Torrens Catchment Water Management Board

First to Fifth Creeks Floodplain Mapping Project

Study Report

Principal Contacts
Ken Schalk
David Kon

March 2007
Ref No 20020975RA6

ADELAIDE
TONKIN CONSULTING
5 Cooke Terrace
Wayville SA 5034
T +61 8 8273 3100
F +61 8 8273 3110
adelaide@tonkin.com.au

www.tonkin.com.au

MOUNT GAMBIER
JONES TONKIN
1 Krummel Street
Mount Gambier SA 5290
PO BOX 1192
Mount Gambier SA 5291
T +61 8 8723 5002
F +61 8 8723 5004
mtgambier@tonkin.com.au

BERRI
TONKIN CONSULTING
27 Vaughan Terrace
Berri SA 5343
PO BOX 2248
Berri SA 5343
T +61 8 8582 2700
F +61 8 8582 2777
berri@tonkin.com.au

Table of Contents

Torrens Catchment Water Management Board
First to Fifth Creeks Floodplain Mapping Project
Study Report

Tables

Figures

Appendices

Document History and Status

Rev	Description	Author	Rev'd	App'd	Date
A	Draft for comment	DK	KSS	KSS	20/10/05
B	Final draft for comment	DK	KSS	KSS	20/09/06
C	Final	DK	KSS	KSS	16/03/07

Executive Summary

Tonkin Consulting was commissioned by the Torrens Catchment Water Management Board (CWMB) to undertake the floodplain mapping of several of the numbered creeks of the River Torrens, namely First, Botanic, Second, Stonyfell, Third, Fourth and Fifth Creeks. The primary purpose of the Study has been to define the extent of inundation and categorise the potential hazard resulting from a series of design storm events within the creek catchments.

The Study was undertaken for the Torrens CWMB as well as the Bureau of Meteorology, the South Australian Government, and the Cities of Adelaide, Burnside, Campbelltown as well as Norwood, Payneham & St Peters. The Department for Transport, Energy and Infrastructure (DTEI, and formerly Transport SA) conducted a hydrological study of the creek catchments, while a combination of aerial photogrammetry and ground survey was supplied by Aerometrex and Allsurv Engineering Surveys. WBM Oceanics Australia assisted Tonkin Consulting in the hydrodynamic modelling of the creeks as well as the consequence assessment.

The Study covers an area of approximately 54 km^2 and is bounded to the north-west between Adelaide and Athelstone by the River Torrens, to the east by an area extending from Black Hill Conservation Park to Cleland Conservation Park, and to the south-west by an area extending from Cleland Conservation Park to the River Torrens.

A digital terrain model (DTM) covering the Study Area was developed using the new survey for modelling of the following scenarios:

- 1:20 Annual Exceedance Probability (AEP) flood event
- 1:50 AEP flood event
- 1:100 AEP flood event
- 1:500 AEP flood event
- Probable Maximum Flood (PMF) event

The Study Area was divided into 5 smaller areas for modelling events with AEP's of 1:20 – 1:500 with a separate model for each of the 5 numbered creeks. The PMF event was modelled as a single model domain for all creeks.

Critical storm durations varied across the catchments and hence storm durations ranging from 30 minutes to 72 hours were modelled. The maps show an envelope of the flooding produced by various storm durations for a given AEP and do not represent expected flooding patterns attributable to any particular storm event.

The modelling was carried out using the TUFLOW (and ESTRY) computer program jointly funded and developed by WBM Oceanics Australia Pty Ltd and The University of Queensland in 1990. TUFLOW is a two-dimensional hydrodynamic model that links with the ESTRY one-dimensional network modelling system to provide a combined 2D/1D model for modelling the interaction between the creeks and their floodplains.

The results of the modelling showed the following:

- For each of the scenarios analysed, the inundation of the floodplain generally followed the route of the creeks within the Study Area.

- A range of inundation depths (up to 5 metres during the PMF) can potentially be experienced within the Study Area, with the deepest floodwaters occurring mostly along creek channels. In general, during events with an AEP of 1:500 or greater the majority of inundation depths are in the range of 0 – 0.5 m.

- During the PMF, 50 - 55 % of the Study Area is expected to be inundated by floodwaters. This represents an area of approximately 27 – 30 km^2.

- In general, most of the developed areas that are inundated by the various flood events fall into the “low hazard” category. Conversely, creek channels are likely to fall in the “extreme hazard” category. Streets and other defined flow paths often fall into the “medium” or “high” hazard categories with flow depths and velocities in between the “low” and “extreme” hazard category limits.

- As expected, the level of flood damages increased with a decrease in the AEP of the storm modelled. The consequence assessment summaries are presented in the tables below:

- Damage estimates are determined based on the envelope of possible flooding that could occur during a range of storm durations. For any given AEP, the damage from a specific localised event is likely to be less than the figures shown in the table because the inundated area would be smaller than is represented by the flooding envelope of various storm durations.

Total damages estimates using ANUFLOOD ($ million)

Creek System	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
First	2.05	6.46	8.01	16.12
Second	1.69	2.76	4.08	13.47
Third	3.37	4.95	6.11	9.75
Fourth	1.43	1.59	1.76	3.31
Fifth	0.18	0.22	0.24	0.47

The Annual Average Damages (AAD) were determined for each creek and are summarised in the table below:

AAD for all Creeks ($ million)

Creek System	Annual Average Damages (AAD)
First Creek	0.55
Second Creek	0.63
Third Creek	0.7
Fourth Creek	0.2
Fifth Creek	0.05

1. Introduction

The eastern suburbs of Adelaide drain to the River Torrens by a number of creek systems. These creeks have their headwaters in the Hills Face escarpment to the east of Adelaide and flow onto the plains where significant urban development has occurred adjacent to the creek channels.

Flooding of development along the creek systems has occurred since the late 1890's. However, following flood events in the 1970s and 1980s, several flood investigations and flood mitigation works have been carried out on First to Fourth Creeks. Despite these works being carried out, there remains a potential for flooding along the various creek systems.

This Study concerns the floodplain mapping of an area of approximately 54 km^2, through which First to Fifth, as well as Botanic and Stonyfell Creeks flow. The Study Area is depicted in Figure 1.1.

Tonkin Consulting was engaged by the Torrens Catchment Water Management Board (CWMB) to carry out the preparation of the floodplain maps. In turn, WBM Oceanics Australia, Aerometrex and AllSurv Engineering Surveys were engaged by Tonkin Consulting to assist in carrying out the investigation and preparation of the maps.

The primary purpose of the Study has been to define the extent of inundation and categorise the potential hazard resulting from a series of design storm events within the creek catchments. The Department for Transport, Energy and Infrastructure (DTEI, and formerly Transport SA) conducted a hydrological study of the creek catchments and provided inflow hydrographs that could be applied at various points within the models.

Due to the magnitude as well as the nature of the project, it was necessary to develop a number of hydraulic models that were able to simulate the creek hydraulic behaviour at a level of detail sufficient for a broad scale study. Various scenarios were modelled including the 1:20, 1:50, 1:100, and 1:500 AEP events, as well as the Probable Maximum Flood (PMF).

The results of the floodplain mapping study will be used to assist local government organisations in future planning, as well as the investigation of mitigation options to reduce the consequences of flooding. The mapping will also serve to identify existing problem areas and provide information for flood forecasting and warning in critical locations.

The findings of the flood inundation and hazard modelling of First to Fifth Creeks are discussed in detail in the following sections of the report.

Figure 1.1 Study Area and Inflow Locations

2. Scope of Works

2.1 Outline of Project

The general scope of works for the project was to determine the extent of flood inundation during various flood events for urban areas adjacent to First, Botanic, Second, Stonyfell, Third, Fourth, and Fifth Creeks. The project included the following tasks:

- Combining both new and existing ground survey, GIS data and photogrammetry to produce an accurate digital terrain model (DTM) of the Study Area.
- Obtaining details of the hydraulic structures along the creeks, as described in the project brief.
- Preparing a TUFLOW combined 2D / 1D hydrodynamic computer model of the creeks and floodplains including:
  - First Creek from Cleland National Park to the River Torrens;
  - Botanic Creek from Wakefield Road in Adelaide to its junction with First Creek in the Adelaide Botanic Gardens;
  - Second Creek from Michael Perry Reserve in Stonyfell to the River Torrens;
  - Stonyfell Creek from the eastern boundary of Stonyfell to its junction with Second Creek at Magill Road;
  - Third Creek from Horsnells Gully Road to the River Torrens;
  - Fourth Creek from the Morialta Conservation Park at Woodforde to the River Torrens;
  - Fifth Creek from Athelstone to the River Torrens.
- Analysing flooding for the following events:

- 1:20 AEP flood event;
- 1:50 AEP flood event;
- 1:100 AEP flood event;
- 1:500 AEP flood event;
- PMF event.

- Producing flood inundation and hazard zone maps for various specified flood events within the Study Area. These maps have been provided both in hard copy and digital/graphic form.

- Assessing potential economic damage in the inundation zone for the floods specified.

- Providing copies of draft maps and a draft report for comment prior to finalisation of modelling results. On completion of the work, multiple copies of the final report, associated flood inundation maps and data were supplied in GIS format as well as hard copy.

2.2 Project tasks

The project tasks consisted of the following:

Photogrammetry
Task 1 - Flights
Task 2 - Preparing the initial DTM

DTM Development
Task 3 - Identifying data gaps
Task 4 - Obtaining supplementary ground survey
Task 5 - Integrating ground survey into DTM

Floodplain Modelling
Task 6 - Collating structure data
Task 7 - Developing initial TUFLOW models
Task 8 - Conducting initial model runs and stabilisation
Task 9 - Calibration
Task 10 - Summarising structure capacities within the creeks
Task 11 - Conducting design runs

Mapping
Task 12 - Creating draft maps
Task 13 - Creating final maps

Reporting
Task 14 - Undertaking an estimation of flood damages
Task 15 - Writing the draft report
Task 16 - Steering Committee review
Task 17 - Writing the final report and supplying all deliverables

3. Data & Assumptions

3.1 General

A number of TUFLOW and ESTRY models were developed to simulate flooding along the creeks. These models were highly complex and hence required careful data input and verification throughout the modelling process. The following sections describe the key issues and assumptions made in the modelling.

3.2 Data

Data was gathered for the modelling from many sources. Previous floodplain mapping studies for some of the creeks were referred to, as well as input from the project stakeholders such as the Torrens CWMB, Bureau of Meteorology, Councils and the DTEI. New data gathered consisted mostly of hydrology and survey. A full list of references can be found in Section 11 of this report.

3.3 Assumptions

The catchment modelled in TUFLOW covers an area of approximately 54 km^2. During the modelling the following assumptions were made:

3.3.1 TUFLOW Model

- Existing survey data was used to verify new photogrammetric elevation data developed for the Study.
- A grid spacing of 5 metres was used for all models with the exception of the PMF which used a grid spacing of 10 m.
- Structure information applicable to the modelling of bridges and culverts was entered into the model within the one-dimensional domain.
- Terrain hydraulic roughness values for various types of land use were digitised based on aerial photography.
- The downstream boundary condition within the 1D domain was assumed to be the corresponding peak water level expected in the River Torrens for a flood having the same AEP as the event being modelled.
- There were two boundary conditions within the 2D domain for models with an AEP of 1:500 or greater. The first was the Torrens boundary condition,

in which water was allowed to discharge directly into the Torrens over the edges of the banks. The second was a constant water surface elevation of 0 mAHD at the model perimeter excluding the Torrens. This limited edge effects as flood waters approached model boundaries (in effect allowing water to 'fall off' the edge of the model).

- The PMF model used a single boundary condition around the model perimeter. This 2D boundary condition was in the form of a head – discharge relationship which also allowed water to 'fall off' the edge of the model.

- Calibration information for the creek floodplains does not exist and hence theoretical terrain hydraulic roughness values were used.

- At the model boundaries it was assumed that flood waters would continue to spread if no restrictions were imposed.

- There was no momentum transfer between the 1D and 2D connections.

- The capacities of the creek channels were insignificant in comparison to the peak flows generated by the PMF and were therefore ignored in the analysis of the PMF.

- The floodplain model did not provide for dynamic changes to the DTM due to erosion that can occur and possibly change the distribution of flow by altering flow paths.

- All channels were clean and no objects in and around the channels were swept into the creeks causing blockages of both the channels and culverts or bridges through which the water flows. It should be noted that this assumption may be unrealistic, particularly for the upper reaches of First Creek. Blockages of channels and culverts would cause an increase in surrounding flood levels.

- Roughness values were based on cadastral information. Building footprints were not taken into account meaning that it is possible for water to flow through buildings within the model. The high bed resistance values applied to residential and commercial areas provide an allowance for the obstructions created by buildings.

3.3.2 Catchment

- Clean and maintained channels and culverts were assumed for the simulations.

3.3.3 Hydrology

- DTEI provided hydrographs at 55 locations along the creeks. The hydrographs nominated to be uniformly distributed over a reach were distributed by a series of point inflows at individual nodes within the 1D domain.

3.3.4 Consequence Assessment

- The model domains overlapped between First and Second, and Second and Third Creeks. Therefore some of the damage estimates for First, Second and Third Creek were duplicated.
- The ANUFLOOD method used for the analysis assumed a property was flooded if the flood extents reached the centre of the property.
- It was assumed that the floor levels for residential properties were 150mm above the surveyed ground level and floor levels for commercial and industrial premises were equal to the ground level.

.

4. Hydrology

The Stormwater Services Section of DTEI undertook a hydrological study of First to Fifth Creeks and their respective catchments. The study resulted in a total of 55 inflow hydrographs being produced at various locations along the creeks. Some of the hydrographs were nominated as point inflows and others were to be distributed over specified reaches. The hydrographs were developed to serve as model inputs for the 1:20, 1:50, 1:100 and 1:500 AEP events as well as the PMF.

The hydrographs were provided for storm durations ranging from 30 minutes to 72 hours for the 1:20 – 1:500 AEP flood events, and storm durations ranging from 1 hour to 3 hours for the PMF. It was found that the critical storm durations varied between the creeks so the overall flood envelope was constructed from the maxima of individual flood envelopes resulting from both short and long duration storms. The Hydrology Report is included as Appendix A with the associated hydrographs provided on the enclosed CD.

The locations of all inflows are provided in Figure 1.1.

5. Development of the Surface Model

5.1 Development of the Digital Terrain Model

The survey data collected for the First to Fifth Creeks Floodplain Mapping Project was used to generate a digital terrain model (DTM) of the area expected to be inundated by the creeks. This data was collected by a combination of photogrammetry and ground survey techniques. The aerial photography was flown at a scale of 1:6,000 and a total of 157 photographic frames were acquired during the flights. The photography was controlled and triangulated to enable the generation of points over the Study Area that could be converted into a DTM using surface modelling software such as Vertical Mapper within MapInfo. The process used for the generation of the photogrammetric data was such that individual points are assigned elevations that nominally have a +-100 mm accuracy at the 90 % confidence level and a +- 150 mm accuracy at the 97 % confidence level.

Following the completion of the aerial photography, areas in which ground visibility was obstructed became apparent. Where these areas lay along creek lines, ground survey was undertaken to supplement the photogrammetry. Overall approximately 18.5 km of creek channels were surveyed on the ground. A more detailed description of the survey methods used as well as diagrams showing the survey extents can be found in the accompanying Survey Report (Appendix B).

The generated DTM consisted of a data set initially triangulated into a grid size of 0.3 metres for all model areas. From this DTM, TUFLOW z-points were created at a grid spacing of 5 or 10 metres, depending on the whether the model was for the 1:20 – 1:500 AEP storms or the PMF. The rationale behind the grid size selection is explained in Section 6.

6. Floodplain Modelling

6.1 Introduction

The area covered by the modelling (shown in Figure 1.1) has a large, predominantly urban floodplain. The model boundary covers an area of approximately 54 km^2 and extends from Waterfall Gully to Athelstone at the upstream end, and then along the River Torrens at the downstream end from North Adelaide to Athelstone. The creeks flow through the Cities of Adelaide, Burnside, Campbelltown as well as Norwood, Payneham and St Peters. There are approximately 80 culverts and bridges in the area, not including minor footbridges and diversion drains. Second, Stonyfell, Third and Fourth Creeks each have at least one trash rack along their alignments. There are also significant underground sections of creek particularly at the downstream ends of First, Botanic, Second, Stonyfell, and Fourth Creeks.

6.2 Modelling Software

The modelling was carried out using the TUFLOW (and ESTRY) computer program jointly funded and developed by WBM Oceanics Australia Pty Ltd and The University of Queensland in 1990. The program simulates depth averaged, two and one-dimensional free surface flows such as those that occur from floods and tides (WBM Oceanics Australia Pty Ltd, 2005). TUFLOW (Two-dimensional Unsteady FLOW) has the ability to dynamically link to the 1D network program ESTRY, enabling the user to set up a model containing both 1D and 2D domains. The models use text files for controlling simulations and simulation parameters, while the majority of data input is undertaken using GIS. GIS is also used for viewing and managing the results of the TUFLOW and ESTRY simulations. The TUFLOW model is based on the Stelling (1984) solution scheme, which is a finite difference, alternating direction implicit (ADI) scheme solving the full 2D free surface flow equations. The ESTRY model is based on a numerical solution of the unsteady momentum and continuity fluid flow equations (WBM Oceanics Australia Pty Ltd, 2005).

The models were developed so that the creeks and associated structures were modelled in 1D using ESTRY, while the floodplain was modelled in 2D using TUFLOW. This allowed a considerable amount of flexibility in the way that network elements could be interconnected, as well as allowing variable resolution within the network so that areas of particular interest could be modelled in finer detail. The model area was divided into fixed rectangular cells that can be either wet or dry during a simulation. The model had the ability to simulate the variation in water level and flow inside each cell once information regarding the ground resistance, topography and boundary conditions was entered.

The TUFLOW model is continually being improved, particularly in areas such as structure hydraulic routines, model stability, the ability to model increasingly complex hydraulic phenomena and ease of use.

6.3 Computer Model

6.3.1 Number of Models and 2D Cell Size

Determining an appropriate 2D cell size to be used by TUFLOW required a compromise between the accuracy of modelling necessary to sufficiently reproduce the hydraulic behaviour of the creeks, and a detailed understanding of the specific requirements of the Study. Limitations in computing power and the extent of the Study Area were other factors considered.

During initial simulations of First to Fifth Creeks, the TUFLOW model was limited to a maximum of 500,000 cells within a 2D domain. Modelling the entire 54 km^2 Study Area would have required approximately 2,160,000 5 x 5 metre square cells, or 540,000 10 x 10 metre cells, which was not possible at the time. Using a grid size of 11 metres would have reduced the cell count to fewer than 500,000 but such a cell size would result in a very coarse model. It was therefore decided to develop 5 separate models consisting of First and Botanic Creeks, Second and Stonyfell Creeks, Third Creek, Fourth Creek, and Fifth Creek. This allowed a cell size of 5 metres to be used within each model, which was considered suitable to adequately represent creek hydraulic behaviour for such a broad scale floodplain mapping study. This cell size was used in simulations of storm events with Annual Exceedance Probabilities ranging from 1:20 – 1:500.

The 500,000 cell limit was later eliminated as part of the continual TUFLOW program improvement allowing all the creeks to be modelled within a single model for the PMF simulations. Here the cell size used in the 2D domain was increased to 10 metres as it was concluded that a 5 metre cell size would result in lengthy simulation times. It was considered vital to model the PMF event as a single model due to the interaction of floodwaters between adjacent watercourses.

6.3.2 Topography

A description of the development of the DTM can be found in Section 5. The DTM is used to assign elevations to individual cells within the 2D domain. These elevations are assigned at the cell centres, corners and mid-sides to enable interaction with surrounding cells.

The 1D domain was constructed from the ground survey and details used to supplement the photogrammetry. The 1D domain consisted of creek sections (both open and enclosed) as well as all structures along the creek flow paths.

During the 1:20, 1:50, 1:100, and 1:500 AEP runs the 1D and 2D domains were dynamically linked to simulate the expected hydraulic interaction of each creek with its associated floodplain. The 1D domain was not used during the PMF simulations as it was understood that due to the rapid submergence of structures their overall effect on the floodplain would be negligible.

6.3.3 Resistance Parameters

The bed resistance is an essential element used to define the flow and hence the water depth at any location within the model domain. In TUFLOW, bed resistance values for 2D domains are most commonly created by using GIS layers containing polygons with varying Materials values. The Materials values specified in GIS correspond to a user defined Manning's n value described in the Materials File. This approach allows for a relatively quick and simple adjustment of Manning's n values, especially during model calibration.

The bed resistance values used in the modelling are specified in Table 6.1. These values were chosen based on literature as well as the experience of Tonkin Consulting and WBM engineers.

Table 6-1 Adopted Resistance Parameters

Type of Land Use	Manning's n
Residential	0.200
Sporting field	0.035
Floodplain (rough)	0.080
Floodplain (smooth)	0.050
Rough natural channel	0.060
Commercial and flow obstructors	0.300
Street reserves (with significant trees)	0.030
Street reserves (without significant trees)	0.020
Concrete lined channel	0.018
Concrete lined culverts	0.013
Bluestone stone pitching	0.025
Concrete waffle panel with grass	0.030

6.3.4 Time Step

The time step selection in the 2D domain is an important aspect of TUFLOW modelling as it is directly proportional to the running time of a model. A small time step will create more accurate results and is less likely to cause instabilities, however the simulation time can often stretch to days for long duration storm events. On the other hand, a large time step will shorten simulation times but may lead to meaningless results.

A general rule for TUFLOW models (although this is not a necessity) is to use a time step (in seconds) equal to approximately half the cell size (in metres). The 1:20 –

1:500 AEP events (with a 5 metre grid size) were modelled with a 2 second time step. The PMF (10 metre grid size) was modelled with a 1 second time step. This reduction in time step was necessary to avoid model instabilities that would frequently occur with the large volumes and flow rates of water being processed during such an extreme event.

It should be noted that 99% of the computational effort is in solving the 2D surface flow equations and hence the impact of the time step on simulation times is negligible in the 1D domain. Therefore the 1D ESTRY time step for all models was set to 1 second.

6.3.5 Boundary Conditions

During the modelling of the 1:20 – 1:500 AEP events, consideration was given to three separate boundary conditions. The first was the River Torrens boundary at the downstream end of the model within the 1D domain. In this case the boundary condition for a given scenario was a constant water surface level equal to the corresponding flood level within the River Torrens. Two boundary conditions were required within the 2D domain. The first was the Torrens boundary condition, in which water was allowed to discharge directly into the Torrens over the edges of the banks. The second was the 2D boundary condition around the model perimeter excluding the Torrens. This boundary condition consisted of a constant elevation of 0 mAHD, which was below the surface elevation at any point within the model. The purpose of this approach was to allow water to "disappear" once flood flows reached the model boundaries. The benefit of this approach was that results in the floodplain were not affected at model edges.

The PMF model (which was purely 2D) required only one boundary condition around the entire perimeter of the model, and this was in the form of a head-discharge relationship. This boundary condition covered a range of water surface elevations from 0 – 500 mAHD, and had flows ranging from 1,000 to 15,000 m^3/s. This was to ensure that no edge-induced backwater effects would occur as flood waters approached model boundaries.

6.3.6 Inflows

The inflow hydrographs were originally provided by DTEI at the locations shown in Figure 1.1. However, certain hydrographs were specified to be distributed over a given reach, rather than being treated as a point inflow. In these cases multiples of the same hydrograph were distributed over separate nodes within a given reach, and each hydrograph was assigned a multiplier equal to the inverse of the number of multiples. For example, the hydrograph called "23 Inflow" was distributed at 10 separate nodes within First Creek. However, at each node of "23 Inflow" a multiplier of 0.1 was assigned so that only 10% of its flow rate could enter the channel. This approach also assisted model stability by limiting abrupt changes to inflows over certain reaches.

7. Floodplain Study Results

7.1 Scenarios Analysed

As discussed in Section 6.3, 5 separate models were developed for the creeks to simulate the 1:20 – 1:500 AEP events. However the PMF model was larger, encompassing all the creeks due to the interactions between neighbouring watercourses. It should be noted that each creek had different catchment characteristics and hence different duration storms were found to be critical for the various models. The results presented are the inundation and hazard envelopes arising from a combination of the critical storms.

Table 7.1 lists the storm durations that were found to be critical in different areas for each of the models.

Table 7-1 Critical Storm Durations

Model Description	AEP's Analysed	Critical Storm Durations
First and Botanic Creeks	1:20, 1:50, 1:100	90 min, 72 hr
	1:500	2 hr, 9 hr
Second and Stonyfell Creeks	1:20, 1:50, 1:100	30 min, 72 hr
	1:500	1 hr, 18 hr
Third Creek	1:20, 1:50, 1:100	90 min, 24 hr, 72 hr
	1:500	1 hr, 12 hr
Fourth Creek	1:20, 1:50, 1:100	3 hr, 36 hr, 48 hr
	1:500	1 hr, 18 hr
Fifth Creek	1:20, 1:50, 1:100	36 hr, 48 hr, 72 hr
	1:500	3 hr, 12 hr
All Creeks	PMF	1 hr, 3 hr

7.2 Flood Inundation and Hazard Maps

A full size set of 16 B1 format maps have been prepared as part of this Study, and have been submitted separately. A3 size maps are included in Appendix C. Table 7.2 lists the maps produced.

Table 7-2 List of Maps

Scenario	Map Number
1:20 AEP – Flood Inundation	Map 1 North, Map 1 South
1:50 AEP – Flood Inundation	Map 2 North, Map 2 South
1:100 AEP – Flood Inundation	Map 3 North, Map 3 South
1:500 AEP – Flood Inundation	Map 4 North, Map 4 South

PMF – Flood Inundation	Map 5 North, Map 5 South
1:50 AEP – Flood Hazard	Map 6 North, Map 6 South
1:100 AEP – Flood Hazard	Map 7 North, Map 7 South
1:500 AEP – Flood Hazard	Map 8 North, Map 8 South

Both the inundation and hazard maps show the following features:

- Cadastral information, including main road and suburb names;
- Council boundaries;
- Railway lines, roads, bridges;
- Emergency facilities including major hospitals and police stations;
- Sports grounds;
- Natural watercourses;
- Limits of mapping;
- An index to adjoining sheets;
- A scale bar;
- A title block;
- An appropriate legend for inundation or hazard;
- Stakeholder logos;
- Explanatory notes and disclaimer;
- Unique map reference numbers.

The inundation maps show flooding in layered depth ranges for all scenarios as shown in Figure 7.1.

Figure 7.1 Legend used for Flood Inundation Mapping

The criteria adopted for determining the flood hazard rating at a particular location is shown in Figure 7.2. These hazard classes can be found in the SCARM Report 73 (CSIRO, 2000).

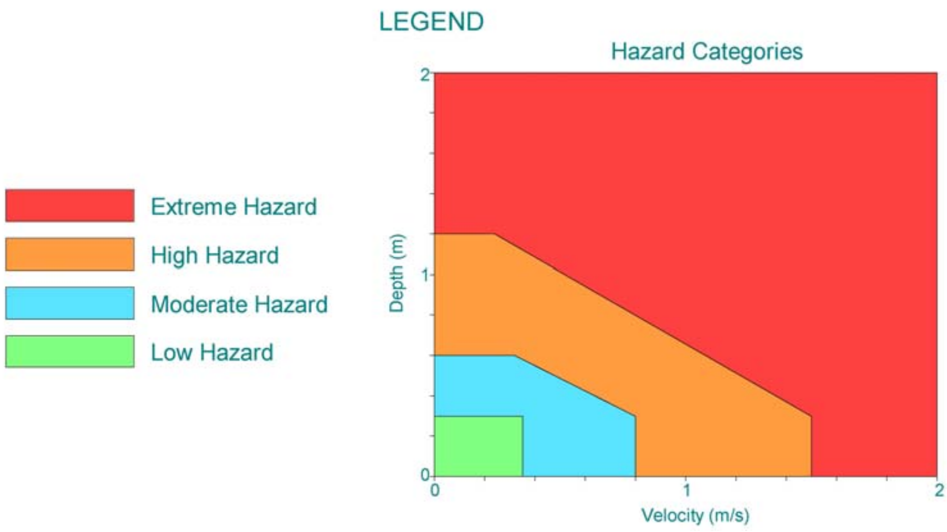

Figure 7.2 Adopted Hazard Criteria

7.3 Flood Inundation

Maps 1 - 5 show the extents of flood inundation for the various scenarios analysed.

A description of the locations of major breakouts for all creeks is provided below. These relate to the 1:20 AEP event, but are common to all events.

7.3.1 First Creek

- Russell Avenue and Moore Avenue, Hazelwood Park. Flood flows overtop both culverts and make their way towards Greenhill Road before heading further west. Shallow flooding is also present on Glynburn Road just upstream of the major breakouts at Russell and Moore Avenues.

- Hazelwood Avenue, Hazelwood Park and Tusmore Avenue, Tusmore. Flood flows make their way overland towards Tusmore Park, with a portion of flow continuing west along Stirling Street. In addition, excess flow overtopping the Tusmore Avenue culvert heads north along Tusmore Avenue before spreading out and inundating parts of Heathpool and Marryatville.

- Alnwick Terrace, Heathpool. Water spills from the creek and heads north through Marryatville High School before heading west along Kensington Road. A portion of the spill also heads west from Alnwick Terrace and over Portrush Road.

- Corner of Portrush and Kensington Roads, Marryatville. Shallow flooding occurs at this location with flood waters continuing down Kensington Road and making their way into Queen and Gertrude Streets in Norwood.

- Osmond Terrace to Sydenham Road, Norwood. Flood waters travel in a north westerly direction between these two streets.

- North Terrace, Kent Town and Hackney Road, Hackney. First Creek breaks out and flows from North Terrace towards Hackney Road. The flood waters travel north along Hackney Road before pooling in the vicinity of Athelney Avenue.

7.3.2 Botanic Creek

- Botanic Creek breaks out and ponds in all open channel sections upstream of Bartels, Rundle and Botanic Roads. However, the creek does not spill onto any of the main roads and is contained within the reserves.

7.3.3 Second Creek

- Kensington Road, Kensington. Floodwaters escape Second Creek upstream of Kensington Road and travel north west through properties along Maesbury Street and Bridge Street before reaching Borthwick Park.

- Magill Road, Norwood. At this location Second Creek receives additional flows from Stonyfell Creek and the resulting floodwaters spread through a large portion of Stepney to the west of Nelson Street. Most of the flooding is less than 0.25 m deep.

7.3.4 Stonyfell Creek

- Hallett Road, Erindale. Downstream of this point, the floodwaters spread out and travel in a north westerly direction as sheet flow through Erindale, Kensington Gardens, Kensington Park, and Beulah Park. This location has the largest breakout of any creek modelled and it is difficult to determine whether other locations downstream contribute additional flooding. The floodwaters travel west along Kensington Road, The Parade and Magill Road until they combine with the floodwaters of Second Creek.

7.3.5 Third Creek

- Shakespeare Avenue, Magill. Third Creek overtops the culvert and flood flows travel west towards the Gums Reserve where some ponding occurs. A portion of flow also travels further down Shakespeare Avenue until a point immediately upstream of Glynburn Road.

- Richardson Avenue, Tranmere. Third Creek spills to the north upstream of Glynburn Road with flood flows travelling west along Richardson Avenue.

- Glynburn Road to Payneham Road. In this section of creek there are many minor spills with shallow flooding being experienced by some properties in Firle and Payneham. The largest breakout occurs along Ashbrook Avenue upstream of Payneham Road.

- Felixstow Reserve, Felixstow. Floodwaters pond to the east of the creek in this location.

7.3.6 Fourth Creek

- Denis Morrissey Park, Hectorville. Minor spills occur on both sides of the creek between St Bernard's and Montacute Roads.

- Montacute Road, Hectorville. The local drainage network in the vicinity of Robson Road is undersized and flood flows travel west down Montacute Road before being picked up by the creek in the vicinity of the diversion drain.

7.3.7 Fifth Creek

- Schulze Court, Paradise. The Schulze Court culvert is undersized and overtops causing Fifth Creek to spill towards the Torrens Valley Sports Field. Fifth Creek also spills over its banks between Gorge Road and Schulze Court.

7.4 Extent of Flooding During Larger Events

As expected, the extent of flood inundation within the Study Area increases during the more severe rainfall events. The following sections describe the 1:50, 1:100, and 1:500 AEP events.

7.4.1 First Creek

- Flooding on Greenhill Road increases. The model limit is reached at the intersection of Greenhill and Portrush Roads during the 1:100 and 1:500 AEP events. It is expected that flood flows would continue to travel further west if no restrictions on the model domain were imposed.

- Flooding to the west of Tusmore Park is a lot more pronounced during the larger return period storms than was the case during the 1:20 AEP model runs. Floodwaters continue to flow west well past Portrush Road and then head in a north westerly direction through Toorak Gardens, Rose Park and Norwood.

- Surface flooding becomes apparent in Kent Town and Hackney, as flood waters escape the underground sections of First Creek and head towards the Botanical Gardens. First Creek also breaks out to the north within the Botanical Gardens and flows west towards the Torrens.

7.4.2 Botanic Creek

- Ponding along all open channel sections of the creek increases during the larger events, with the Bartels Road culvert overtopping during the 1:500 AEP event.

7.4.3 Second Creek

- Second Creek begins to break out in the vicinity of Rochester Street with floodwaters travelling west through Leabrook and Marryatville towards Kensington Road. The flooding extents downstream of Kensington Road also increase when compared to those experienced during the 1:20 AEP event.

- Shallow flooding occurs through Norwood, between The Parade and Osmond Terrace.

- Flooding of the creek downstream of Magill Road increases substantially, with parts of Stepney and College Park inundated with flood water depths of up to 1 metre. This flooding continues all the way to the Torrens.

7.4.4 Stonyfell Creek

- During larger events, Stonyfell Creek begins to break out upstream of Hallett Road in Erindale. The floodwaters then spread out in a fan shape, however the interaction with Second Creek and its floodwaters is more pronounced than was the case during the 1:20 AEP event. Flooding also occurs north of Magill Road in St Morris, however model limits are reached. It is expected that in the absence of these limits floodwaters would travel further north before heading wast through Trinity Gardens.

7.4.5 Third Creek

- The previously stated breakout at Shakespeare Avenue sends floodwaters further west past Portrush Road, with selected roads experiencing very shallow (< 0.1 m) inundation.

- The Glynburn Road Culvert overtops and a large spill spreads north of the Firle Shopping Centre.

- Flooding of Third Creek occurs along the entire length from Glynburn Road to the River Torrens. The largest breakouts occur immediately upstream and downstream of Payneham Road.

7.4.6 Fourth Creek

- Minor spills occur downstream of Stradbroke Road, and shallow inundation can be expected in the vicinity of the Campbelltown Council Offices during the 1:500 AEP event.
- Spills occur in the Denis Morrissey Park for all events, with floodwaters travelling west through a few properties in the vicinity of the trash rack upstream of Montacute Road during the 1:500 AEP event.
- Shallow flooding occurs downstream of Robson Road with the northern third of Newton Primary School experiencing inundation depths of up to 0.25 m.
- During the 1:500 AEP event, a severe breakout occurs downstream of Lower North East Road and affects properties on both sides of the diversion drain in Wicks Avenue. The floodwaters spread out at the downstream end of the diversion drain and travel through parts of Felixstow.

7.4.7 Fifth Creek

- The creek breaks out upstream of Maryvale Road during the 1:100 and 1:500 AEP events, with floodwaters flowing parallel to the creek until the Torrens Valley Sportsfield. Most major road crossings are overtopped for all events with an AEP of 1:50 or lower.

7.5 Extent of Flooding During the Probable Maximum Flood

The results of the PMF model show that approximately 50 – 55 % of the Study Area is likely to be inundated. This represents an area of approximately 27 – 30 km^2 within Adelaide's eastern suburbs. Floodwaters from all the creeks interact with each other with the exception of Fifth Creek.

Flooding during the PMF event was most severe within the First, Second and Stonyfell Creek catchments. Only the upstream areas such as Burnside, Stonyfell and Wattle Park were not subject to major inundation. There were some isolated areas between Third and Fourth, and Fourth and Fifth Creeks especially in Hectorville, Paradise, Campbelltown and Newton that were not subjected to flooding.

Within the inundated areas, the majority of flooding had a depth greater than 0.5 m. The floodwaters during the PMF simulations reached the model boundary to the west of First Creek as shown on the maps. If the model boundary was extended further west it is expected floodwaters would continue to travel through Rose Park, Dulwich and parts of Glenside.

7.6 Structure Capacities

The flows through selected structures within the 1D domain for all creeks have been documented as part of this Study and are listed in Tables 7.3 – 7.9 below. These flows are provided for the 1:20 – 1:500 AEP events only, as the PMF model was simulated purely in 2D. The flow rates listed relate only to the flow passing through a given structure without giving consideration to the amount of flow overtopping a structure or breaking out of the creek.

Table 7-3 Peak Flows through Structures along First Creek

Location	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
Glynburn Road	11.6	19.6	20.0	21.4
Russell Avenue	11.4	13.7	15.4	21.0
Moore Avenue	11.1	13.7	14.2	15.3
Greenhill Road	11.7	14.9	15.7	16.5
Hazelwood Avenue	8.2	13.7	14.2	14.8
Tusmore Avenue	10.7	13.3	13.7	19.5
Alnwick Terrace	13.7	19.3	20.5	22.0
Portrush Road	12.3	13.1	13.2	13.3
Osmond Terrace	11.4	11.5	11.7	14.4
Sydenham Road	13.6	17.7	19.1	24.9
Charles Street Entrance	15.3	18.0	19.4	24.7
North Terrace	13.3	13.9	14.2	14.8
Hackney Road	13.3	13.9	14.2	15.6
Frome Road	16.2	17.9	19.5	23.0

Table 7-4 Peak Flows through Structures along Botanic Creek

Location	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
Bartels Road	3.4	3.6	3.7	3.9
Rundle Road	7.4	8.1	10.0	10.4
Botanic Road	4.1	4.7	4.8	4.8
Diversion to First Creek	3.3	3.3	3.4	3.4

Table 7-5 Peak Flows through Structures along Second Creek

Location	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
Hallett Road	6.0	8.0	9.5	10.6
Lockwood Road	6.0	7.9	9.5	10.6
Moorcroft Court	7.2	9.5	11.1	16.7
Glynburn Road	8.4	9.9	11.5	13.9
Rochester Street	9.6	10.7	12.1	16.1
Phillip Avenue	11.0	12.2	14.4	24.2
Statenbourgh Street	12.1	13.8	16.0	24.5
Stanley Street Entrance	11.9	13.5	15.6	25.3

Thornton Street	12.0	13.4	13.9	24.4
Portrush Road	11.8	13.6	15.0	15.3
Osmond Terrace	20.0	20.2	20.5	20.7
Henry Street	21.5	21.7	21.7	22.0
Payneham Road	27.0	28.5	29.8	41.5

Table 7-6 Peak Flows through Structures along Stonyfell Creek

Location	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
Stonyfell Road	2.6	3.7	3.9	3.9
Bellyett Reserve	3.0	3.3	3.5	5.5
Hallett Rd Pipe Entrance	2.7	3.5	3.5	4.1
Kensington Road	3.0	3.0	2.9	3.3
East Terrace	2.8	2.8	2.9	3.6
South Terrace	2.8	2.8	2.9	3.7
Myall Avenue	5.6	5.7	5.8	5.8
Downstream Dunstan Ave	3.8	3.8	3.8	3.8
Brand Street	5.4	5.5	5.7	6.9
Cnr Magill and Nelson	12.3	14.4	14.8	16.0
Junction with Second Crk	24.9	25.2	25.2	25.5

Table 7-7 Peak Flows through Structures along Third Creek

Location	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
Vine Street	12.5	16.0	18.8	22.5
St Bernards Road	7.5	10.0	12.8	17.3
Lorne Avenue	13.8	17.5	18.7	20.0
Balmoral Avenue	13.8	18.3	21.5	26.9
Colton Avenue	13.8	18.0	19.9	20.4
Shakespeare Avenue	15.8	16.9	17.1	17.1
Fourth Street	13.8	16.2	17.4	21.1
Glynburn Road	13.8	18.5	23.0	24.9
Hampden Street	13.7	14.1	14.2	14.3
Somers Avenue	9.9	13.7	13.7	13.7
Gage Street	13.9	21.8	22.1	23.1
Marian Road	14.7	25.5	26.4	26.6
John Street	13.1	15.5	15.6	15.7
Rosella Street	15.2	20.0	20.1	20.5
Bridge Road	15.3	19.9	20.1	20.0
Henry Street	15.6	21.8	22.5	23.8
Ashbrook / Lewis Road	13.3	13.5	14.1	14.1
Payneham Road	16.1	17.3	19.7	23.0
Turner Street	20.7	21.5	28.6	34.6

Table 7-8 Peak Flows through Structures along Fourth Creek

Location	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
Stradbroke Road	11.3	14.0	15.7	18.8
Sheila Drive	11.8	15.6	17.5	25.2
Forest Avenue	11.6	14.6	17.3	21.2
St Bernards Road	13.6	18.0	21.4	32.0
Montacute Road	14.8	19.9	23.8	34.3
Munchenburg/Maynard Ave	10.3	14.2	18.0	25.6
Clairville Road	10.4	14.4	17.5	29.6
Lower North East Road	10.4	14.4	17.5	30.4
Sycamore Terrace	11.3	15.5	18.0	34.2
Diversion Drain	11.9	12.6	16.5	17.6

Table 7-9 Peak Flows through Structures along Fifth Creek

Location	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
Maryvale Road	12.0	12.8	13.0	13.1
Manresa Court	13.6	17.8	21.4	30.1
Gorge Road	13.5	17.7	21.4	37.0
Schulze Road	12.2	12.4	12.4	12.4
George Street	14.2	15.7	15.8	15.8

7.7 Flood Hazard

Maps 6 - 8 show the flood hazard categories for the various scenarios analysed.

In general, most of the built up areas that are inundated by the various flood events fall into the “low hazard” category due to the shallow (less than 0.35 m) depths of flooding and low (less than 0.3 m/s) velocities in these areas. Conversely, creek channels are likely to experience high flow velocities (greater than 1.5 m/s) and large depths (greater than 1.2 m) which place them in the “extreme hazard” category. Streets and other defined flow paths often fall into the “medium” or “high” hazard categories with flow depths and velocities in between the “low” and “extreme” hazard category limits.

8. November 2005 Flooding

8.1 Introduction

On the morning of the 7th of November 2005, a storm event produced 20 – 40 mm of rainfall within the Mt Lofty Ranges, which lead to the saturation of catchments that had already been exposed to higher than average rainfall during October. Between the evening of the 7th and the morning of the 8th of November, a further 80 – 100 mm of rain fell within the Ranges causing flooding of many of the creeks running though the eastern and south eastern suburbs of Adelaide. One of the most severely affected was First Creek, with Second and Stonyfell Creeks affected to a lesser degree.

As an addition to the floodplain mapping project for First to Fifth Creeks, the Torrens CWMB requested that Tonkin Consulting model the effect of the November 2005 storm on the First and Second Creeks.

8.2 Hydrology

The RRR model used by the DTEI to produce the inflow hydrographs for the floodplain mapping study was calibrated for the November 2005 flooding. A more detailed description can be found in the addendum to the Hydrological Study of the First to Fifth Creek Catchments in Appendix A.

8.3 Modelling Process

The First and Second Creek TUFLOW models used for the November 2005 storm events were identical to the models used for the floodplain mapping of those creeks during the 1:20, 1:50, 1:100, and 1:500 AEP events. The only point of difference was the input hydrographs which were provided by the DTEI following the calibration of the hydrological model.

8.4 Modelling Results

8.4.1 First and Botanic Creeks

A description of the locations of major breakouts for First and Botanic Creeks as predicted by the model is provided below.

- Russell Avenue and Moore Avenue, Hazelwood Park. Flood flows overtop both culverts and make their way towards Greenhill Road before heading further west. Flooding is also present on Glynburn Road just upstream of the major breakouts at Russell and Moore Avenues.

- Floodwaters reach the model limit at the intersection of Greenhill and Portrush Roads. It is expected that flood flows would continue to travel further west if no restrictions were imposed.

- Hazelwood Avenue, Hazelwood Park and Tusmore Avenue, Tusmore. Flood flows make their way overland towards Tusmore Park, with a portion of flow continuing west along Stirling Street. In addition, excess flow overtopping the Tusmore Avenue culvert heads north along Tusmore Avenue before spreading out and inundating parts of Heathpool and Marryatville. Floodwaters escaping the creek in the vicinity of Tusmore Park flow north west through Toorak Gardens, Rose Park and Norwood before re-entering First Creek upstream of Osmond Terrace.

- Alnwick Terrace, Heathpool. Water spills from the creek and heads north inundating most of Marryatville High School before heading west along Kensington Road. A portion of the spill also heads west from Alnwick Terrace and over Portrush Road.

- Corner of Portrush and Kensington Roads, Marryatville. Overtopping of the culvert in this location causes flood waters to travel down Kensington Road and making their way into Queen and Gertrude Streets in Norwood.

- Flooding in Norwood generally follows the path of the creek from Portrush Road to the Charles Street culvert entrance.

- Substantial surface flooding can be seen in Kent Town and Hackney, as flood waters escape the underground sections of First Creek and head towards the Botanical Gardens. First Creek also breaks out at Hackney Road and travels north before changing direction to the west and making its way towards the Torrens.

- Botanic Creek breaks out and ponds in all open channel sections upstream of Bartels, Rundle and Botanic Roads. However, the creek does not spill onto any of the main roads and is contained within the reserves.

With the exception of the breakout at Hackney and the extent of flooding along Greenhill Road, the general pattern of flooding predicted by the model closely matched the observed flooding within the limits of accuracy of the hydrology and hydraulic model. The shallow surface flooding predicted by the model in a number of locations did not occur, however this would be expected to be significantly affected by fencing and other factors.

8.4.2 Second and Stonyfell Creeks

A description of the predicted locations of major breakouts for Second and Stonyfell Creeks is provided below.

- Magill Road, Norwood. At this location Second Creek receives additional flows from Stonyfell Creek and the resulting floodwaters spread through a small portion of Stepney to the west of Nelson Street. Most of the flooding is less than 0.25 m deep.

- Hallett Road, Erindale. Downstream of this point, the Stonyfell Creek floodwaters spread out and travel in a north westerly direction as sheet flow through Erindale, Kensington Gardens, Kensington Park, and Beulah Park. This location has the largest breakout of any creek modelled and it is difficult to determine whether other locations downstream contribute additional flooding. The floodwaters travel west along Kensington Road, The Parade and Magill Road until they combine with Second Creek.

The model predicted a greater extent of flooding than actually occurred. However, there is a high level of uncertainty as to the peak flows in the creek, and hence further calibration of the model was not considered to be warranted.

9. Consequence Assessment

WBM undertook a study to assess the damages caused by flooding of First to Fifth Creeks. The damages estimates were undertaken using the ANUFLOOD method. The results presented are based on the floodplains generated by the 1:20, 1:50, 1:100 and 1:500 AEP events.

As expected, the impact of flood damages increased with a decrease in the AEP of the event modelled as shown in Table 9.1.

Table 9-1 Total Flood Damages using ANUFLOOD ($ million)

Creek System	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
First	2.05	6.46	8.01	16.12
Second	1.69	2.76	4.08	13.47
Third	3.37	4.95	6.11	9.75
Fourth	1.43	1.59	1.76	3.31
Fifth	0.18	0.22	0.24	0.47

A summary of the Annual Average Damages (AAD) is presented in Table 9.2. The AAD is the average damage in dollars per year that would occur in a designated area from flooding over a long period of time. Estimation of the AAD provides a basis for comparing the effectiveness of various floodplain management measures.

Table 9-2 AAD – All Creeks ($ million)

Creek System	Annual Average Damages (AAD)
First Creek	0.55
Second Creek	0.63
Third Creek	0.7
Fourth Creek	0.2
Fifth Creek	0.05

It is noted that the ANUFLOOD analysis is based on the assumption that residential property floor levels were 150 mm above the ground level and that commercial property floor levels were at ground level.

A summary of the methodology used as well as more detailed results can be found in the Damages Report included as Appendix D.

10. Conclusions

Based on the investigations carried out for this Study, it can be concluded that:

- Out of the 7 creeks modelled, all are unique in their response to, and their ability to cater for large rainfall events within their respective catchments. However, for each of the scenarios analysed, the inundation of the floodplain generally followed the route of the creek within the Study Area.

- The level of inundation within the floodplain was generally greater during longer duration storms.

- Stonyfell Creek had the largest flood inundation envelope of all creeks modelled.

- First and Second Creeks were more likely to spill than Third, Fourth, or Fifth Creeks. This implies that the three northern creeks offer a higher level of protection and have a higher design standard than the southern creeks.

- A range of inundation depths (up to 5 metres during the PMF) can potentially be experienced within the Study Area, with the deepest floodwaters occurring mostly along creek channels. In general, during events with an AEP of 1:500 or greater the majority of inundation depths are in the range of 0 – 0.5 m.

- During the PMF, 50 - 55 % of the Study Area is expected to be inundated by floodwaters. This represents an area of approximately 27 – 30 km^2.

- In some scenarios modelled (and due in part to the modelling limitations encountered during the Study), the floodwaters reached the model boundary which would cause water to “disappear” from the edge of the model. If no restrictions were imposed, it is expected that floodwaters would continue to flow past these model boundaries. Therefore the inundation envelope is likely to cover a slightly larger area than is currently shown on the maps.

- In general, most of the developed areas that are inundated by the various flood events fall into the “low hazard” category. Conversely, creek channels are likely to fall in the “extreme hazard” category. Streets and other defined flow paths often fall into the “medium” or “high” hazard categories with flow depths and velocities in between the “low” and “extreme” hazard category limits.

- As expected, the impact of flood damages increased with a decrease in the AEP of the event modelled. The consequence assessment summary is presented in Tables 10.1 and 10.2.

Table 10-1 Total Flood Damages using ANUFLOOD ($ million)

Creek System	1:20 AEP	1:50 AEP	1:100 AEP	1:500 AEP
First	2.05	6.46	8.01	16.12
Second	1.69	2.76	4.08	13.47
Third	3.37	4.95	6.11	9.75
Fourth	1.43	1.59	1.76	3.31
Fifth	0.18	0.22	0.24	0.47

Table 10-2 AAD – All Creeks ($ million)

Creek System	Annual Average Damages (AAD)
First Creek	0.55
Second Creek	0.63
Third Creek	0.7
Fourth Creek	0.2
Fifth Creek	0.05

11. References

BC Tonkin & Associates (1982) *1st Creek Drainage Study*

BC Tonkin & Associates (1982) *Review of Second Creek Flood Mitigation Strategies*

BC Tonkin & Associates (1982) *Fourth Creek Flood Mitigation Study*

BC Tonkin & Associates (1984) *Third Creek Flood Mitigation Study*

BC Tonkin & Associates (1989) *2nd Creek Flood Plain Mapping*

CSIRO (2000) *Floodplain Management in Australia – Best Practice Principles and Guidelines* SCARM Report 73, CSIRO Publishing.

Read, Sturgess and Assoc. Consulting Economists (2000) *Rapid Appraisal Method (RAM) for Floodplain Management* Department of Natural Resources & Environment, Victoria.

Stelling, G.S. (1984) *On the Construction of Computational Methods for Shallow Water Flow Problems* Rijkswaterstaat Communications, No. 35/1984, The Hague, The Netherlands.

Tonkin Consulting (1997) *1st Creek Flood Plain Mapping*

Tonkin Consulting (1998) *St Peters Catchment Drainage Study*

Tonkin Consulting (1999) *Payneham Catchment Drainage Study*

Tonkin Consulting (2001) *3rd Creek Flood Plain Mapping*

WBM Oceanics Australia (2005) *TUFLOW (and ESTRY) User Manual.*

Appendix A

Hydrology Report

Appendix B

Survey Report

Appendix C

Flood Inundation and Hazard Maps

Appendix D

Damages Report

Appendix E

Project GIS and Supporting Files