall event. No flooding of properties in this area is predicted for the current climate 1 in 100 AEP rainfall event.

Flooding of the low area bounded by Blackburn Drive and the Bass Highway is predicted for all modelled flood events.

Overtopping of the waste water ponds was not predicted to occur for the existing climate flood events however overtopping was predicted for the 2100 climate condition.

Flooding of the western floodplain was found to be initiated by a low section in Levee A. This low section of Levee A would be overtopped by the 1 in 10 AEP 2100 climate surge level.

Levee D was found to reduce the severity of the eastern flooding in the vicinity of the Harvest Moon infrastructure. However the levee also results in an increase in flood levels in the main channel and the western floodplain. The maximum increase in flood levels in the river channel as a result of Levee D was estimated to be 0.18m for the 1 in 100 AEP current climate rainfall event.

It was found that Levee D has varying levels of flood immunity. The southern section adjacent to the river channel has an immunity approximately equivalent to the 1 in 100 AEP 2100 climate rainfall event while the northern section will be overtopped by a 1 in 50 AEP existing climate rainfall event.

Based on the modelling carried out for this study the Leith Road floodstop barrier is not expected to provide any benefit for the 1 in 100 AEP rainfall event (in terms of prevent flooding of the eastern floodplain) until at least 2100.

It was found that Levee C, with a top level of 2.05m AHD, could be built with minimum impact on surrounding flooding.

Overtopping of the waste water ponds is not predicted to occur for the current climate conditions. The estimated freeboard for the 1 in 100 AEP rainfall event is approximately 0.21m.

Significant overtopping of the waste water ponds is predicted to occur for the 2100 climate conditions 1 in 100 AEP rainfall or storm surge events.

7.2 Recommendations

It is recommended that a one way flow device be provided to the DN750mm diameter culvert under the Bass Highway to prevent flood of the low lying land between Blackburn Drive and the Bass Highway.

It is recommended that a review of the Levee D design be carried out to determine whether it can be optimised to provide a consistent level of flood protection to Harvest Moon infrastructure while minimising the impacts on surrounding flooding.

It is recommended that the relevant authority review the level of freeboard required for the wastewater treatment ponds for the 1 in 100 AEP flood event to determine whether any work is required to provide the facility with the adequate level of flood protection.

It is recommended that the relevant authority put in place plans to, in the future, review the waste water ponds and level of flood protection required, once the potential consequences of climate change on rainfall and sea level rise are better understood.

Once the potential consequences of climate change on rainfall and sea level rise are better understood, it is recommended that CCC review flood mitigation measures that would be required to prevent flooding of properties in Turners Beach.

Page left intentionally blank

8. References

Central Coast Council. (11 March 2008). *Lower Forth Flood Response and Recovery Plan.* Ulverstone: Central Coast Council.

Climate Futures for Tasmania. (2011). *Flood Inundation Mapping.* Hobart: Antarctic Climate and Ecosystems CRC.

Jokanovic, A. (August 2012). *Proposed Railway Bridg on Forth River Hydraulic Modelling.* Hobart: Entura.

Tasmanian Climate Change Office. (August 2012). *Derivation of the Tasmania Sea Level Rise Planning Allowances Technical Paper.* Hobart.

Page left intentionally blank

Appendices

A – Survey

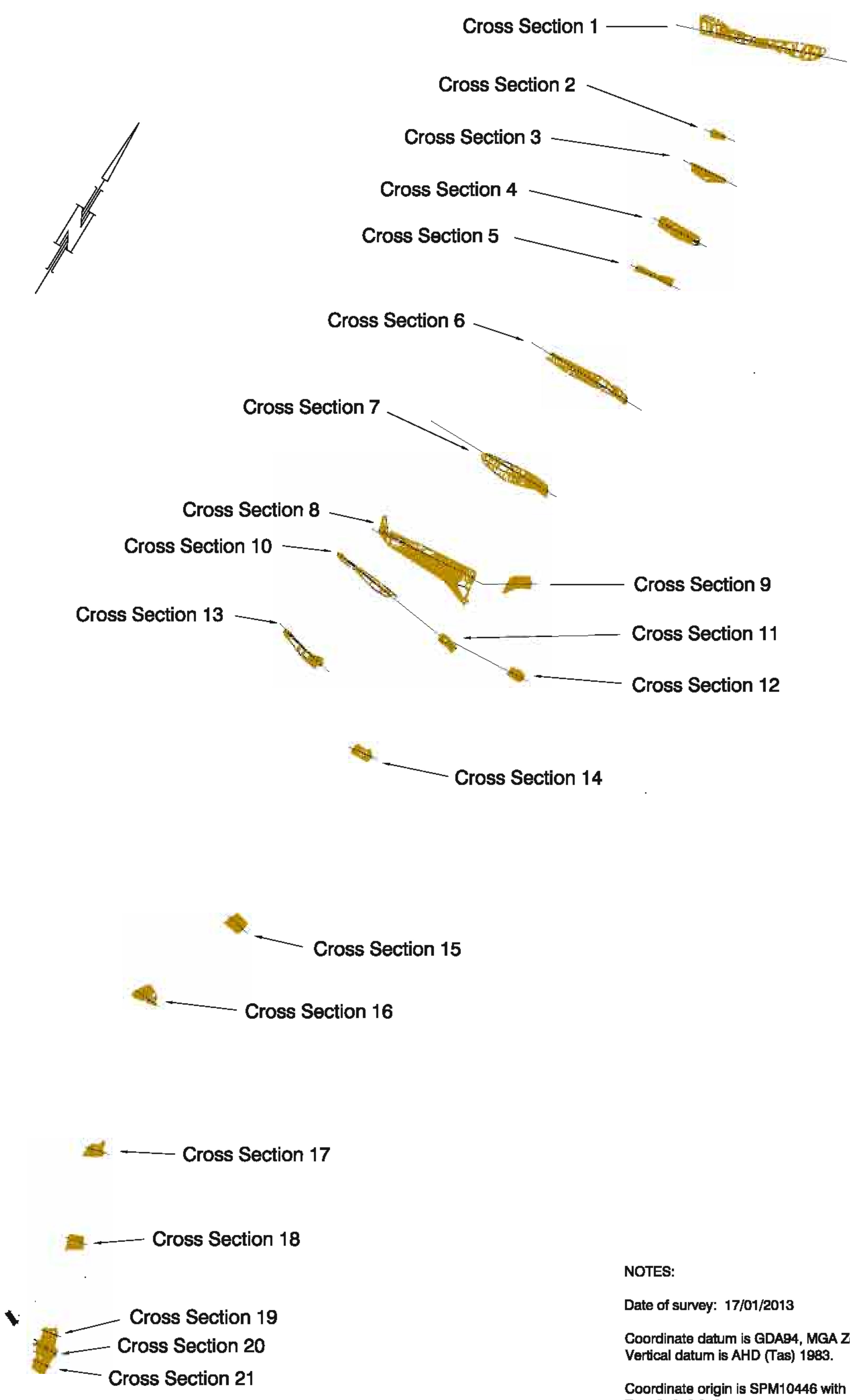
B – Flood hydrographs

C – Flood maps

Page left intentionally blank

Survey

Page left intentionally blank



SCALE 1:10000 (A3)

0 100 200 300 400 500 metres

NOTES:

Date of survey: 17/01/2013

Coordinate datum is GDA94, MGA Zone 55
Vertical datum is AHD (Tas) 1983.

Coordinate origin is SPM10446 with reputed coordinates:
E: 437248.048
N: 5439864.185
RL: 7.439

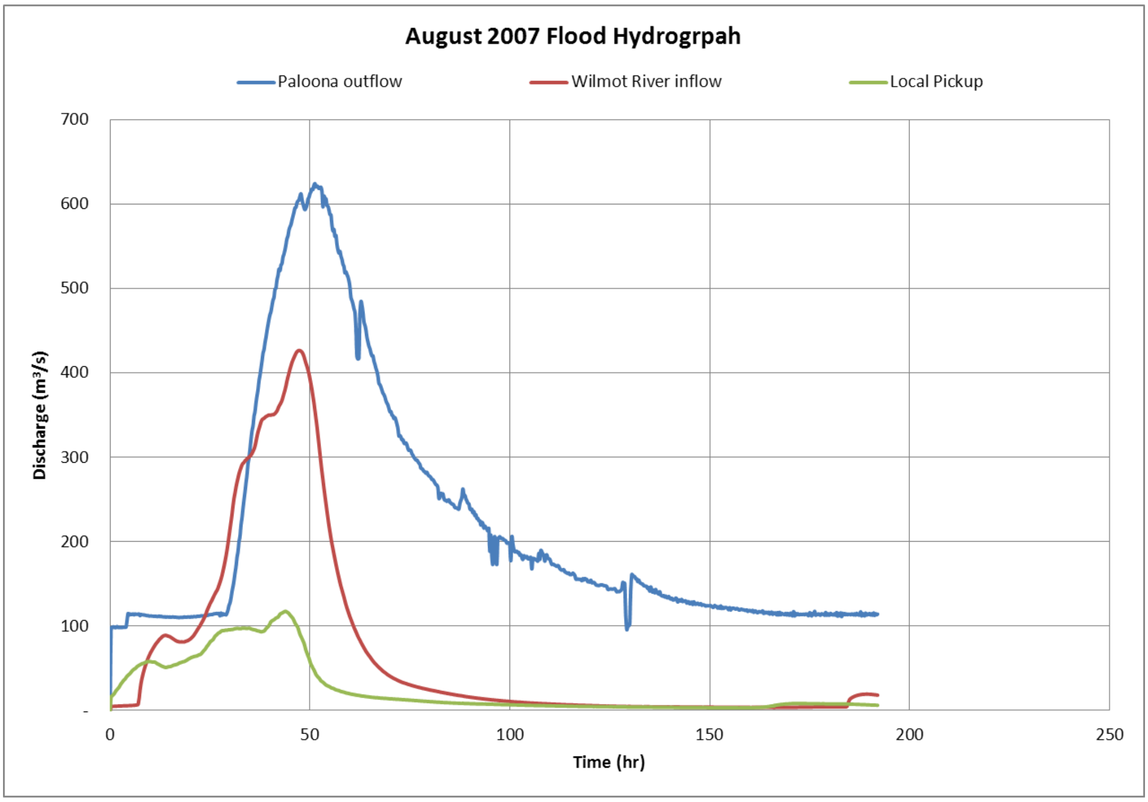
SURVEYOR	GEOCIVIL
J.M.	15544
DRAWN	CHECKED
N.A.W.	A.J.H.
DATE	
04MAR13	

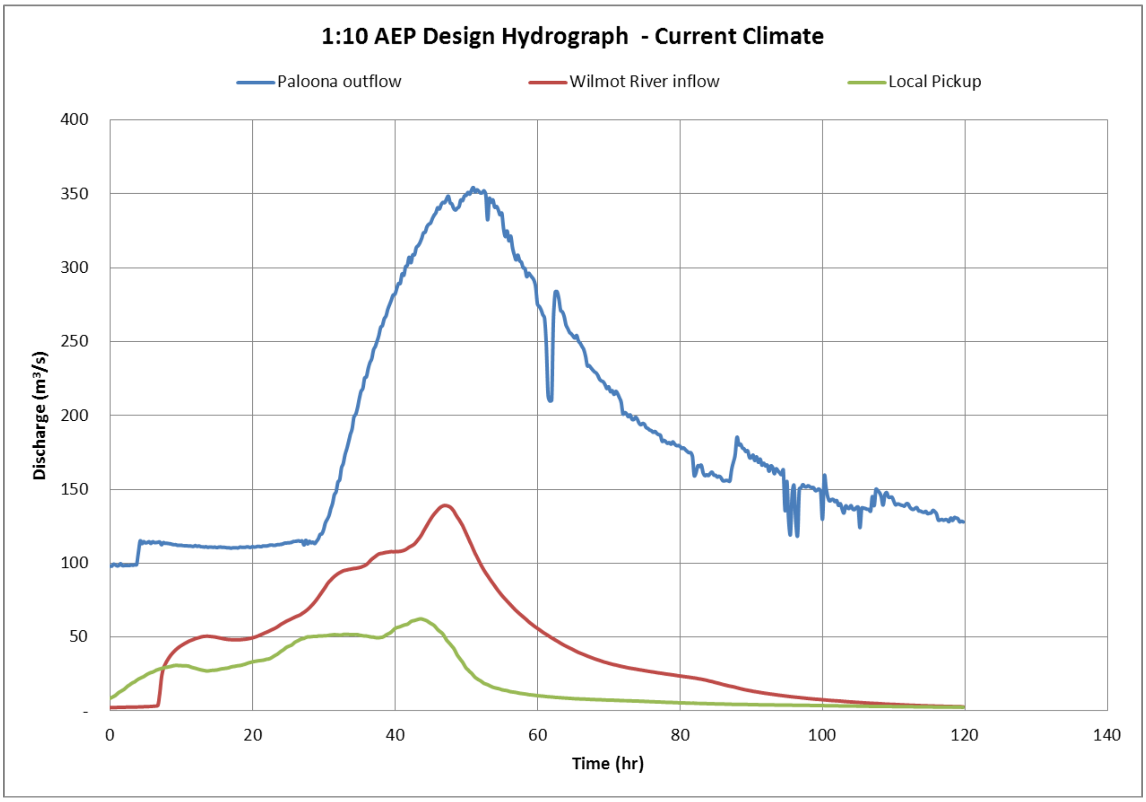
CENTRAL COAST COUNCIL
FORTH RIVER
FORTH
BATHYMETRIC DATA SURVEY

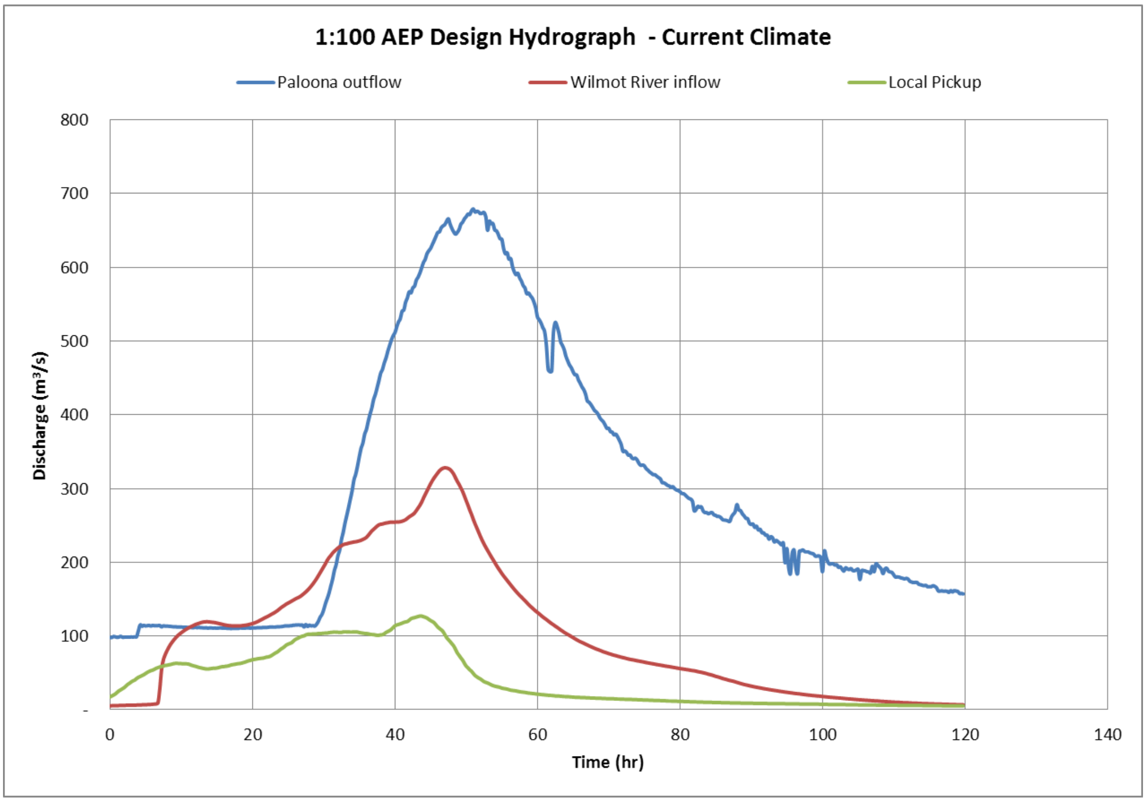
PDA SURVEYORS
ENGINEERS & PLANNERS
6 Queen Street
Burnie, Tasmania, 7320
www.pda.com.au
Also at: Hobart, Launceston & Kingston
PHONE: +61 03 6431 4400
FAX: +61 03 6431 6663
EMAIL: pda.bne@pda.com.au

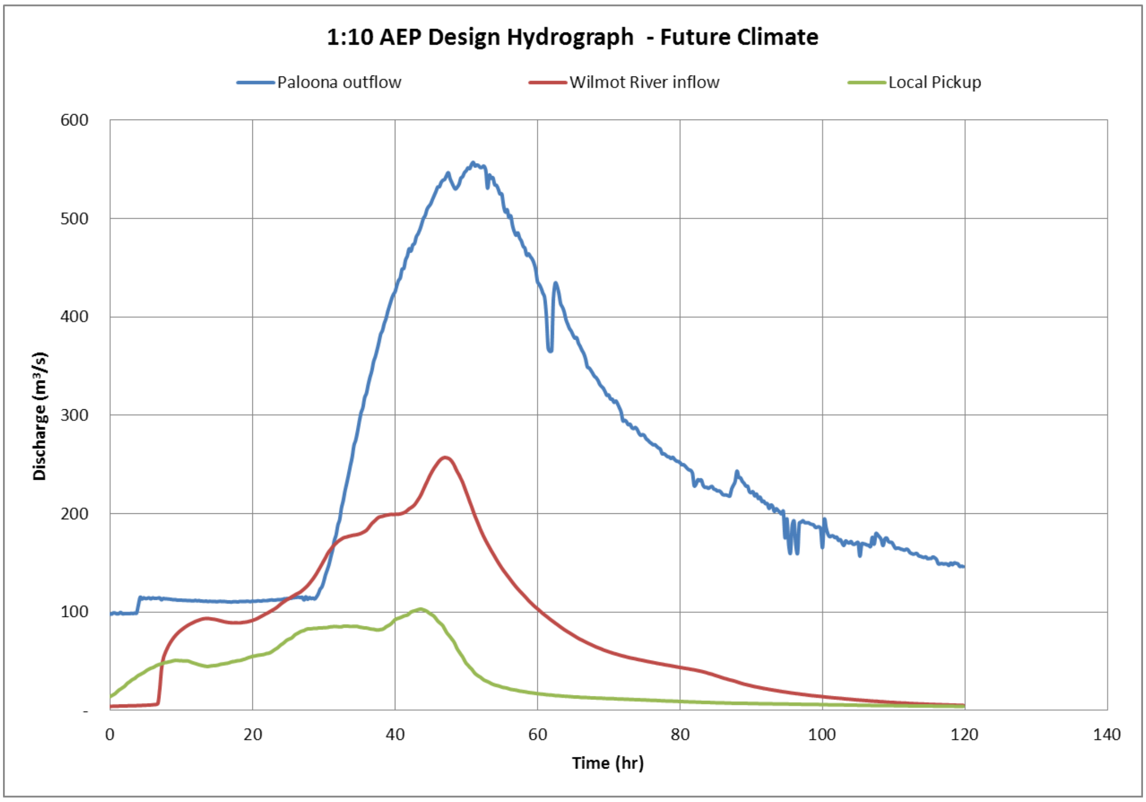
SCALE	PAPER
1: 10000	(A3)
JOB NUMBER	DRAWING
15544	1

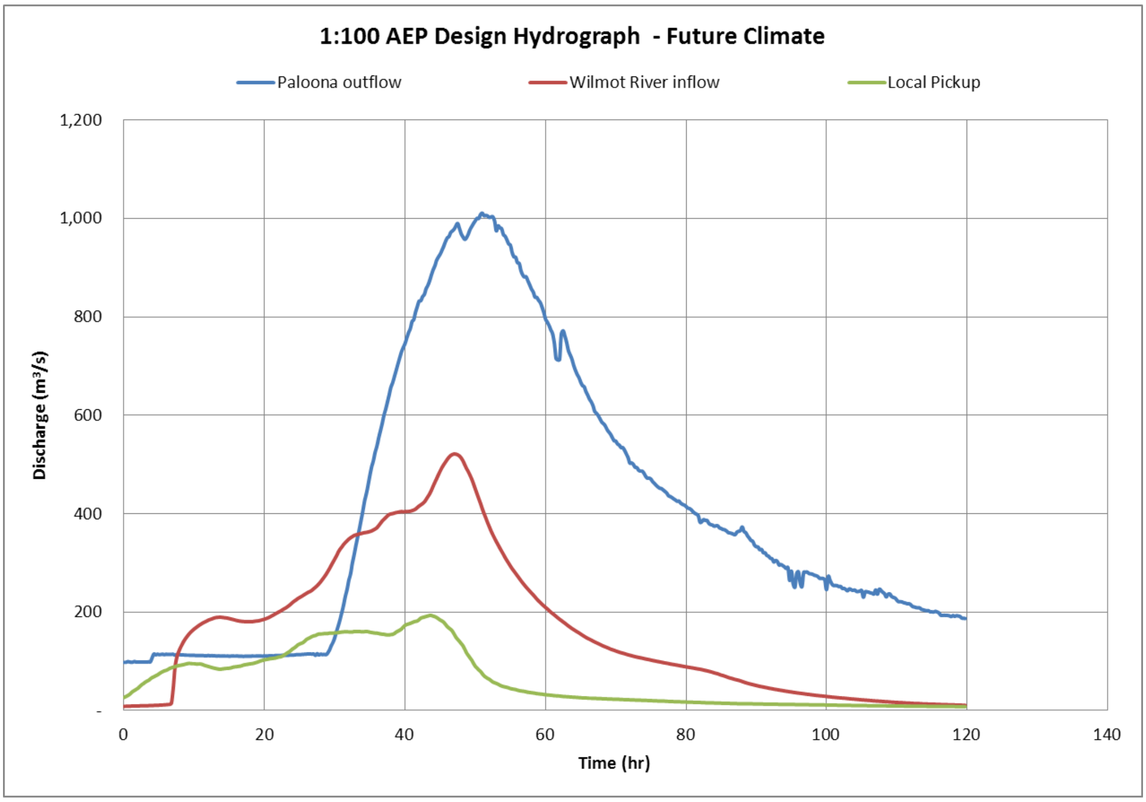
Flood hydrographs






1:100 AEP Design Hydrograph - Current Climate
Paloona outflow
Wilmot River inflow
Local Pickup
Discharge (m³/s)
800
700
600
500
400
300
200
100
-
0
20
40
60
80
100
120
140
Time (hr)


1:10 AEP Design Hydrograph - Future Climate
Paloona outflow
Wilmot River inflow
Local Pickup
Discharge (m³/s)
600
500
400
300
200
100
-
0
20
40
60
80
100
120
140
Time (hr)


1:100 AEP Design Hydrograph - Future Climate
Paloona outflow
Wilmot River inflow
Local Pickup
Discharge (m³/s)
1,200
1,000
800
600
400
200
-
0
20
40
60
80
100
120
140
Time (hr)

Page left intentionally blank

Flood maps

Flood extent maps

Scenario 1: Flood extent map for August 2007 flood event.

Scenario 3: Flood extent map for existing levee and current climate condition with 1:100 AEP flow and 1:10 AEP storm surge.

Scenario 4: Flood extent map for existing levee and current climate condition with 1:10 AEP flow and 1:100 AEP storm surge.

Scenario 5: Flood extent map for existing levee and future climate condition (2100) with 1:100 AEP flow and 1:10 AEP storm surge.

Scenario 6: Flood extent map for existing levee and current climate condition with 1:10 AEP flow and 1:100 AEP storm surge.

Scenario 7: Flood extent map, Levee D removed, for current climate condition with 1:100 AEP flow and 1:10 AEP storm surge.

Scenario 8: Flood extent map, Levee D removed, for future climate condition (2100) with 1:100 AEP flow and 1:10 AEP storm surge.

Scenario 9: Flood extent map, Levee C in place, for current climate condition with 1:100 AEP flow and 1:10 AEP storm surge.

Scenario 10: Flood extent map, Levee C in place, for future climate condition (2100) with 1:100 AEP flow and 1:10 AEP storm surge.

Level differences maps

Scenario 7 - 3: Level difference and extent map with and without Harvest Moon Levee and Leith Road Levee for current climate condition with1:100 AEP flow and 1:10 AEP storm surge.

Scenario 8 - 5: Level difference and extent map with and without Harvest Moon Levee and Leith Road Levee for future climate condition (2100) with1:100 AEP flow and 1:10 AEP storm surge.

Scenario 9 - 3: Level difference and extent map with and without Levee C for existing levee and climate condition with 1:100 AEP flow and 1:10 AEP storm surge.

Scenario 10 - 5: Level difference and extent map with and without Levee C for existing levee and future climate condition (2100) with 1:100 AEP flow and 1:10 AEP storm surge.

Page left intentionally blank