Sans Souci Flood Study Review

Flood Study Report - Final

NA49913054

Prepared for
Rockdale City Council

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Executive Summary

Cardno were commissioned by Rockdale City Council to undertake a flood study review for the Sans Souci drainage catchment. Previous flood studies have been undertaken for Waradiel Creek in 1994 and Bado-Berong Creek and Goomun Creek in 1997 using one dimensional (1D) hydraulic modelling software. The objective of this study is to define existing flood behaviour within the study area including both mainstream and overland flooding using the combined one-dimensional and two-dimensional (1D/2D) Tuflow hydraulic modelling software.

The study area extends approximately 3.1km^2 in area, is highly developed and generally comprises low to medium density residential properties. The study area is drained by three main creeks generally flowing parallel from north to south in direction. Waradiel Creek, also known as Sans Souci Drain No. 1, originates near Ramsgate Road and discharges to Botany Bay at Peter Depena Reserve. Bado-Berong Creek, also known as Sans Souci Drain No. 2, conveys flow via open channel through a linear open space from Park Road to Riverside Drive where it discharges to Botany Bay. Goomun Creek, also known as Sans Souci Drain No. 3, conveys flows from Russell Avenue to Lawson Street via concrete channel and subsequently via culverts beneath Fraters Avenue to Botany Bay.

The storm event of 10 March 1975 was used to calibrate the Tuflow 1D/2D hydraulic model. Two approaches were assessed based on recorded rainfall data from nearby gauges at Mortdale Bowling Club and Sydney Airport. Both approaches resulted in modelled flood levels higher than flood levels observed during the 1975 event. At a number of locations the observed flood marks are lower than surveyed ground levels which limit the applicability of the observed flood marks to the calibration process.

Flood modelling was undertaken for a range of storm events including the 20%, 10%, 5%, 1% Annual Exceedance Probability (AEP) events and the PMF event with mapping produced for flood extents, peak water depths, velocities, potential hazard and hydraulic categories. Areas subject to flooding and high hazard along each creek alignment are discussed further below.

A number of residential areas are affected by flooding associated with Waradiel Creek including properties between Park Road and Chuter Avenue in all events greater than 20% AEP and properties between Alfred Street and The Grand Parade with up to 1.0m expected in a 1% AEP event. Areas of high provisional hazard are generally confined to the open channel itself or a number of trapped low points.

Flood extents along Bado-Berong Creek are generally confined to the linear open space along the creek alignment in events up to the 1% AEP. At Waldron Street two stormwater networks flow to the creek and overland flow associated with these networks inundates residential properties with depths ranging from 0.15m to 0.8m estimated in a 1% AEP event.

At the upper part of Goomun Creek, stormwater ponding is associated with a pipe network draining to Bado-Berong Creek and results in property inundation of up to 0.6m between Bonanza Lane and Russell Lane with 0.8m ponding estimated on Russell Lane itself in a 1% AEP event. Overflow from Goomun Creek at Toyer Avenue, Ida Street and Kendall Street results in stormwater ponding of up to 0.8m which impacts residential properties in the area. Areas of high provisional hazard are evident on Ida Street and along the entire concrete channel from Russell Avenue to Lawson Street.

A sensitivity analysis of results was undertaken to evaluate the range of uncertainty in modelled flood behaviour to changes in key parameters including catchment rainfall, roughness and rainfall losses. Results indicated a maximum impact of 0.15m on flood levels based on a 20% variance in catchment rainfall. Impacts based on amended roughness and rainfall loss rates were relatively minor indicating the model results are not sensitive to changes in these parameters.

Changes to climate conditions are expected to have adverse impacts on rainfall intensities and sea levels. Potential changes to flood behaviour have been modelled for the 1% AEP and PMF events for a range of scenarios incorporating increases in rainfall intensity ranging from 10% to 30% and sea level rise benchmarks of 0.4m and 0.9m in Botany Bay. The lower parts of Bado-Berong Creek and Goomun Creek are considered to have the greatest impacts due to increasing rainfall intensity with up to 0.2m flood level increases in a 1% AEP event. Increasing sea levels will adversely affect the study area with the lower terrain near the outlet of Waradiel Creek likely to experience the greatest impact in a 1% AEP event. Widespread significant increases in flood levels of up to 0.5m are expected in the PMF event, given the relatively flat terrain in the study area and the inability of stormwater to discharge to Botany Bay.

The flood planning area has been determined for the study area based on the 1% AEP flood extents plus 0.5m freeboard. The sensitivity of the flood planning area to sea level rise has also been assessed.

The next stage of the floodplain risk management process following the adoption of the Flood Study is the Floodplain Risk Management Study and Plan which will investigate potential flood mitigation measures to alleviate the impacts of flooding in the study area.

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Glossary

Annual Exceedence Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded each year; it would occur quite often and would be relatively small. A 1%AEP flood has a low probability of occurrence or being exceeded each year; it would be fairly rare but it would be relatively large.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that periods between exceedances are generally random
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Creek Rehabilitation	Rehabilitating the natural 'biophysical' (i.e. geomorphic and ecological) functions of the creek.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events. E.g. some roads may be designed to be overtopped in the 1 in 1 year or 100%AEP flood event.
Development	The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood fringe	The remaining area of flood-prone land after floodway and flood storage areas have been defined.
Flood hazard	Potential risk to life and limb caused by flooding.
Flood-prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land. Floodplain Risk Management Plans encompass all flood-prone land, rather than being restricted to land subject to designated flood events.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain management measures	The full range of techniques available to floodplain managers.
Floodplain management options	The measures which might be feasible for the management of a particular area.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls.

Flood planning levels	Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plains. The concept of FPLs supersedes the “Standard flood event” of the first edition of the Manual. As FPLs do not necessarily extend to the limits of flood prone land (as defined by the probable maximum flood), floodplain management plans may apply to flood prone land beyond the defined FPLs.
Flood storages	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often, but not always, aligned with naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas.
Geographical Information Systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Low hazard	Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.

Mathematical/computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.
Overland Flow	The term overland flow is used interchangeably in this report with “flooding”.
Peak discharge	The maximum discharge occurring during a flood event.
Probable maximum flood	The flood calculated to be the maximum that is likely to occur.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Annual Exceedance Probability.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area.

Terminology in this Glossary have been derived or adapted from the NSW Government Floodplain Development Manual (2005), where available.

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1 Introduction

1.1 Overview

Rockdale City Council have completed a number of flood related studies within the study area including:

> Muddy Creek, Scarborough Ponds and Sans Souci Drain No.1 Flood Study (AWACS 1997);
> Sans Souci Drain No.2 and No.3 Flood Study (Webb McKeown & Associates 1994); and
> Sans Souci Drainage Catchments Floodplain Risk Management Study & Plan (Cardno 2005).

These previous studies generally used a one-dimensional (1D) hydraulic modelling system to define flood behaviour in Sans Souci. Hydraulic modelling systems have improved during the last decade, with 1D/2D hydraulic modelling systems dominating in this field. In order to define flood behaviour under existing conditions, which incorporates topographic features and the existing drainage system, Rockdale City Council commissioned Cardno to undertake a Flood Study Review for the Sans Souci catchment using the Tuflow 1D/2D hydraulic modelling software.

This report outlines the development of the 1D/2D Tuflow hydraulic model and provides a summary of calibration results for the 1975 storm event. The calibrated hydraulic model has subsequently been used to model the design flood events and assess existing flood behaviour within the catchment including provisional hazard and hydraulic categories, risk precincts and climate change impacts.

The findings of this report will form the basis for a future Floodplain Risk Management Study and Plan.

1.2 Study Context

The NSW Floodplain Management process progresses through six steps in an iterative process:

1. Formation of a Floodplain Management Committee;
2. Data Collection;
3. Overland Flow / Flood Study;
4. Overland Flow / Floodplain Risk Management Study;
5. Overland Flow / Floodplain Risk Management Plan; and
6. Implementation of the Overland Flow / Floodplain Risk Management Plan.

This document outlines work undertaken as part of Stage 3 of the process.

2 Catchment Description

The study area is bounded by Rocky Point Road in the west which is a localised high point and Rockdale City Council boundary. The northern extent of the study area is formed by Clarkes Road and Ramsgate Road and includes the uppermost part of the Scarborough Ponds catchment. The catchment is drained by three distinct channels namely Waradiel Creek, Bado-Berong Creek and Goomun Creek flowing south in direction and outfalling to Botany Bay. The overall study area extends approximately 3.1km^2 in area.

Land use within the catchment is dominated by low and medium density residential properties with commercial areas along Rocky Point Road and Russell Avenue. Several parks and reserves are located within the catchment and are generally adjacent to the three creeks.

The study area is shown in Figure 2-1 with description of each of the main creeks outlined below.

2.1 Waradiel Creek

Waradiel Creek, also known as Sans Souci Drain No. 1, conveys flows from Ramsgate Road generally southeast in direction via pipe network to Alfred Street where it discharges to an open channel. Flow is conveyed south via a combination of open channel and pipe network that discharges into Botany Bay adjacent to Georges River Sailing Club. The overall length of the combined pipe and channel network is 1.5km.

2.2 Bado-Berong Creek

Bado-Berong Creek, also known as Sans Souci Drain No. 2, begins south of Park Road and conveys flow in a well-defined channel to Botany Bay. A relatively wide vegetated floodplain exists along the creek alignment and is used as public recreation space. Culverts convey flow beneath road crossings at Alice Street, Ritchie Street, Sandringham Street, Russell Avenue, Ida Street and Riverside Drive where the creek discharges into Botany Bay. A number of pedestrian bridges traverse the channel providing connectivity to residents on each side of the creek. The overall length of Bado-Berong Creek is approximately 1.9km.

2.3 Goomun Creek

Goomun Creek, also known as Sans Souci Drain No. 3, comprises a rectangular concrete lined open channel from Russell Avenue to Kendall Street Reserve with a length of approximately 1.2km. The channel is bordered by residential properties along its alignment to Kendall Street Reserve. At the Reserve it continues as an enclosed channel and culvert network to its outfall to Botany Bay west of Rocky Point Road.

2.3.1 Drain No. 3A

Drain No. 3A is located between Bado-Berong Creek and Goomun Creek and comprises a piped stormwater network located beneath Brantwood Street and discharges into Botany Bay. It extends approximately 9ha in area and has been included as part of this assessment, in addition to the three main creeks.

3 Review of Available Information

3.1 Available Data

The following data was supplied by Council for use in this assessment:

> LiDAR topographical survey data;

> DRAINS model for the catchment including channel, pit and pipe data (February 2013);

> Details of recently completed stormwater improvement works including Alice Street diversion, Pemberton Reserve detention basin and Waradiel Creek amplification works at Georges Creek Sailing Club;

> GIS data including cadastre; and

> Aerial photography.

3.2 Previous Flood Assessments

3.2.1 Muddy Creek, Scarborough Ponds and Sans Souci Drain No. 1 Flood Study

A Watershed Bounded Network Model (WBNM) was developed for hydrological modelling of Muddy Creek, Scarborough Ponds and Sans Souci Drain No. 1 Flood Study (AWACS 1997) with hydraulic modelling undertaken using MIKE11. Cross-sectional survey was undertaken along Drain No. 1 and the model included detailed information on hydraulic structures within the study area. No streamflow information was available to calibrate the hydrological model, nor historical flood level information to calibrate the MIKE11 model. It is noted that the Muddy Creek and Scarborough Ponds Flood Studies are currently being updated on behalf of Council.

3.2.2 Sans Souci Drain No. 2 and No. 3 Flood Study

A WBNM hydrological model was developed for the catchment with a RUBICON hydraulic model for the Drains No. 2 and No. 3 Flood Study (Webb McKeown & Associates 1994). No streamflow information was available to calibrate the hydrological model. The hydraulic model was calibrated to the March 1975 event with recorded peak flood levels provided by Council. Sensitivity analysis of the model was undertaken for the parameters of design rainfall, loss rates, Manning 'n' roughness values and Botany Bay water levels.

3.2.3 Sans Souci Drainage Catchments Floodplain Risk Management Study & Plan

A flood study review was undertaken as part of the Sans Souci Drainage Catchments Floodplain Risk Management Study and Plan (Cardno 2005). Hydrological modelling for Drains No. 1, No. 2 and No. 3 was undertaken using XP-RAFTS. MIKE11 was used for hydraulic analysis which was based on the Drain No. 1 MIKE11 model and extended to include Drains No. 2 and 3. Rainfall from the March 1975 event was used in the hydrological model with resulting hydrographs input to the hydraulic model to calibrate to observed flood levels for Drains No. 2 and No. 3.

3.2.4 Rockdale Floodplain Risk Management Study & Plan

Council commissioned Bewsher Consulting and GLN Planning to review various Floodplain Risk Management Studies undertaken within the LGA with the objective of consolidating these studies and develop an overarching floodplain risk management policy document. This study established a reduced number of Flood Risk Precincts to simplify categorisation of land affected by flood hazard.

3.3 Rainfall Recording Stations

Historical rainfall data was available from daily and pluviograph stations in the vicinity of the catchment with station details outlined in Table 3-1.

Table 3-1 Recording Station Details

Station ID	Station Name	Station Type	Start of Records	End of Records	Source
066058	Sans Souci (Public School)	Daily	1899	Current	BOM
066037	Sydney Airport AMO	Pluviograph	1929	Current	BOM
566047	Mortdale Bowling Club	Pluviograph	1971	Current	Sydney Water
566090	Carss Park	Pluviograph	1981	2006	Sydney Water

The locations of the recording stations are shown in Figure 3-1 in Appendix A.

4 Model Setup

4.1 Modelling Methodology

A fully dynamic one and two-dimensional (1D/2D) hydraulic model was developed for the study area using Tuflow modelling software. The rainfall-on-grid (direct rainfall) methodology applies the rainfall pattern directly to each cell of the 2D grid, thus the hydrologic and the hydraulic calculations are undertaken in the same modelling package. Channels, hydraulic structures and pipes are represented as 1D elements within the 2D domain.

Advantages of the direct rainfall methodology include:

> As rainfall is applied directly to the 2D terrain the hydraulic model automatically routes the flow, therefore overland flowpaths are generated by the model and are not assumed;

> Minor overland flow paths are easily identified; and

> Interaction of overland flows between Drain Nos. 1, 2 and 3 may be better defined.

4.2 2D Terrain

LiDAR data supplied by Council defines the topographic features in the study area. Generally, the accuracy of LiDAR data is ±0.15m on hard surfaces.

The terrain grid for the Tuflow model was developed based on the LiDAR data with a terrain grid resolution of 2mx2m resulting in approximately 2.1 million grid points. Some features such as channels and culverts are generally not well-defined in LiDAR data and thus are modelled as 1D elements. The terrain data used in the model is shown in Figure 4-1 in Appendix A.

Council has advised of landfill which has occurred at two locations in the study area, namely:

> A villa development facing both Ida Street and Kendall Street constructed in 1992-1994 with filling ranging from 1.0m to 1.5m across the site (excluding channel); and

> Kendall Street Reserve where filling occurred during February 1975 to December 1976.

4.3 1D Elements

4.3.1 Stormwater Pipes and Pits

Stormwater pits and pipes have been incorporated into the model as 1D elements. In the model, once the pipe capacity is exceeded, excess flows spill into the 2D domain via the pits. Similarly, overland flow is able to enter the pipe network through a nearby pit when the drainage system at that location has capacity.

Approximately 480 pipes and 450 pits were included in the model. Detailed information about pits and pipes were collated from Council's DRAINS model and pit and pipe data provided by Council.

Assumptions were made based on upstream and downstream network details, where pipe diameters and invert levels were inconsistent between Councils DRAINS model and the pit and pipe information provided.

The following recently completed stormwater drainage works were also incorporated into the model:

> Alice Street diversion;

> Pemberton Reserve detention basin; and

> Waradiel Creek (Drain No. 1) amplification works at Georges River Sailing Club.

4.3.2 Waradiel Creek, Bado-Berong Creek and Goomun Creek

The three main creeks namely, Waradiel, Bado-Berong and Goomun are approximately 3.7km in length and have been modelled as one-dimensional elements, using cross-section data extracted from the MIKE11 model developed as part of the Sans Souci Drainage Catchments Floodplain Risk Management Study and Plan (Cardno, 2005).

Pipe invert levels were adjusted based on upstream network and channel details, where pipe data was inconsistent with channel details. The channel, pipe and pits incorporated into the Tuflow model are shown in Figure 4-2 in Appendix A.

4.4 Hydraulic Structures

Hydraulic structures (culverts and bridges) may have a significant impact on flood behaviour since the debris carried down the channel has the potential to be trapped by these structures located along the drainage line. Eleven hydraulic structures along Drains No. 1, No. 2 and No. 3 have been incorporated into the model.

4.5 Inlet Capacity

Inlet capacity is one of the key factors that affect flows into the drainage system in urban hydraulic modelling. The capacity of inlets depends on the depth and velocity of approaching runoff and the configuration of the inlets.

Pit types and inlet opening dimensions were obtained from Councils existing DRAINS model and the pit and pipe data. Inlets were modelled in Tuflow using capacity curves in accordance with the inlet classification in Table 4-1. Inlet curves were developed according to pit inlet rating curves as identified in DRAINS.

No allowance for blockage of pits and other hydraulic structures has been allowed for in this study.

Table 4-1 Pit Inlet Capacity Classification

Pit Type	Pit Inlet Classification	Grate Width (m)	Grate Length (m)	Inlet Length (m)
Grated Pit	1	≤0.7	0.45	-
	2	0.7<x≤1.1	0.45	
	3	1.1<x≤1.6	0.45	
	4	1.95	0.9	
	5	4.0	2.0	
	6	5.0	5.0	
Side Entry Pit	7	-	-	≤1.5
	8			1.5<x≤2.1
	9			2.1<x≤2.7
	10			2.7<x≤3.3
	11			3.3<x≤3.9
Combined Side Entry and Grated Pit	12	0.9	0.45	≤1.5
	13	0.9	0.45	1.5<x≤2.1
	14	0.9	0.45	2.1<x≤2.7
	15	0.9	0.45	2.7<x≤3.3
	16	0.9	0.45	3.3<x≤3.9
	17	0.9	0.45	3.9<x≤4.5
	18	0.9	0.45	>4.5

4.6 Buildings

There are two common approaches to model buildings in a 2D hydraulic model including blocking of the buildings and modelling them with high roughness. Syme (2008) undertook analysis on these two methodologies for incorporating buildings in 2D models. The testing indicated that both approaches resulted in similar upstream water levels, although local velocity behaviour could potentially differ. This suggests that the approach of modelling buildings as high roughness would provide sufficient detail and has been used for study.

4.7 Roughness

A hydraulic roughness map is required for 2D modelling to classify the surface roughness for various land uses. The roughness map was determined using both aerial photography from NearMap (http://www.nearmap.com/) and site inspections carried out by Cardno and Council in May 2013.

There is no standard reference that provides guidelines on estimating the hydraulic roughness for overland flow in 2D models in urban areas. Previous experience gained from calibrating catchment models with similar land uses and topography features provides a better guide to determine the roughness values.

Figure 4-3 shows the hydraulic roughness layout applied in the 2D model. The roughness values adopted for the 2D areas are listed in Table 4-2.

Table 4-2 2D Roughness Values

Zone / Land Use	Manning's 'n'
Road	0.02
Road Vegetated Median	0.035
Open Space	0.035
Bush	0.05
Residential	0.1
Building	0.1
Creek	0.045
Paved Surface	0.02
Bay	0.012

The roughness values adopted for 1D elements are listed in Table 4-3.

Table 4-3 1D Roughness Values

Zone / Land Use	Manning's 'n'
Concrete Pipes	0.014
Natural Channel	0.045
Concrete Channel	0.02

4.8 Loss Rates

Different loss rates are applied for individual land uses in the Tuflow model. A general guideline for initial losses and continuous losses for impervious and pervious areas is provided in Australia Rainfall and Runoff (Institution of Engineers Australia, 1987).

Previous studies provide insight into the values adopted with the following used in AWACS (1997):

> Impervious Areas: Initial Loss 0mm, Continuing Loss 0 mm/hr; and

> Pervious Areas: Initial Loss 10mm and Continuing Loss 2.5 mm/hr.

The initial and continuing losses used in the Tuflow model for various land uses are summarised in Table 4-4.

Table 4-4 Initial and Continuing Loss Rates

Zone / Land Use	Initial Loss (mm)	Continuous Loss (mm/hr)
Road	0	0
Road Vegetated Median	10	2.5
Open Space	10	2.5
Bush	10	2.5
Residential	5	2.5
Building	0	0
Creek	0	0
Paved Surface	0	0
Bay	0	0

4.9 Tailwater Conditions

The water level in Botany Bay may affect flood levels within the lower parts of the catchment for the three creeks and in particular along Waradiel Creek. Flooding may occur due to elevated ocean water levels independent of runoff generated on the catchment therefore the impacts of flooding have been assessed based on rainfall dominated events and ocean dominated events.

Table 4-5 lists Botany Bay tailwater levels used as part of the Cardno (2005) study which have been adopted for the design runs in this study. A tailwater level of 1.0m AHD was adopted in the calibration models.

Table 4-5 Tailwater Levels for Design Events

Design Event	Tailwater Level	
AEP	Rainfall Dominated Event	Ocean Dominated Event
PMF	2.0	
1% AEP	1.0	1.70 + 20% AEP
5% AEP	1.0	1.50 + 20% AEP
10% AEP	1.0	1.42 + 20% AEP
20% AEP	1.0	1.35 + 20% AEP

5 Model Validation and Calibration

5.1 Model Validation

As the direct rainfall methodology is relatively new to the industry, the Tuflow model has been validated against a traditional hydrological model. This has been undertaken by comparing the results of a 100 year ARI event to an XP-RAFTS model.

The modelled XP-RAFTS subcatchment is west of Walmer Street and is shown in Figure 5-1 in Appendix A. The subcatchment has an area of 21.6ha and estimated 60% impervious area. The key parameters used in the development of the XP-RAFTS model are listed in Table 5-1 and Table 5-2.

Table 5-1 Model Validation XP-RAFTS Parameters

Parameter	Urban Pervious Surface	Urban Impervious Surface
Catchment roughness	0.1	0.015
Storage delay parameter (B_X)	1.0	

Table 5-2 Model Validation Adopted Design Rainfall Losses

Surface Type	Initial Loss (mm)	Continuing Loss (mm/hr)
Impervious	1.5	0
Pervious	10	2.5

Flow hydrographs estimated by the Tuflow and XP-RAFTS models for the 100 year ARI, 90mins design event are shown in Figure 5-2.

The peak flow result from Tuflow is 9.5m^3/s, whilst the peak flow from the XP-RAFTS model is 9.9m^3/s. The Tuflow model generates a total water volume of 21,800m^3, whilst the XP-RAFTS model generates a total water volume of 20,800m^3.

The Tuflow model comprises an elevation grid which takes into consideration localised depression storages, which are not accounted for in the XP-RAFTS model. As a result, the XP-RAFTS model reports slightly higher peak flows. The hydrographs show similar rise and fall between both models, noting the delay in the Tuflow rise due to runoff retained in localised depressions. Results indicate reasonable agreement between the direct rainfall Tuflow model and the XP-RAFTS model.

5.2 Model Calibration

Calibration is typically undertaken by adjusting the model parameters within acceptable ranges so that the modelled flood levels reasonably match the recorded flood levels at calibration locations.

The storm event of March 1975 was used to calibrate the Tuflow hydraulic model. Previous surveyed and observed flood levels were used to confirm the results of the model accurately represent the reported flood behaviour.

Information regarding rain gauges in the surrounding areas is discussed in Section 3.3. Daily rainfall on 10 March 1975 at the surrounding rain gauges are listed in Table 5-3.

Table 5-3 Storm Daily Rainfall Data

Date	Mortdale Bowling Club (mm)	Sydney Airport (mm)	Sans Souci (mm)
10 March 1975	81.4	202.3	239.0

5.2.2 Mortdale Gauge Rainfall

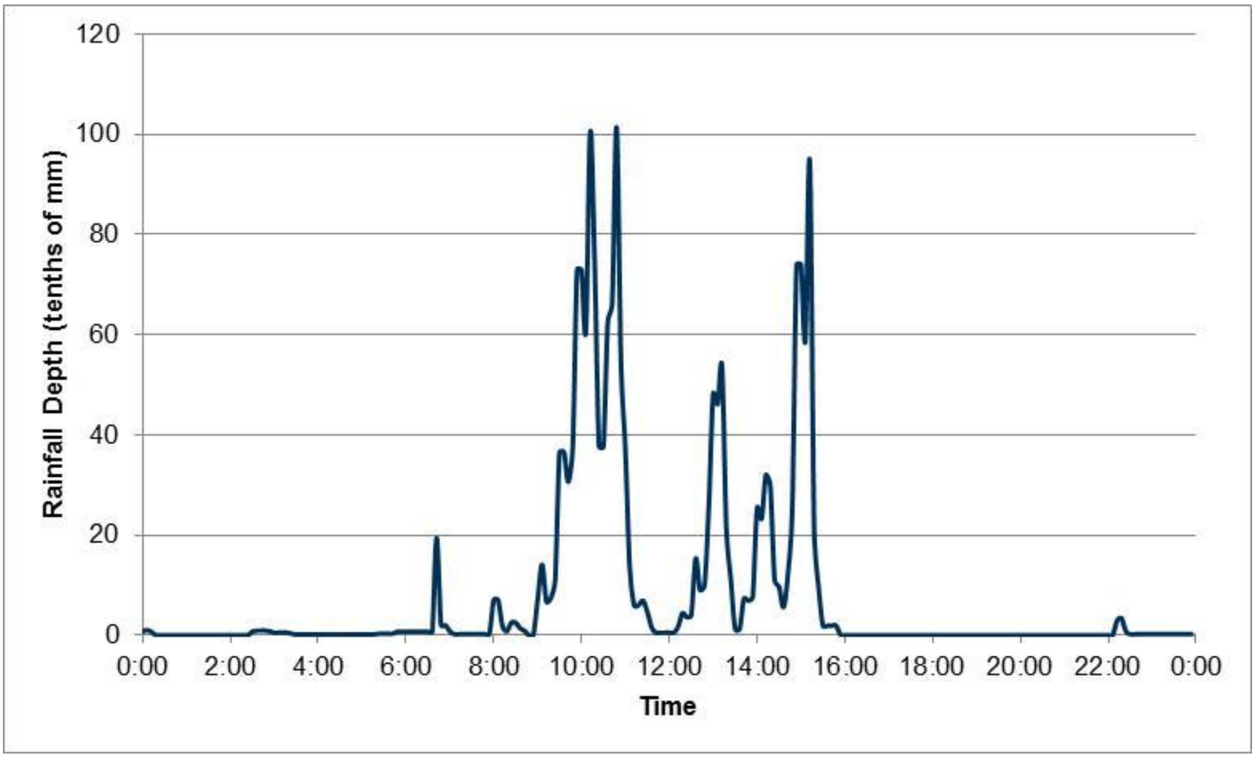
The pluviograph at Mortdale Bowling Club is approximately 6km northwest of Sans Souci. Rainfall data could not be sourced from Sydney Water with records at this gauge only dating back to 1977.

Previous analysis of rainfall at the Mortdale pluviograph indicates a rainfall depth of approximately a 10 year ARI event (Webb McKeown & Associates, 1994). The first approach adopted in the current study is to use the daily rainfall values for the Sans Souci (Public School) gauge and apply a 10 year temporal pattern.

5.2.3 Sydney Airport Gauge Rainfall

The Sydney Airport AMO gauge (66037) is located approximately 7.1km northeast of Sans Souci. Figure 5-3 shows pluviometer rainfall data recorded at the Sydney Airport AMO gauge on 10 March 1975.

Figure 5-3 Pluviometer Rainfall on 10 March 1975 at Sydney Airport AMO



The total daily rainfall on 10 March 1975 at Sydney Airport AMO gauge is approximately 202mm. The previous studies indicate that the daily rainfall reached 239mm over the same period in Sans Souci (Webb McKeown & Associates, 1994). The second approach adopted in this study is to use the pluviometer rainfall data at Sydney Airport AMO gauge.

5.2.4 Calibration Results

Information regarding historical flood levels at 14 locations was sourced from the Sans Souci Drains No.2 and No.3 Flood Study (Webb McKeown & Associates, 1994).

A comparison of the observed flood marks and modelled flood levels based on both Mortdale and Sydney Airport rainfall is outlined in Table 5-4. The locations of observed flood marks are shown in Figure 5-4.

Table 5-4 Summary of Historical Flood Levels and Calibration Results

Location (Fig. 5-4)	No.	Street Name	Observed Flood Marks	Surveyed Spot Level 1976	Tuflow Grid Level		Model Level (Mortdale)		Model Level (Airport)	
					Min	Max	Min	Max	Min	Max
P1	39	Bonanza Parade	2.35	2.40	2.18	2.42	2.69	2.70	2.65	2.65
P2	49	Evans St	2.38	2.30	2.40	2.51	-	-	-	-
P3	55	Griffiths St	2.35	2.30	2.40	2.51	-	-	-	-
P4	25	Toyer Ave	2.34	2.30	2.34	2.54	-	-	-	-
P5	36	Ida St	1.98	2.60	2.02	2.60	2.36	2.41	2.37	2.40
P6	5/38	Ida St	1.98	2.60	2.25	2.52	-	-	-	-
P7	33	Kendall St	1.70	1.90	1.90	2.05	2.33	2.34	2.26	2.27
P8	20	Fontainebleau St	1.93	1.80	1.98	2.47	2.46	2.48	2.43	2.47
P9	16	Meriel St	2.16	2.10	2.07	2.38	2.48	2.48	2.47	2.47
P10	16	Ida St	1.73	2.20	1.88	2.32	2.35	2.36	2.27	2.27
P11	47	Sandringham St	2.47	1.70	1.74	2.09	2.36	2.39	2.31	2.34
P12	69	Griffiths St	1.82	1.90	1.91	2.10	-	-	-	-
P13	60	Ida St	1.93	2.10	2.30	2.39	-	-	-	-
P14	18	Brantwood St	2.23	1.80	1.74	2.46	2.67	2.67	2.75	2.75

Note '-' indicates property is unaffected by the flood extent. Units are m AHD

Table 5-4 provides the minimum and maximum values of ground levels from the terrain grid and the modelled flood levels within the affected area of a property from the corresponding flood extent.

The accuracy of LiDAR data is one of the key factors in determining the model calibration performance. The topographic features may have undergone significant change in some areas due to development since 1975. Council provided ground spot height data collected in 1976 to assess the differences between this data and the terrain data adopted in the Tuflow model.

5.2.5 Comparison of Results to Historical Flood Marks

There are a number of factors that can affect the calibration including:

> Accuracy of surveyed flood levels;

> Accuracy of LiDAR data;

> Impacts of localised effects such as debris (blocking inlets of overland flow paths);

> Uncertainty regarding level of blockage of structures during the event; and

> Accuracy of the hydraulic model including initial and continuous losses, roughness and rainfall data used.

5.2.6 Comparison of 1976 Spot Height Data to Modelled Ground Levels

Ground levels surveyed in 1976 were compared to the ground levels adopted in the Tuflow flood model which are based on the LiDAR data. The following points are noted:

> Surveyed levels from 1976 are not available for all specific locations, thus those listed in Table 5-4 are the nearest available record;

> Changes to the ground elevations would have occurred in the 30 years between the two survey sources; and

> LiDAR is generally quoted with an accuracy of +/-0.15m, thus there will be some variation expected in levels.

Figure 5-5 shows the differences in elevation of the modelled ground surface compared to the ground surface prepared for the 1976 surveyed levels.

Almost half of the reference locations in Table 5-4 have a 1976 surveyed level within the range of the modelled ground surface levels. Other locations are generally within the quoted tolerance of +/-0.15m for LiDAR data for the elevation range within the extent of the property. The maximum difference is 0.2m.

Therefore, some differences would be expected between the modelled flood levels and the observed flood marks due to the accuracy of the LiDAR data. The LiDAR data however, provides many more spot levels enabling a better resolution for the ground elevation to be modelled.

5.2.7 Review of Historical Flood Marks and Ground Elevations

Ten of the fourteen observed flood marks listed in Table 5-4 are lower than the ground elevations of either the 1976 survey or the modelled ground surface. Several of the observed flood marks are inconsistent with nearby levels, for example:

> P4 is 0.36m higher than adjacent levels at P5 and P6; and

> P9 is 0.23m higher than the adjacent level at P8.

These factors thus limit the applicability of the observed flood marks to the calibration process.

5.2.8 Results based on Mortdale Approach

The flood extent based on the Mortdale rainfall is shown in Figure 5-4. The model results indicate that P2, P3, P4, P6, P12 and P13 are not directly affected by 1975 flood extent. At these locations, the minimum ground level is higher than the observed flood level. Potentially there may be an error for the observed flood levels, or the model DTM does not accurately represent the ground features at these locations.

The flood levels at P11 show reasonable agreement to the corresponding observed water level (within 0.11m). In general, flood levels are much higher than the observed flood levels at other locations. The water level differences at these locations are in a range of 0.32m-0.63m. This may be due to an inconsistency between the observed water levels and the ground levels.

A large ponding area along the major overland flowpath of Drain No. 3 is evident between Toyer Avenue and Meriel St with flood levels ranging from 2.33m-2.48m AHD. Ponding in this area is due to flow being blocked by the higher ground at the intersection of Fraters Avenue and Rocky Point Road.

5.2.9 Results based on Sydney Airport Approach

The water level differences for the 1975 event based on Sydney Airport and Mortdale approaches are shown in Figure 5-6.

The Sydney Airport approach results in a reduction in water levels of up to 0.08m in the upstream areas of the catchment with an increase in water levels of up to 0.08m in the downstream areas of the catchment. The water level increase in the downstream areas is due to a longer simulation time with potentially additional rainfall volume.

The modelled water levels at calibration locations using the Sydney Airport rainfall are presented in Table 5-4. The water levels at calibration locations reduce by up to 0.09m, compared with the Mortdale approach although are generally still higher than the observed flood marks. The increased flood extent as a result of using Sydney Airport rainfall is shown in Figure 5-4.

5.3 Model Parameter Sensitivity

The sensitivity of the model was analysed to determine the range of uncertainty in the model results for changes in key parameters. The following variables were tested for the March 1975 calibration event based on Mortdale approach:

> Catchment rainfall – increased and decreased by 20%;

> Catchment roughness – increased and decreased by 20%; and

> Rainfall loss rates, initial loss and continuing loss.

5.3.1 Catchment Rainfall

The model results are likely to be impacted by rainfall intensity and temporal patterns. The historical events adopted in the two calibration approaches may not be fully representative of the 1975 event in Sans Souci. A sensitivity test was undertaken to evaluate the uncertainty of the model results to ±20% change in rainfall.

The flood level impact of an increase/decrease of rainfall by 20% is shown in Figure 5-7 and Figure 5-8 respectively. A rainfall increase of 20% results in an increase of 0.06m-0.14m in flood levels in general, whilst a decrease of 20% in rainfall results in flood level decreases in the range of 0.05m-0.15m. Differences are not greater than 0.15m on a 20% variation in rainfall.

5.3.2 Catchment Roughness

The flood level impact of an increase/decrease in hydraulic roughness is shown in Figure 5-9 and Figure 5-10 respectively. Variations in hydraulic roughness have a relatively minor impact on the predicted flood levels in the 1975 event. The flood level differences are typically within +/-0.03m for a 20% variation in hydraulic roughness.

5.3.3 Rainfall Loss Rates

Initial and continuing loss rates for pervious areas for different scenarios are listed in Table 5-5. A sensitivity test on rainfall loss rates was undertaken by varying initial and continuing loss rates for pervious areas.

Table 5-5 Rainfall Loss Rates for Sensitivity Scenarios

Scenario	Initial Loss (mm)	Continuous Loss (mm/hr)
1975 Mortdale	10	2.5
Sensitivity Case 1	15	3.5
Sensitivity Case 2	20	5.0

The flood level impact of two rainfall loss rate scenarios is shown in Figure 5-11 and Figure 5-12. Water level decreases of approximately 0.01m and 0.03m result for Case 1 and Case 2 respectively. This suggests that the model results are not significantly affected by rainfall loss rates.

6 Flood Modelling Results

6.1 Critical Storm Duration

The model was run for the 1% AEP event storms of 30 minute, 1 hour, 2, 3, 4.5, 9 and 12 hour durations. Results indicated the 1 hour storm duration was critical in the upper half of Bado-Berong Creek, the 9 hour storm duration dominated in both Waradiel Creek and the lower half of Bado-Berong Creek, while the 12 hour storm duration is critical along Goomun Creek. The difference in flood levels between the 12 hour critical storm duration on Goomun Creek and the 9 hour duration storm elsewhere in the study area was less than 0.1m and is considered relatively minor. Therefore the design storms were run for both the 1 hour and 9 hour storm durations only.

6.2 Flood Extents, Depths and Velocities

Flood modelling of design storms was undertaken for the 20%, 10%, 5%, 1% AEP events and the PMF event.

Flood extents and depths for the design storms are shown in Figure 6-1 to Figure 6-5 with expected velocities shown in Figure 6-6 to Figure 6-10.

The model results have been filtered as follows:

> Remove any cells where the flood depth is less than 0.15m; and

> Remove any areas of discrete stormwater ponding that are less than 200m^2 in area.

Flood profiles along each drain alignment are shown in Figure 6-11, Figure 6-12 and Figure 6-13.

6.3 Provisional Flood Hazard

Provisional flood hazard is determined through a relationship between the depth and velocity of floodwaters and is based strictly on hydraulic considerations (Appendix L; NSW Government, 2005). The Floodplain Development Manual (NSW Government, 2005) defines two categories for provisional hazard – high and low.

Hazard is calculated for each grid cell at each time step based on velocity, depth and velocity x depth, with the highest value giving the hazard rating for the cell. Provisional hazard was prepared for five design events, namely the 20%, 10%, 5%, 1% AEP events and the PMF event and is shown on Figure 6-14 to Figure 6-18.

Areas of high provisional hazard dominate along the open channel sections of each of the three main creeks and at trapped low points for all design events. Further discussion on areas affected by high hazard is outlined in Section 6.6.

6.4 Hydraulic Categories

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The Floodplain Development Manual (2005) defines flood prone land to be one of the following three hydraulic categories:

> Floodway: areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows which may adversely affect other areas;

> Flood Storage: areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%; and

> Flood Fringe: remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

Floodways were determined for the 1% AEP event by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways are described below (based on Howells et al, 2003).

As a minimum, the floodway was assumed to follow the channel alignments from bank to bank. In addition, the following depth and velocity criteria were used to define a floodway:

> Velocity x Depth product must be greater than $0.25m^2/s$ and velocity must be greater than 0.25m/s; or

> Velocity is greater than 1m/s.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.15m and/or would cause peak discharge anywhere to increase by more than 10%. The criteria were applied to the model results as described below.

Previous analysis of flood storage in 1D cross sections assumed that if the cross-sectional area is reduced such that 10% of the conveyance is lost, the criteria for flood storage would be satisfied To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2 m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

> Depth greater than 0.2m; and

> Not classified as floodway.

All areas that were not categorised as Floodway or Flood Storage, but are within the flood extent, with a depth greater than 0.15m, are represented as Flood Fringe.

The hydraulic categories for the design events are shown in Figure 6-19 to Figure 6-23.

6.5 Flood Risk Precinct Mapping

Flood Risk Precinct mapping has been prepared for the study area based on the methodology as outlined in Bewsher (May 2013) and includes the following:

> High Flood Risk Precinct categorised as mainstream floodway or flood storage (high hazard) or overland flow floodway (high hazard);

> Medium Flood Risk Precinct categorised mainstream flood storage (low hazard) or flood fringe (low hazard);

> Low Flood Risk Precinct categorised as floodplain area above the flood planning level and below the PMF extents; and

> Overland Flow Flood Risk Precinct categorised as overland flow margin (low hazard).

The Flood Risk Precincts for the study area are shown in Figure 6-24.

6.6 Discussion of Results

6.6.1 Waradiel Creek

Waradiel Creek originates as a pipe network south of Ramsgate Road. The stormwater network along Ramsgate Road conveys flow northwards through Rotary Park as part of the Scarborough Ponds catchment. The existing detention basin at Pemberton Reserve provides storage with up to 1m ponding in a 1% AEP event. Downstream of the detention basin, overland flow results in inundation of residential properties between Park Street and Chuter Avenue in all events greater than 20% AEP.

Stormwater is conveyed eastwards along Alice Street where the pipe network discharges to an open channel on Alfred Street. The 1% AEP flood extents are generally contained within the open channel to Sandringham Street where it reverts to a piped network. An overland flow path develops between Alfred Street and The Grand Parade and flows southwest in direction to Sandringham Street with expected flood depth ranging from 0.6m to 0.8m in a 1% AEP event. The stormwater network discharges to the open channel south of Russell Avenue and flows through Peter Depena Reserve to its outlet with Botany Bay.

Between Alfred Street and The Grand Parade, an extensive area of stormwater ponding occurs in a 1% AEP event with up to 1.0m depth affecting residential properties. The nearby drainage network on The Grand Parade does not help alleviate flooding in this area.

Areas of high provisional hazard are evident along open channel sections of the creek in all design events assessed and at residential properties between Walter Street and Chuter Avenue along the overland flow path in the 1% AEP event.

6.6.2 Bado-Berong Creek

At the upstream end of the creek, north of Alice Street, the 1% AEP flood extents are generally confined within open space east of the channel with some impact on adjacent residential properties in the vicinity of Park Road. Both Park Road and Alice Street are inundated with up to 0.4m water ponding depth. South of Ritchie Street, the 1% AEP flood extents are mostly confined within Bona Park with some inundation of properties off Horbury Street.

Between Sandringham Street and Russell Avenue, two stormwater pipe networks discharge to the channel from the east with an associated overland flow path evident flowing south in direction and resulting in ponding depth of up to 0.4m on Russell Avenue. On the western side of the creek, a stormwater network conveys flows beneath Bonanza Parade to Bado-Berong Creek. Bonanza Parade forms the upper part of the Goomun Creek catchment and overland flow associated with the stormwater network is conveyed south in direction as part of Goomun Creek and not towards Bado-Berong Creek.

South of Russell Avenue the 1% AEP flood extents are typically confined within the elongated open space to Ida Street, residential properties along Napoleon Street and Dickin Avenue may be impacted by overland flow in storm events greater than 5% AEP.

Significant property inundation is expected along Waldron Street where two stormwater networks join Bado-Berong Creek. A low point exists on Waldron Street and overflow from a minor channel, combined with overland flow, results in water depths ranging from 0.15m to 0.8m at the properties.

Areas of high provisional hazard are generally confined to the creek itself and at the confluence of the stormwater networks and creek north of Russell Avenue.

6.6.3 Goomun Creek

Stormwater ponding associated with Bado-Berong Creek, at the upper end of Goomun Creek, results in property inundation of up to 0.6m between Bonanza Lane and Russell Lane with 0.8m ponding estimated on Russell Lane itself in a 1% AEP event. Significant ponding of up to 0.4m is expected at residential properties in a 5% AEP event.

The channel begins at Russell Avenue and generally contains peak flows in a 20% AEP event. Significant inundation of properties is expected due to overbank flow in a 1% AEP event between Russell Avenue and Griffiths Street.

Upstream of Kendall Street Reserve, widespread inundation is evident in a 1% AEP event with flow breaking out of the channel at Toyer Avenue, Ida Street and Kendall Street resulting in above ground ponding of up to 0.8m. Kendall Street Reserve is higher than the surrounding terrain and the creek conveys flow around the northern and western sides of the Reserve. The creek then flows through culverts beneath Lawson Street to Botany Bay. Low points on Fontainebleau Street and Meriel Street result in stormwater ponding up to 0.4m which impacts on adjacent residential properties.

High provisional hazard is evident on Ida Street and along the entire concrete channel from Russell Avenue to Lawson Street.

6.6.4 Drain No. 3A

The stormwater network conveys flow southwards beneath Brantwood Street and Tuffy Avenue to Botany Bay. Slightly higher ground levels along Riverside Drive cause overland flow to pond in low areas with inundation of residential properties between both streets with up to 0.6m and 1.0m estimated in a 10% AEP and 1% AEP event, respectively.

7 Sensitivity Analysis

7.1 Climate Change

Changes to climate conditions are expected to have adverse impacts on sea levels and rainfall intensities. The NSW Office of Environment and Heritage (formerly Department of Environment, Climate Change and Water (DECCW)) guideline, Practical Consideration of Climate Change (2007), provides advice for consideration of climate change in flood investigations. The guideline recommends sensitivity analysis is conducted for:

> Rainfall intensities – for 10%, 20%, and 30% increase in peak rainfall and storm volume; and

> Sea level rise – for low, medium, and high level impacts up to 0.9m.

7.1.1 Rainfall Intensity Increase

The model was run for the 1% AEP event (1 hour and 9 hour storm durations) with increased rainfall intensities of 10%, 20% and 30% all with a tailwater level of 1.0 mAHD. The differences in peak water levels as a result of these increases are shown in Figure 7-1, Figure 7-2 and Figure 7-3.

Increases in 1% AEP flood levels of up to 0.1m are expected for a 10% increase in rainfall intensity with increases ranging up to 0.2m for a 30% increase in rainfall intensity. These increases are most evident along the open channel sections of each of the three main creek alignments. The increase in rainfall intensities results in greater volume of runoff arriving at these locations and an associated increase in peak water levels as a result.

7.1.2 Sea Level Rise

Sea level rise planning benchmarks for assessing potential flood risk impacts due to sea level rise in coastal areas are listed in two documents:

> NSW Coastal Planning Guideline: Adapting to Sea Level Rise (August 2010, prepared by the NSW Department of Planning); and

> Flood Risk Management Guide - Incorporating sea level rise benchmarks in flood risk assessments (August 2010, prepared by the Department of Environment, Climate Change and Water NSW).

The benchmarks are a projected rise in sea level relative to the 1990 mean sea level of 0.4m by 2050 and 0.9m by 2100.

The model was run for the 1% AEP event with a tailwater level increase of two scenarios:

> +0.4m to 1.4m AHD; and

> +0.9m to 1.9m AHD.

The estimated increases in peak water levels are shown in Figure 7-4 and Figure 7-5. The higher tailwater level of 1.9m AHD results in increases in flood levels ranging from 0.1m on Goomun Creek to 0.5m on Waradiel Creek. The significant flood level increases in the lower parts of Waradiel Creek is due to the relatively low terrain in the area and impacts residential properties on Russell Avenue.

The model was run for the PMF event with a tailwater level increase of two scenarios:

> +0.4m to 2.4m AHD; and

> +0.9m to 2.9m AHD.

The estimated increases in peak water levels are shown in Figure 7-6 and Figure 7-7. The higher tailwater level of 2.4m AHD significantly impacts the lower part of Waradiel Creek, given the lower terrain in the area, with increases in 1% AEP flood levels ranging from 0.2m to 0.5m impacting residential properties south of Gannon Avenue. The higher tailwater level of 2.9m AHD results in widespread increases in inundation along all three creeks given the study area is relatively flat combined with the inability of stormwater to discharge to Botany Bay.

Flood profiles based on sea level rise benchmarks along each drain alignment are shown in Figure 7-8, Figure 7-9 and Figure 7-10.

7.2 Flood Planning Level

The Rockdale Local Environmental Plan 2011 (LEP) is applied to manage development within the catchment to minimise flood risks and to avoid significant impacts on flood behaviour. The Flood Planning Level (FPL) is defined as “the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metre freeboard”.

Figure 7-11 shows the extent of the modelled flood planning level area. It was determined by extrapolating the 1% AEP modelled peak flood levels to locations with elevations that are up to 0.5 m higher (in locations where flows are more than 0.15m deep). A significant portion of the study area is shown within the extent.

Properties within the floodplain which are outside the FPL extents and less than the estimated PMF extents are identified in Figure 7-12. These properties are located within a Low Flood Risk Precinct as discussed in Section 6.5.

The sensitivity of increasing sea level rise on the existing flood planning area has been assessed with extents shown in Figure 7-13 and Figure 7-14 for the 2050 and 2100 sea level rise benchmarks, respectively.

8 Conclusion

Flood modelling has been undertaken for the Sans Souci catchment using the Tuflow 1D/2D hydrological and hydraulic model in order to assess existing flood behaviour as part of the NSW Floodplain Management Process. The calibrated hydraulic model was used to asses a range of design events, namely:

- 20% Annual Exceedence Probability (AEP);
- 10% AEP;
- 5% AEP;
- 1% AEP; and
- The Probable Maximum Flood (PMF).

Peak water levels, depth and velocities have been mapped as well as provisional flood hazards and hydraulic categories were determined for each AEP event. Flood risk precincts for the study area have been categorised and climate change impacts based on increasing rainfall intensity and sea level rise have been assessed.

The outcomes of this investigation will form the basis for a Floodplain Risk Management Study and Plan for the Sans Souci Catchment.

9 References

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APPENDIX A

FIGURES