LITHGOW
FLOOD STUDY REVIEW

VOLUME 1 – REPORT

MAY 2017

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FOREWORD

The State Government's Flood Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through the following four sequential stages:

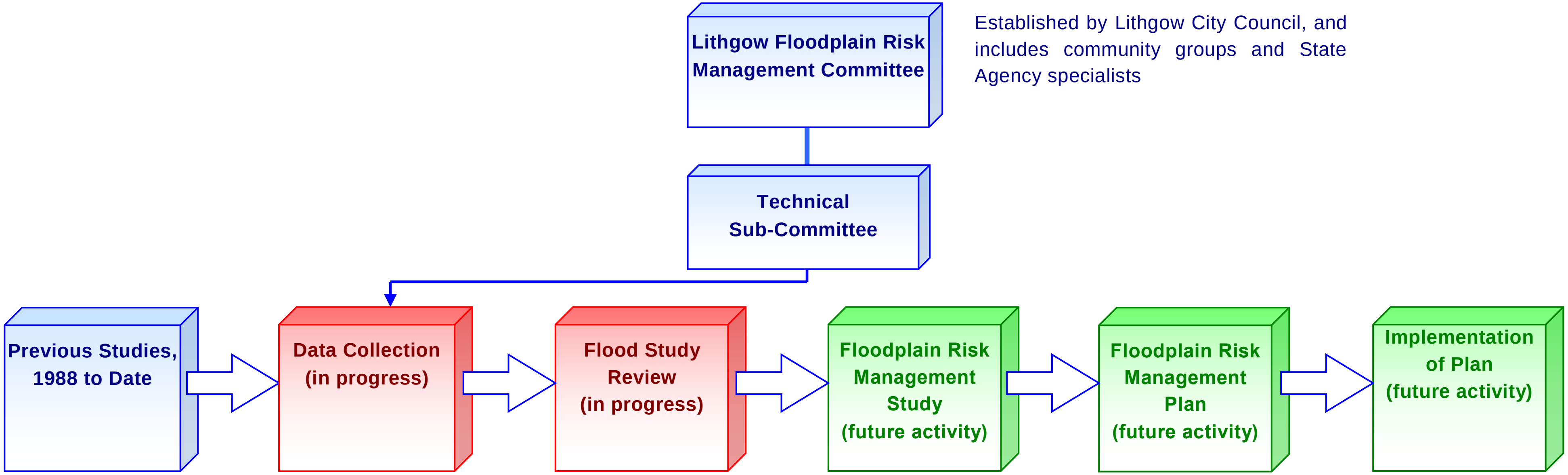
1.	Flood Study	Determines the nature and extent of flooding.
2.	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed development.
3.	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4.	Implementation of the Plan	Construction of flood mitigation works to protect existing development. Use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Lithgow Flood Study Review is jointly funded by Lithgow City Council (**LCC**) and the NSW Government, via the Office of Environment and Heritage (**OEH**). The Flood Study Review constitutes the first stage of the Floodplain Risk Management process (refer over) for this area and has been prepared for LCC to define flood behaviour under current conditions.

ACKNOWLEDGEMENT

This report has been prepared with financial assistance from the NSW and Australian Governments through the Natural Disaster Resilience Program. This report does not necessarily represent the opinions of the NSW or Australian Governments.

FLOODPLAIN RISK MANAGEMENT PROCESS



Previous Studies, 1988 to Date: A flood study was undertaken by the then Department of Water Resources (now OEH) in 1988, which documented the pattern of flooding experienced along Farmers Creek. A Floodplain Management Study was undertaken in 1991 to identify potential mitigation options for Lithgow. Subsequent studies have been undertaken to further investigate these options.

Data Collection: Involves the compilation of existing data and the collection of additional data.

Flood Study Review: Involves detailed hydrologic and hydraulic modelling of the Farmers Creek and Marrangaroo Creek catchments and their tributaries in the Study Area.

Floodplain Risk Management Study: The Floodplain Risk Management Study will determine options which will seek to reduce the impact of flooding on the community in consideration of social, ecological and economic factors.

Floodplain Risk Management Plan: Preferred floodplain management options will be publicly exhibited and the responses from the community incorporated in the Plan. The Plan will then be formally approved by Council following the public exhibition period.

Implementation of Plan: Implementation of the Plan will allow Council to reduce the impact of flooding on the community through flood, property, and response modification measures. The measures may include structural works, planning controls, flood warnings, flood readiness and response plans, ongoing data collection and monitoring.

TABLE OF CONTENTS

Page No.

Cont'd Over

TABLE OF CONTENTS (Cont'd)

Page No.

APPENDICES
(BOUND IN VOLUME 1)

LIST OF FIGURES
(BOUND IN VOLUME 2)

NOTE ON FLOOD FREQUENCY

The frequency of floods is generally referred to in terms of their Annual Exceedance Probability (**AEP**) or Average Recurrence Interval (**ARI**). For example, for a flood magnitude having 5% AEP, there is a 5% probability that there will be floods of greater magnitude each year. As another example, for a flood having a 5 year ARI, there will be floods of equal or greater magnitude once in 5 years on average. The approximate correspondence between these two systems is:

ANNUAL EXCEEDANCE PROBABILITY (AEP) %	AVERAGE RECURRENCE INTERVAL (ARI) YEARS
0.2	500
0.5	200
1	100
2	50
5	20
10	10
20	5

The report also refers to the Probable Maximum Flood (**PMF**). This flood occurs as a result of the Probable Maximum Precipitation (**PMP**). The PMP is the result of the optimum combination of the available moisture in the atmosphere and the efficiency of the storm mechanism as regards rainfall production. The PMP is used to estimate PMF discharges using a model which simulates the conversion of rainfall to runoff. The PMF is defined as the limiting value of floods that could reasonably be expected to occur. It is an extremely rare flood, generally considered to have a return period greater than 1 in 10^5 years.

NOTE ON QUOTED LEVEL OF ACCURACY

Peak gauge heights and flood levels have on occasion been quoted to more than 1 decimal place in the report in order to identify minor differences in values. For example, to demonstrate minor differences between peak heights reached by both historic and design floods and also minor differences in peak flood levels which will result from, for example, a partial blockage of hydraulic structures. It is not intended to infer a greater level of accuracy than is possible in hydrologic and hydraulic modelling.

ABBREVIATIONS

AEP	Annual Exceedance Probability (%)
AHD	Australian Height Datum
ALS	Airborne Laser Scanning
AMC	Antecedent Moisture Condition
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval (years)
ARR	Australian Rainfall and Runoff (IEAust, 1998)
BOM	Bureau of Meteorology
DPIOW	NSW Department of Primary Industries Office of Water
DTM	Digital Terrain Model
FDM	Floodplain Development Manual (NSW Government, 2005)
FRMS&P	Floodplain Risk Management Study and Plan
GEV	General Extreme Value
GLC	Greater Lithgow Council
IFD	Intensity-Frequency-Duration
IFPA	Interim Flood Planning Area
IFPL	Interim Flood Planning Level
LCC	Lithgow City Council (formerly Greater Lithgow Council [GLC])
LFMS	Lithgow Floodplain Management Study
LFSR	Lithgow Flood Study Report
LGA	Local Government Area
LP3	log-Pearson Type 3
OEH	Office of Environment and Heritage, Department of Premier and Cabinet (formerly Department of Environment, Climate Change and Water [DECCW], formerly Water Resources Commission of NSW [WRC])
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RCP	Reinforced Concrete Pipe
RFS	Rural Fire Service
RMS	Roads and Maritime Services (formally Roads and Traffic Authority [RTA])
SES	State Emergency Service
SRTM	Shuttle Radar Topography Mission
SWC	Sydney Water Corporation

Chapter 8 of the report contains definitions of flood-related terms used in the study.

EXECUTIVE SUMMARY

Lyall & Associates was commissioned by Lithgow City Council (**LCC**) to undertake the *Lithgow Flood Study Review*. The primary objectives of the study were to:

- review and update the flood modelling which has been undertaken for the Farmers Creek catchment;
- develop a similar set of flood models for the adjacent Marrangaroo Creek catchment; and
- define the nature of major overland flow and main stream flooding in both the urbanised and future growth areas of Lithgow.

An extensive data collection and review process was undertaken as part of the study. This included a review of LCC's stormwater database, survey of critical hydraulic structures in the study area, the collation of historic rainfall and stream gauge data for significant historic storm events and review of previous studies including the *Lithgow Flood Study* (DWR, 1988) and the *Lithgow Floodplain Management Study* (Kinhill, 1991). The data collection also included the distribution of approximately 200 Newsletters and Questionnaires to flood prone properties, with a total of 26 responses received by the closing date for submissions.

Flood behaviour was defined using a computer based hydrologic model of the catchments to generate flood flows and a hydraulic model of the stream channels and floodplains to convert flows into peak flood levels, flow patterns and extents of inundation.

The hydrologic model was calibrated using rainfall and stream flow data which are available for storms that occurred in August 1986, February 1990, January 2011 and February 2013. A reasonable fit was achieved with flow data recorded by the NSW Department of Primary Industries Office of Water's Farmers Creek at Mount Walker stream gauge (GS 212042) for the four historic events. Due to the limited availability of historic flood level data at Lithgow, the hydraulic model was only calibrated using data recorded during the February 1990 and February 2013 storms in the Farmers Creek catchment. A good fit was achieved between the hydraulic model results and the available historic flood record.

The study provides information on the present day flooding patterns for flood frequencies ranging between 5 and 200 year Average Recurrence Interval (**ARI**), as well as for the Probable Maximum Flood. The study also defines the provisional flood hazard and hydraulic categories for the 100 year ARI event. An Interim Flood Planning Area for Lithgow has also been derived as part of the present investigation, based on a set of Interim Flood Planning Levels which were set equal to the peak 100 year ARI flood level plus an allowance of 500 mm for freeboard.

The flooding patterns in the study area are based on ground level data which has an accuracy of about 100 to 150 mm and sampled on a 3 m grid. Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding patterns in individual allotments. Site survey would be required to confirm the degree of flood affectation or otherwise of individual allotments.

The outcomes of this study will form the basis for the preparation of the future Floodplain Risk Management Study and Plan for Lithgow.

The **Summary** over page provides a more detailed description of the study methodology and key findings.

SUMMARY

S.1 Study Objective

The study objective was to review and update the hydrologic and hydraulic modelling for the Farmers Creek catchment to define both overland flow and main stream flooding patterns in the urbanised parts of Lithgow for flood frequencies ranging between 5 and 200 year Average Recurrence Interval (**ARI**), as well as for the Probable Maximum Flood (**PMF**). A requirement to provide similar information in future growth areas lead to the development of new hydrologic and hydraulic models for the adjacent catchment of Marrangaroo Creek. The extent of the area in which both overland flow and main stream flooding patterns have been defined is shown on **Figure S1**.

The information presented in this report will form the basis for the preparation of the future *Floodplain Risk Management Study and Plan* (***FRMS&P***) for Lithgow. The *FRMS&P* will assess the economic impact of flooding on existing urban development, review options for flood mitigation and prepare a Plan of works and measures for managing the present and future flood risk in Lithgow.

S.2 Background Information

Lithgow is located 140 km west of Sydney on the leeward (western) side of the Great Dividing Range. The urban centre of Lithgow is situated in the headwaters of Farmers Creek, a tributary of the Coxs River. Farmers Creek has a catchment area of 67 km^2 at the location of a NSW Department of Primary Industries Office of Water (**DPIOW**) operated stream gauge which is located on the main arm of the creek a short distance downstream of Lithgow (**Farmers Creek at Mount Walker – GS 212042**).

The main arm of Farmers Creek has been modified over the past century, initially to repair a collapsed section of the creek and more recently to increase its hydraulic capacity. Lithgow City Council (**LCC**) is presently in the process of constructing channel improvement works which were identified as part of the Lithgow Floodplain Management Study (Kinhill, 1991). The channel improvement works, the extent of which are shown on **Figure 2.2**, **Sheet 2** are principally aimed at reducing flood damages on the northern (right) overbank area of the creek in the Hermitage Flat area. Construction of the channel improvement works has been split into four primary stages. Stages 1A and 1B were completed in 2006 and 2008, respectively, while work on Stage 2 was completed in 2015.

The Marrangaroo Creek catchment lies to the north of Lithgow and has a catchment area of about 54 km^2 at its confluence with the Coxs River. Development within the catchment is predominately rural residential in nature. The Lithgow Correctional Centre is located adjacent to the main arm of the creek immediately upstream of the Great Western Highway and Main Western Railway bridges (refer **Figure 2.2**, **Sheet 4**).

A key feature of the Farmers Creek and Marrangaroo Creek catchments are their steep heavily wooded upper reaches. Rainfall-runoff response times from these parts of the catchments are typically short, resulting in flash flooding in parts of Lithgow. These areas have also historically been the source of high debris loads, especially when heavy rain occurs following a bushfire event.

A Community Newsletter and Questionnaire was distributed to about 200 residents in known flood prone areas, with about 26 responses received by the closing date of submissions. A copy of the Community Newsletter and Questionnaire is contained in **Appendix A** of this report. Of those that responded, only 11 noted that they had observed flooding in or adjacent to their property.

While damaging flooding has been experienced in Lithgow dating back to 1928, flood level data is generally limited to storms that occurred in February 1990 and February 2013. There are no pluviographic rainfall stations located in either the Farmers Creek or Marrangaroo Creek catchments to enable the temporal variability of historic storm activity to be accurately derived. **Appendix B** contains details of the data that were available for the *Flood Study*. Several plates showing observed flooding in Lithgow during the February 1990 and February 2013 storms are contained in **Appendices C** and **D**, respectively. **Appendix E** contains a list of historic peak height and discharge data for DPIOW's Mount Walker stream gauge.

An annual series flood frequency relationship for DPIOW's Mount Walker stream gauge was derived using the available 33 years of data. While the 100 year ARI peak flow estimate for Farmers Creek at the stream gauge compared closely with that adopted in Kinhill, 1991, peak flows for higher frequency storm events were found to be lower than were adopted by this (and subsequent) studies. The reason for this is attributed to the previous study adopting a zero initial and continuing loss model which tends to overestimate flows in the drainage system for the more frequent storm events. **Table S1** gives a comparison of peak flows on Farmers Creek at the gauge site.

TABLE S1
COMPARSION OF PEAK FLOWS
(m^3/s)

Flood Frequency (year ARI)	Kinhill, 1991	Present Investigation			
		Annual Series Flood Frequency Relationships(1)		Lumped Farmers Creek Hydrologic Model	Farmers Creek TUFLOW Model
		LP3 Distribution	GEV Distribution		
5	189	80	82	125	113
100	347	320	263	372	330
200	357	445	324	418	370

1. Peak flows taken from relationship which was derived by omitting low flows. Refer **Section 2.4.2** for details.

S.3 Development and Calibration of Flood Models

Flood behaviour was defined using a computer based hydrologic model of the catchments to generate flood flows and a hydraulic model of the stream channels and floodplains to convert flows into peak flood levels, flow patterns and extents of inundation.

The hydrologic model used a rainfall-runoff routing approach based on the RAFTS software to determine the discharge hydrographs from the rural parts of the catchment, and incorporated a ILSAX sub-model to assess flows generated in the urban areas. The layout of the hydrologic model is shown on **Figure 3.1**.

A network hydraulic model was adopted to model the passage of flows in the main streams and overland flow paths. A two-dimensional (in plan) model was chosen based on the TUFLOW software, which allowed for the interaction of flows between the channels and the floodplain, flow through culverts and flow over control structures such as weirs and road embankments. TUFLOW also routed flows through the urban piped and open channel trunk stormwater system and modelled the passage of overland flow over the natural surface. The extent of the hydraulic model is shown dashed in **Figures 4.1**.

In addition to LiDAR (Light Detection and Ranging) survey of the study area field surveys of the creeks and the stormwater drainage system were undertaken to provide topographic data for the development of the TUFLOW hydraulic model.

A lumped version of the hydrologic model which was developed for the Farmers Creek catchment (**Lumped Farmers Creek Hydrologic Model**) was calibrated using rainfall and stream flow data which is available for storms that occurred in August 1986, February 1990, January 2011 and February 2013. A reasonable comparison was achieved with flow data recorded by DPIOW's stream gauge for the four historic events (refer **Figure 2.3**).

Due to the limited availability of historic flood level data, the TUFLOW model that was developed for the Farmers Creek catchment (**Farmers Creek TUFLOW Model**) was only calibrated using data recorded during the February 1990 and February 2013 storms. **Figures 4.3** and **4.4** show the TUFLOW model results for the February 1990 and February 2013 storms, respectively. **Table 4.4** gives a comparison of modelled flood levels versus those recorded during the February 1990 storm, while **Table 4.5** gives a comparison of observed versus modelled flood behaviour for the February 2013 storm.

The hydrologic and hydraulic model parameters that were found to give a reasonable fit to recorded flood data were adopted for defining main stream flooding and overland flow patterns in both the Farmers Creek and Marrangaroo Creek catchments over the full range of design storm events.

S.4 Design Flood Estimation

Figures 6.1 to **6.6** show the TUFLOW model results for the 5, 10, 50, 100 and 200 year ARI floods, together with the PMF. These diagrams show the indicative extents of inundation along the major watercourses, as well as the local overland flow in the urbanised parts of Lithgow.

Table F1 in **Appendix F** gives peak design flows at selected locations throughout the study area, while **Table G1** in **Appendix G** contains information in relation to the inundation of existing road and pedestrian crossings at Lithgow

Design water surface profiles along Farmers Creek and its major tributaries, as well as for the main arm of Marrangaroo Creek are shown on **Figure 6.7**. **Figure 6.8** shows stage and discharge hydrographs at selected locations throughout the study area.

Flooding in Lithgow is generally confined to the inbank area of Farmers Creek and its major tributaries up to about the 10 year ARI level. However, several properties located along Coalbrook Street in Hermitage Flat and Lockyer Street, Bowenfels were found to be affected at the 5 year ARI level.

Existing development in the Marrangaroo Creek catchment is generally not affected by main stream flooding with the exception of two rural residential properties that are located on the northern (downstream) side of Reserve Road and the Lithgow Correctional Centre, all of which are affected by depths of flow greater than 100 mm at the 50 year ARI level.

Several residential properties located to the south of the Main Western Railway line in the Farmers Creek catchment and to the south of the Lithgow Golf Club in the Marrangaroo Creek catchment are affected by major overland flow. These properties are affected by depths of overland flow exceeding 300 mm at the 100 year ARI level, principally due to surcharge of the local stormwater drainage system.

The road and pedestrians crossing located in the study area will generally remain flood free for flood events up to about 50 year ARI, with the following exceptions:

- The Mills Street and Geordie Street causeways on Farmers Creek, both of which will be inundated during freshes in the creek system.
- The Victoria Avenue crossing of Farmers Creek, which will be overtopped during a 50 year ARI flood event. Flooding of the road at this location will result in the isolation of the residents of Oakey Park.
- The Reserve Road crossing of two unnamed tributaries of Marrangaroo Creek. The road will be overtopped during storms as frequent as 5 year ARI, resulting in the isolation of several rural residential properties.

It is noted that the State Mine Gully Road crossing of State Mine Creek will be overtopped during a 100 year ARI storm event, isolating the residents of Morts Estate.

Diagrams showing the *provisional flood hazard* and *hydraulic categorisation* of the floodplain for the 100 year ARI flood are shown on **Figures 6.9** and **6.10**.

The *provisional flood hazard* is dependent on the depth and velocity of flow in the channels and the floodplains. The floodplain is divided into High and Low Hazard areas on the basis of those two variables. The *provisional flood hazard* diagrams will be reviewed in the *FRMS&P* and converted into a *final* determination of hazard based on a number of additional factors such as rate of rise of floodwaters and difficulties associated with evacuation from the floodplain.

The *hydraulic categorisation* requires the assessment of the main flow paths. Those areas of the floodplain where a significant discharge of water occurs during floods are denoted *Floodways* and are often aligned with naturally defined channels. *Floodways* are areas that, even if only partially blocked, would cause a significant re-distribution of flood flow or a significant increase in flood levels. The remainder of the floodplain is denoted *Flood Storage* or *Flood Fringe* areas.

The main arm of Farmers Creek upstream of the Sandford Avenue road bridge is incised and of relatively high hydraulic capacity. The major tributaries of Farmers Creek are similarly incised and of relatively high hydraulic capacity. As a result, the majority of the area affected by main stream flooding in a 100 year ARI event functions as a floodway. However, the hydraulic capacity of Farmers Creek reduces downstream of the Sandford Avenue road bridge, with the result that areas which lie on its overbank also function as a floodway during a 100 year ARI event. The areas of “flood storage” are confined to the major ponding areas which are located on the southern (upstream) side of the Main Western Railway line and also within the detention basins that have been constructed to control runoff in several parts of Lithgow.

In the Marrangaroo Creek catchment, the flood fringe areas are more pronounced given the flatter nature of the overbank area, especially on the portion of the floodplain which lies to the north of Reserve Road.

S.5 Sensitivity Analyses

Analyses were undertaken to test the sensitivity of flood behaviour to:

a. An increase in hydraulic roughness. **Figure 6.11** shows the effects a 20 per cent increase in the adopted 'best estimate' hydraulic roughness values would have on flooding behaviour at the 100 year ARI level.
b. A partial blockage of major hydraulic structures by debris. **Figure 6.12** shows the effects a partial blockage of both bridges and major culvert structures would have on flooding behaviour at the 100 year ARI level.
c. Increases in rainfall intensity associated with future climate change. **Figures 6.13**, **6.14** and **6.15** show the effects a 10 and 30 per cent increase in design 100 year ARI rainfall intensities would have on flooding behaviour.

The analyses showed that peak 100 year ARI flood levels could be increased by up to 500 mm as a result of changes in hydraulic roughness or increases in rainfall intensity, while increases of greater than 500 mm would occur were certain hydraulic structures to experience a partial blockage by debris during a major storm event. The analyses also showed that the extent of flooding does not increase significantly for the case where the intensity of a 100 year ARI storm event is increased by 30 per cent (refer **Figure 6.15**).

S.6 Interim Flood Planning Area and Levels

An *Interim Flood Planning Area* (***IFPA***) for Lithgow (refer **Figure 6.16** for extent) has been derived as part of the present investigation for areas subject to both main stream flooding and major overland flow. The *IFPA* for Lithgow is based on a set of *Interim Flood Planning Levels* (***IFPL's***) which were set equal to the peak 100 year ARI flood level plus an allowance of 500 mm for freeboard. The *IFPA* was defined from the LiDAR survey of the study area, which has an accuracy of about 100 to 150 mm. The extent shown is therefore indicative. Site survey would be required to confirm the degree of flood affectation or otherwise of individual allotments.

Consideration will need to be given during the preparation of the future *FRMS&P* to the setting of an appropriate freeboard for areas subject to major overland flow, given that the adopted value of 500 mm may be found to be too conservative. The adoption of an allotment based approach to the identification of individual properties subject to major overland flow related planning controls should also be considered.

1 INTRODUCTION

1.1 Study Background

This report presents the findings of an investigation of flooding in the Farmers Creek and Marrangaroo Creek catchments at Lithgow and has been jointly sponsored by Lithgow City Council (**LCC**) and the NSW Government, via the Office of Environment and Heritage (**OEH**). **Figure 1.1** shows the location of Lithgow on the western draining slopes of the Great Dividing Range in the Farmers Creek catchment.

The study objective was to define flood behaviour in terms of flows, water levels and flooding patterns for floods ranging between 5 and 200 year average recurrence interval (**ARI**), as well as for the Probable Maximum Flood (**PMF**) and to compare the study findings to those of previous investigations. The present investigation involved rainfall-runoff hydrologic modelling of the catchments and drainage systems to assess flows in both Farmers Creek and Marrangaroo Creek, and application of these flows to a hydraulic model to assess peak water levels and flow patterns. The model results were interpreted to present a detailed picture of flooding under present day conditions.

The scope of the study included investigation of main stream flood behaviour along Farmers Creek and its major tributaries, as well as overland flooding which occurs as a result of surcharges of the local drainage system in Lithgow. Main stream flooding behaviour along Marrangaroo Creek and several of its tributaries was also investigated.

The study forms the first step in the floodplain risk management process for Lithgow (refer process diagram presented in the Foreword), and is a precursor of the future *Floodplain Risk Management Study and Plan* (***FRMS&P***) which will consider the impacts of flooding on existing and future urban development, as well as potential flood mitigation measures.

1.2 Community Consultation and Available Data

To assist with data collection and promotion of the study to the Lithgow community, a Community Newsletter and Questionnaire was distributed by LCC in December 2013 to residents in known flood prone areas adjacent to Farmers Creek inviting them to provide information on historic flooding. A copy of the Community Newsletter and Questionnaire which was prepared by the Consultants is attached in **Appendix A** of this report. Public information days were also held in early December 2013 in the Cook Street and Lithgow Valley plazas.

LCC advised that approximately 200 Newsletters and Questionnaires were distributed, with a total of 26 responses received (a response rate of around 13 per cent). Of those that responded, only 11 noted that they had observed flooding in or adjacent to their property. Information on historic flooding patterns obtained from the responses assisted with "ground-truthing" the results of the hydraulic modelling.

The draft *Flood Study Review* report was placed on public exhibition between 9 January 2017 and 10 March 2017, with only two submissions received by the closing date. A review of the submissions resulted in minor amendments to locations referenced in the report. The findings of the study were also presented at two community workshops which were held at Council chambers on 6 and 7 March 2017.

Appendix B contains details of the data that were available for the present study, while **Appendices C** and **D** contain several plates which show historic flooding behaviour in Lithgow during storms that occurred in February 1990 and February 2013, respectively.

1.3 Approach to Flood Modelling

1.3.1. Hydrologic and Hydraulic Modelling

Flood behaviour was defined using a two-staged approach to flood modelling involving the running in series of:

1. The hydrologic models of the study catchments and the urbanised parts of Lithgow, based on the RAFTS and ILSAX rainfall-runoff sub-models, respectively, both of which are contained within the DRAINS software.
2. The hydraulic model of the study creeks and the stormwater drainage system in Lithgow based on the TUFLOW software.

The RAFTS and ILSAX sub-models computed discharge hydrographs, which were then applied to the TUFLOW hydraulic model at relevant sub-catchment outlets.

The TUFLOW model used a two-dimensional (in plan) grid-based representation of the natural surface based on an Airborne Laser Scanning (**ALS**) survey of Lithgow, as well as piped drainage data provided by LCC. Field survey was used to derive cross sections (normal to the direction of flow) along the inbank area of Farmers Creek, State Mine Creek and Vale of Clwydd. Field survey was also used to confirm details of the hydraulic structures crossing the major watercourses in the study area.

1.3.2. Model Calibration

Streamflow data are available for Farmers Creek at Lithgow via the Department of Primary Industries - Office of Water's (**DPIOW's**) Mount Walker stream gauge (GS 212042), which is located about 7 km (by creek) downstream of the Great Western Highway crossing and has been in operation since September 1980. As a result, it was possible to formally "calibrate" the RAFTS hydrologic model to reproduce discharges recorded by the stream gauge for a number of historic storm events.

Flood marks are available at Lithgow for the flood that occurred in February 1990 (Kinhill, 1991). Anecdotal evidence is also available on the extent to which floodwater reached during a storm that occurred in February 2013.

In regards the calibration of the RAFTS rainfall-runoff model that was developed for the Farmers Creek catchment, a reasonable fit was achieved to the discharge hydrographs that were recorded by the Mount Walker stream gauge for the storms that occurred in August 1986, February 1990, January 2011 and February 2013 (refer **Chapter 3** for details).

In regards the calibration of the hydraulic model that was developed for Farmers Creek, a reasonable fit was achieved to flood marks which are available for the storm that occurred in February 1990 and to anecdotal evidence that is available for the storm that occurred February 2013 (refer **Chapter 4** for details).

1.3.3. Design Flood Estimation

Design storms were derived using procedures set out in *Australian Rainfall and Runoff* (**ARR**) (IEAust, 1998) and then applied to the RAFTS and ILSAX sub-models in DRAINS to generate discharge hydrographs. These hydrographs constituted input to the TUFLOW hydraulic model.

An “envelope” approach was adopted for defining design water surface elevations and flow patterns throughout the study area. The procedure involved running the model for a range of storm durations to define the upper limit (i.e. the envelope) of expected flooding for each design flood frequency.

1.4 Layout of Report

Chapter 2 contains background information including a brief description of the Farmers Creek and Marrangaroo Creek catchments and their drainage systems, details of previous flooding investigations and a brief history of flooding at Lithgow.

Chapter 3 deals with the hydrology of the Farmers Creek and Marrangaroo Creek catchments, and describes the development and calibration of the RAFTS and ILSAX hydrologic models which were used to generate discharge hydrographs for input to the hydraulic model.

Chapter 4 deals with the development and calibration of the TUFLOW hydraulic model which was used to analyse flood behaviour at Lithgow.

Chapter 5 deals with the derivation of design discharge hydrographs, which involved the determination of design storm rainfall depths over the catchments for a range of storm durations and conversion of the rainfalls to discharge hydrographs.

Chapter 6 details the results of the hydraulic modelling of the design floods. Results are presented as water surface profiles and plans showing indicative extents and depths of inundation for a range of design flood events up to the PMF. A provisional assessment of flood hazard and hydraulic categorisation is also presented. (The assessment of flood hazard according to velocity and depth of floodwaters is necessarily *“provisional”*, pending a more detailed assessment which includes other flood related criteria, to be undertaken during the future *Floodplain Risk Management Study* (***FRMS***) The results of various sensitivity studies undertaken using the TUFLOW model are also presented, including the effects of changes in hydraulic roughness, a partial blockage of major hydraulic structures, including the piped stormwater system, and potential increases in rainfall intensities due to future climate change. This chapter also deals with the selection of *Interim Flood Planning Levels* and the *Interim Flood Planning Area* for the study area.

Chapter 7 contains a list of references, whilst **Chapter 8** contains a list of flood-related terminology that is relevant to the scope of the study.

Appendix A contains a copy of the Community Newsletter and Questionnaire that was distributed to residents in known flood affected areas of Lithgow, while **Appendix B** contains a description of available data. **Appendices C** and **D** contain several plates which show historic flooding behaviour in Lithgow during storms that occurred in February 1990 and February 2013, respectively. **Appendix E** contains a list of historic peak height and discharge data for DPIOW’s Mount Walker stream gauge. **Appendix F** contains a table of peak flows taken from the TUFLOW model. **Appendix G** contains maximum depths of inundation, time to overtopping and duration of inundation data derived from the hydraulic modelling at the major road and pedestrian crossings which are located in the study area.

Figures referred to in the main report are bound in a separate volume of the report (refer **Volume 2**).

2 BACKGROUND INFORMATION

2.1 Study Catchments

2.1.1. Farmers Creek

The Lithgow City Local Government Area (**LGA**) has a population of about 20,000 and is located 140 km west of Sydney on the Great Western Highway. The urban centre of Lithgow is located on Farmers Creek, which has a catchment area of about 67 km^2 at DPIOW's Mount Walker stream gauge. **Figure 2.1** shows the extent of the catchment which contributes to flow in Farmers Creek at the location of the stream gauge.

The headwaters of the Farmers Creek catchment are located about 7 km east of Lithgow in the Newnes State Forest. The catchment is characterised by a mixture of heavily wooded areas on the steeper slopes and cleared pastoral land on the milder, more undulating western draining slopes of the Great Dividing Range. The urbanised parts of Lithgow are located at the base of the steeper heavily wooded slopes, extending onto the floodplain of Farmers Creek and its major tributaries.

Farmers Creek runs in a westerly direction through the urbanised parts of Lithgow with various tributaries contributing flows to the system from the north and south. Ida Falls Creek, Vale of Clwydd Creek, Good Luck Hollow and two unnamed tributary (herein referred to as Sheedys Gully Tributary and South Bowenfels Tributary) join Farmers Creek from the south, while Oakey Park Creek, State Mine Creek and another unnamed tributary (herein referred to as McKellars Park Tributary) join from the north.

Farmers Creek continues to flow in a westerly direction downstream of Lithgow where it discharges into Lake Lyell on the Coxs River. The Coxs River forms parts of the Hawkesbury-Nepean River system and is one of the major sources of inflows to Warragamba Dam.

In the 1930s the Department of Public Works (**PWD**) undertook major stream improvement works along Farmers Creek in response to severe flooding that occurred in 1928 which broke through the roof of the Cobar Colliery (DWR, 1988). The invert of the creek was concrete lined and realigned over a distance of about 2.5 km, extending from a location 260 m downstream of Tank Street to the Geordie Street low level causeway. **Figure 2.2**, **Sheet 2** shows the extent of channel which was concrete lined, as well as the location where the colliery roof collapsed. The initial 250 m length of concrete lined channel ranges between 11 - 15 m in width and is up to 2.5 m deep. This section of channel formed the repair over the collapsed section of colliery roof. The remaining 2.25 km length of concrete lined channel ranges between 4.8 - 6.1 m in width and is up to 1.4 m deep.

In addition to the lining of the channel, the floodplain of Farmers Creek has been modified over time by the importing of fill to construct railway embankments, sporting fields and residential development.

Investigations undertaken in the 1990s found that about 230 residences and 12 businesses would be flooded above floor level at the 100 year ARI level of flooding. About half of these properties were found to be located in Hermitage Flat. Channel works along a 1040 m length of Farmers Creek aimed at reducing the impact of flooding on properties located in this area were identified in a study which was undertaken in the early 2000s (Bewsher, 2001). The channel works were divided into four stages, the extents of which are shown on **Figure 2.2**, **Sheet 2**.

The first stage of the channel works, which involved enlarging of the waterway along a 350 m reach of Farmers Creek, was split into two works packages (denoted **Stage 1A** and **1B** by LCC). Construction of the Stage 1A and 1B works were completed in 2006 and 2008, respectively. Construction of the Stage 2 works, which involved enlarging of the waterway under the Albert Street Bridge and along a 380 m reach of Farmers Creek was completed in 2015.

A stormwater drainage system comprising a pit and pipe network controls runoff from the urbanised parts of Lithgow, the layout of which is shown on **Figure 2.2**, **Sheets 1** to **4**. The stormwater drainage system at Lithgow can be characterised as follows:

- **Northern side of Farmers Creek** - Runoff from the urbanised areas Oakey Park, Morts Estate, State Mine Gully, Cobar Park, McKellars Park and Hermitage Flat are controlled by a series of stormwater drainage lines that discharge into semi-natural reaches of channel that flow into Farmers Creek. Major tributaries on the northern side of Farmers Creek include Oakey Park Creek, State Mine Creek and McKellars Park Tributary.
- **Southern side of Farmers Creek east of the Great Western Highway** - Runoff from the urbanised areas of Corney Town, Vale of Clwydd, Lithgow, Pottery Estate and Littleton is controlled by a series of stormwater drainage lines that run in a northerly direction and discharge into Farmers Creek. The Main Western Railway bisects this area in an east-west direction and has an impact on local drainage patterns. Major tributaries on the southern side of Farmers Creek include Ida Falls Creek, Vale of Clwydd and Sheedys Gully Tributary.
- **Southern side of Farmers Creek west of the Great Western Highway** - Runoff from the urbanised areas in Bowenfels, South Littleton and South Bowenfels are controlled by a series of stormwater drainage lines that run in either a westerly or northerly direction to their point of discharge into Farmers Creek. A number of small stormwater detention basins have also been built in this area as part of several recent residential subdivision developments (refer **Figure 2.2**, **Sheets 2** and **3** for locations). Good Luck Hollow and South Bowenfels Tributary are the major tributaries west of the Great Western Highway

Commercial development in Lithgow is concentrated along the Main Western Railway between the Great Western Highway and Chifley Road on its southern side and Union Street and James Street on its northern side. Light industrial development is concentrated on both sides of the Vale of Clwydd near its confluence with Farmers Creek and also on the southern side of Farmers Creek in the following three areas:

- immediately upstream of the Lithgow State Mine Railway line;
- along Donald Street between Inch Street and Union Street; and
- downstream of Tony Luchetti Sports Centre.[1]

A large parcel of land which is zoned *IN1 – Industrial General* is located to the south of Farmers Creek and the Main Western Railway in the suburb for Littleton. Runoff from the IN1 zoned land is controlled by a relatively large stormwater detention basin which is located on the eastern side of Finlay Avenue (refer **Figure 2.2**, **Sheet 2** for location).

[1] A small parcel of land zoned *IN2- Light Industrial* is also located on the northern side of Farmers Creek immediately downstream of the sports centre.

2.1.2. Marrangaroo Creek

Similar to the Farmers Creek catchment, the Marrangaroo Creek catchment comprises a mixture of heavily wooded areas in its steeper upper reaches and cleared pastoral land in its flatter middle reaches. While the network of channels in the middle reaches of the catchment have generally been cleared for farming purposes, a riparian corridor has been maintained along the main arm of the creek.

Both the Main Western Railway and Great Western Highway run in a north-south direction through the catchment and cross the main arm of the creek via multiple span bridge structures (refer **Figure 2.2**, **Sheet 4** for location). The catchment area of Marrangaroo Creek at the Great Western Highway is about 48 km^2. Reserve Road, which runs to the east of the Great Western Highway, is the only other formal road crossing of the channel system in the catchment.

Marrangaroo Creek flows generally in a south-westerly direction downstream of the road and rail bridges where it runs through a steep heavily wooded area before joining the Coxs River. The catchment area of Marrangaroo Creek at its confluence with the Coxs River is about 54 km^2.

Runoff from a residential subdivision which is located on the western side of the Main Western Railway Line in the southern portion of the catchment drains across the rail corridor and the Great Western Highway via a series of piped transverse drainage structures (refer **Figure 2.2**, **Sheet 4** for location). Runoff from the residential subdivision contributes to flow in the main arm of the creek at the aforementioned road and rail bridges. Apart from a number of rural residential properties, the only other major development in the catchment is the Lithgow Correctional Services Centre, which is located on the eastern (upstream) side of the highway and rail corridors on the northern overbank area of the creek (refer **Figure 2.2**, **Sheet 4** for location).

2.1.3. Future Growth Areas

LCC has identified 22 km^2 of rural land west of Lithgow where urban development could be expanded in the future. The extent of the future growth area, which spans both the Farmers Creek and Marrangaroo Creek catchments is shown on **Figure 2.1**. It is noted that the southern portion of the future growth area extends into the upper reaches of the Bowens Creek catchment, a minor tributary of the Coxs River.

2.2 Previous Investigations

2.2.1. Lithgow Flood Study Report (DWR, 1988)

The then Department of Water Resources (**DWR**) (now OEH) undertook the Lithgow Flood Study in the late 1980s (DWR, 1988). Prior to this study being undertaken, two relatively large flood events had occurred in March 1978 and August 1986. While DWR, 1988 used several surveyed flood marks to calibrate a hydraulic model, only minimal rainfall and stream flow data were available for calibration of the hydrologic model.

Design flood flows for the Farmers Creek catchment were calculated using the RAFTS rainfall-runoff model. Design rainfalls were taken from the draft of ARR, 1987, while the design temporal patterns were taken from the 1977 edition of ARR. An initial loss value of 10 mm and a continuing loss rate of 0.5 mm/hr were applied to design rainfalls to derive rainfall excess values. **Table 6.1** in **Chapter 6** [refer column E] gives peak 100 year ARI flows that were derived as part of the DWR study.

Cross-sections normal to the direction of flow were surveyed along the reach of Farmers Creek which runs between Oakey Park and Good Luck Hollow. The HEC-2 one-dimensional steady state hydraulic modelling software was used to convert peak flows to peak flood levels and average stream flow velocities. While a reasonable fit was achieved to flood level data that were captured for the March 1978 storm event, DWR, 1988 notes that the hydraulic model could not reproduce the flood level data which were captured for the August 1986 storm event.

2.2.2. Lithgow Floodplain Management Study (Kinhill, 1991)

The Lithgow Floodplain Management Study was undertaken by Kinhill Engineers Pty Ltd in 1991 for the then DWR and Greater Lithgow Council (**GLC**) (now LCC). The aim of the study was to update the hydrologic and hydraulic models that were developed as part of DWR, 1988, as well as present a range of floodplain management options for Lithgow.

The RAFTS rainfall-runoff model developed as part of DWR, 1988 was updated by incorporating the design rainfalls and temporal patterns from ARR 1987. The initial loss value and continuous loss rate in the model were also reduced to zero. **Table 6.1** in **Chapter 6** [refer columns F to I] sets out peak flows that were derived as part of the Kinhill study. The HEC-2 one-dimensional steady state hydraulic model was also updated to include the Great Western Highway road bridges. A flood damages database was developed to quantify the impacts and costs of flooding to the Lithgow community. The community was engaged via a community questionnaire to gauge opinion about flooding issues and possible floodplain management options.

The study found that about 230 houses and 12 businesses would be flooded above floor level at the 100 year ARI level of flooding, the damage bill for which was estimated to be between $6-10 million. The damage bill for a 5 year ARI flood was estimated to be more than $2 million. The cost to protect all properties in Lithgow up to the 100 year ARI flood was estimated to be cost $23.5 million.

About half the flood affected residential properties in Lithgow are located in Hermitage Flat. The recommended flood mitigation works for this area involved the widening and lining of Farmers Creek, as well as the lowering of the playing fields in Watsford Oval, Conran Oval and Glanmire Sportsground to assist in diverting floodwaters away from developed areas. The cost for these works was estimated to be $10.4 million.[2]

2.2.3. 1991 to Present

Following completion of Kinhill, 1991, GLC received sufficient funding to examine a range of flood mitigation options for Hermitage Flat. The following studies were undertaken to refine the mitigation options and examine the viability of the measures:

- *"An Assessment of Vegetation in the Riparian Zones of Farmers Creek, Lithgow, NSW"* (Slaven, 1995)
- *"Flood Mitigation Works – Hermitage Flat, Lithgow – Stage 1 Report – Detailed Analysis of Flood Mitigation Options"* (Bewsher, 1996)
- *"Flood Mitigation Works – Hermitage Flat, Lithgow – Options Assessment"* (Bewsher, 2001)
- *"Flood Mitigation Works – Hermitage Flat, Lithgow – Review of Environmental Factors"* (Bewsher, 2002)
- *"Flood Mitigation Works – Hermitage Flat, Lithgow – Environmental Documentation and Approvals"* (Bewsher, 2003)

[2] As quoted in Bewsher, 2001. All amounts are in year 2000 dollars.

The options assessment process determined the most viable flood mitigation measure for the Hermitage Flat area of Lithgow was the widening of a 1040 m length of existing concrete lined channel between Sandford Avenue and the Geordie Street low level causeway, the construction of which was to be undertaken in four stages (referred to in Bewsher, 2001 as the "*Option A"* flood mitigation measures).

Implementation of the *Option A* flood mitigation measures once completed would reduce the average depth of above-floor inundation at the 100 year ARI level of flooding by 0.6 m and at the 20 year ARI level by 0.5 m. In a 100 year ARI flood event, 82 of the 127 affected houses would be protected from above-floor inundation, while at the 20 year ARI level there would be only nine houses still flooded above floor level.

Note that the abovementioned studies relied upon the peak flows generated by the RAFTS model that was developed as part of Kinhill, 1991.

2.3 Flood History and Analysis of Historic Rainfall

2.3.1. General

Flooding in the urbanised parts of Lithgow is of a flash flooding nature, with flows in the creek system generally reaching their peak in less than an hour following the commencement of heavy rain. The duration of flooding is also fairly short, generally lasting less than a few hours. The hydrologic response of the Farmers Creek catchment is sensitive to the depth of lead rainfall experienced in the catchment prior to the onset of heavy rain. For example, DWR, 1988 found that if greater than 100 mm of rainfall falls in 3 day period or less, then the probability of flooding occurring from any additional rainfall in Lithgow is increased.

There have been seven storm events that are known to have caused major flooding in Lithgow. These occurred in February 1928, June 1963, June 1964, March 1978, August 1986 and February 1990. **Table 2.1** over page is taken from Kinhill, 1991 and gives a brief summary of the storms that occurred prior to the February 1990 event, while **Table 2.2** over page provides a comparison of the height water levels reached at several locations along Farmers Creek during the March 1978, August 1986 and February 1990 storm events.

The March 1978 event produced the highest flood levels of the three storm events, followed by February 1990 and August 1986 events. At the Mount Walker stream gauge, the peak level recorded in the August 1986 event (2.306 m) was higher than the February 1990 event (2.04 m), indicating that heavy rain probably fell in the lower reaches of the catchment (i.e. downstream of the location of the surveyed flood marks) which resulted in the higher gauge reading.

A number of storm events that have caused localised flooding in parts of Lithgow were also identified as part of the present investigation. These occurred in 1981, 1985, 1996, 1997, 2004, and more recently in January 2011 and February 2013. While only anecdotal evidence is available on the extent and depth that property was inundated during these storm events, flooding in the Hermitage Flat area during the two most recent storm events is reported to have been a result of surcharge of the local stormwater drainage system.

TABLE 2.1
SUMMARY OF MAJOR STORM EVENTS
PRE- FEBRUARY 1990 STORM

Date	Description
February 1928	*This was the first severe flood in Lithgow and caused widespread damage. The flood broke through the roof of the Cobar Colliery in the vicinity of Sandford Avenue. One person was killed.*
June 1963	*Roads were cut*
June 1964	*Roads were cut. Again flood water broke through the roof of the Cobar Colliery in the vicinity of Sandford Avenue*
March 1978	*This approximately 7% AEP flood event was used as a calibration for the DWR, 1988 report. It caused widespread damage to cars, houses and roads, and caused landslides. Health risks rose through the overflow of sewers.*
August 1986	*This 10-20% AEP flood event was not as extensive as the March 1978 event. However, it caused widespread damage and one person was killed. This flood was used as a calibration event for the DWR report.*

Reproduced from Table 2.1 of Kinhill, 1991.

TABLE 2.2
COMPARISON OF HISTORIC FLOOD LEVELS AT LITHGOW
(m AHD)

Location	March 1978(1)	August 1986(1)	February 1990(2)
Upstream of Atkinson Street	920.6	918.95	919.1 - 919.6
Guy Street	917.7	-	918
Upstream of Tank Street	915.47	914.88	-
Montague Street	914.54	-	913.7
Glanmire Oval	907.91	907.08	907.3 - 907.5
Upstream Albert Street Bridge	908.5	906.09	907.2
Coalbrook Street Lane	905.9 - 906.2	904.8	905.4 - 905.6
Mount Walker stream gauge(3,4,5)	-	2.306	2.04

1. Taken from Table 4.2 of DWR, 1988.
2. Taken from Table A.3 of Kinhill, 1991.
3. Mount Walker stream gauge installed in September 1980.
4. Levels at Mount Walker stream gauge (GS 212042) are recorded gauge heights in metres.
5. Note that the stream gauge was shifted upstream a short distance in September 2007 while the zero on the gauge, which is to an assumed datum, was maintained. Due to flood slope in Farmers Creek, direct comparison should not be made of recorded gauge heights with those in **Table 2.2** after this date.

Appendix E contains annual peak height and discharge data for DPIOW's Mount Walker stream gauge for the period 1981 to 2013, while **Table 2.3** on page 13 lists the ten largest floods to have been recorded by the gauge. It is noted that the August 1986 and February 1990 storm events are ranked third and sixth respectively in terms of the peak flow rate that was recorded by the stream gauge, whereas the storms that occurred in February 2013 and January 2011 are ranked first and second respectively.[3]

The higher recorded flow rates for the two recent storm events do not correlate with historic flooding in Lithgow, where greater flood damages were experienced during the two storms that occurred in 1986 and 1990. The explanation for the reduction in flood damages is probably due to the flood mitigation benefits that have been achieved through the construction of the Stage 1A and Stage 1B channel improvement works in combination with relative differences in the rate of flow in the tributary arms of Farmers Creek.

2.3.2. August 1986 Storm

As set out in **Table 2.1**, the August 1986 storm caused widespread damage in Lithgow and resulted in the death of one person. The left hand side (**LHS**) of **Figure 2.3**, **Sheet 1** shows the rainfall that was recorded to the north-east and south of the Farmers Creek catchment by the Bureau of Meteorology's (**BoM's**) Colo Heights (Mountain Pass) (GS 61211) and Katoomba (Murri Street) (GS 63039) pluviographic rain gauges on the rain days of 5, 6 and 7 August 1986.

The gauge data shows that steady rain fell over a 48 hour period commencing at 09:00 hours on 4 August 1986 over which period more than 500 mm of rain fell in the area. Flow in Farmers Creek at the location of the stream gauge responded to the rain which fell in the area at around 21:00 hours on 4 August 1986, rising to a peak of about 146 m^3/s[4] at about 07:00 hours on 6 August 1986, around the same time the intensity of the rainfall commenced to ease.

An analysis of the pluviographic data shows that the rainfall that fell to the south of Lithgow had an ARI of greater than 100 years (refer LHS of **Figure 2.4**, **Sheet 1**) for storm durations greater than 10 hours duration.[5] It is noted that a total of 310.4 mm was recorded by BoM's Lithgow (Birdwood Street) (GS 63224) rain gauge, indicating the period of heavy rainfall experienced over the Farmers Creek catchment was probably not as long as occurred to its south.

Adjustments were made to the pluviographic traces based on the relativity between the daily rainfall totals for the various gauges. The intensity-frequency-duration (**IFD**) curve of the adjusted rainfall suggests that the intensity of the rain which fell over the Farmers Creek catchment may have been anywhere between 5 and 100 year ARI for a storm of 9 hours duration which is critical for maximising flows in the main arm of Farmers Creek (refer dashed lines on LHS of **Figure 2.4**, **Sheet 1**).

[3] Based on the findings of DWR, 1988, the storm that occurred in March 1978 generated a peak flow at the gauge site of about 166 m^3/s, which would have ranked it above the August 1986 storm event.

[4] Note that DWR, 1988 estimated the peak flow at the gauge to be 161 m^3/s.

[5] The present investigation found that the critical duration storm for the main arm of Farmers Creek is 9 hours.

2.3.3. February 1990 Storm

Water levels in Farmers Creek rose over a period of a few hours in response to an intense thunderstorm that was experienced over Lithgow on the afternoon of Saturday 10 February 1990, resulting in the inundation of about 30 residences (Kinhill, 1991). The flooding occurred at the end of what had been a relatively wet period, when almost 200 mm of rain was recorded over the previous 8 days.

It was reported that flooding was most severe along Farmers Creek at the Geordie Street low level causeway and in the Hermitage Flat area, although many properties adjoining the creek suffered damage. There were also reports of local flooding problems arising at Sandford Avenue, Macaulay Street and Percy Street on the Vale of Clwydd, as well as at Doctors Gap. **Plates 1** to **4** in **Appendix C** show the flooding that occurred along Farmers Creek in the vicinity of Glanmire Oval.

As discussed in Section 3.3, it is believed that the heaviest rain fill in the upper reaches of the catchment, upstream of the Geordie Street low level causeway of Farmers Creek.

The RHS of **Figure 2.3**, **Sheet 1** shows the rainfall that was recorded to the north and south of the Farmers Creek catchment by Sydney Water Corporations (**SWC's**) Lisdale State Forest (GS 563048) and Lowther (Duddawarra) (GS 563073) pluviographic rain gauges on 10 February 1990. The gauge data shows that during the storm event a total of 25 mm of rain fell over a 3 hour period north of Lithgow while only 11 mm fell over a 2.5 hour period south of Lithgow.

An analysis of the pluviographic data shows that the rainfall that fell to the north of Lithgow had an ARI of between 1 and 2 years (refer RHS of **Figure 2.4**, **Sheet 1**). It is noted that a total of 36.4 mm was recorded by BoM's Lithgow (Birdwood Street) (GS 63224) rain gauge, indicating the rainfall may have been heavier over the middle (and possibly upper[6]) reaches of the Farmers Creek catchment than occurred to its north and south.

Similar to the analysis undertaken for the August 1986 storm data, the pluviographic traces were adjusted based on the relativity of the daily rainfall totals. The ARI of the adjusted rainfall is shown to be less than 1 year for the critical storm duration of 9 hours (refer dashed lines on RHS of **Figure 2.4**, **Sheet 1**).

DPIOW's Mount Walker stream gauge recorded a peak flow of 116 m^3/s at about 15:00 hours on 10 February 1990, about 1 hour after the cessation of rainfall in the area (refer RHS of **Figure 2.3**, **Sheet 1**).

2.3.4. January 2011 Storm

The total depth of rainfall which was recorded by SWC's Mount Victoria (GS 563149) and DPIOW's Mount Walker (GS 212042) pluviographic rain gauges (refer LHS of **Figure 2.3**, **Sheet 2**) was much less than the 83.2 mm that was recorded at SWC's Lithgow (Cooerwull) (GS 63226) daily read rain gauge, indicating more intense rainfall was experienced over the Farmers Creek catchment during the storm event that occurred on 5 January 2011.

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[6] A total of 46.2 mm was recorded by BoM's Hartley Vale (Vellacott Park) (GS 63141) rain gauge on the rain day of 11 February 1990, indicating that heavy rain may have fallen in the upper reaches of the streams which drain the Newnes State Forest.

While relatively intense, the pluviographic traces indicate that the rain fell over a period of only 2 hours. Analysis of the adjusted pluviographic data indicates that the ARI of the rainfall could have been greater than 100 year ARI for durations of between 30 and 180 minutes. The relatively intense but short duration of the storm likely maximised flows in several of the tributary arms of Farmers Creek.

While there is limited information on flooding that occurred in Lithgow as a result of this storm event,[7] oddly the peak flow recorded by DPIOW's Mount Walker stream gauge of 184 m^3/s (refer LHS of **Figure 2.3**, **Sheet 2**) is the highest over the 33 year period of record (i.e. over the period 1981 to 2013).

2.3.5. February 2013 Storm

The flood peak that occurred at around 23:00 hours on 23 February 2013 was a result of constant rain that fell throughout the day. A total of 90.4 mm was recorded by BoM's Lithgow (Cooerwull) (GS 63226) rain gauge on the rain day of 24 February 2013, while 4.5 km to the west a total of 70.5 mm was recorded at DPIOW's Mount Walker stream gauge site over the same period. While it rained constantly throughout the day, there was a short burst of intense rainfall that occurred over a period of 1 hour commencing at 19:00 hours, when 20 mm of rainfall was recorded at the stream gauge site.

The storm event caused only localised flooding in Lithgow and had an ARI equivalent to between 2 and 5 years (refer dashed lines on RHS of **Figure 2.4**, **Sheet 2**). Of the 26 responses which were received to the Questionnaire, 14 made reference to areas that were impacted by floodwater during the February 2013 storm. These included:

- **Farmers Creek** - Several properties located upstream of the Atkinson Street and Tank Street crossings were partially impacted by floodwater which surcharged the banks of the creek. A section of Macauley Street was also observed to have been inundated by floodwater which surcharges the northern bank of the creek. Minor surcharge of the creek in the Hermitage Flat area was observed, although flooding of property as a result of this occurrence was not identified.
- **Ida Falls Creek** - Floodwater was observed to have caused erosion along the side of a property located near the Farmers Creek confluence.
- **State Mine Creek** - Flooding was reported along Guy Street, possibly as a result of a partial blockage of the Laidley Street road bridge by woody debris.

The worst affected properties were located on the eastern side of Hartley Valley Road in the Vale of Clwydd catchment. The local stormwater drainage system which runs under several residential properties became blocked, which caused water to surcharge onto Ramsay Street where it initially ponded before flowing through several residential properties. Several properties were inundated for up to 4 hours, with the worst flooding occurring around 20:00 hours. **Plates 5**, **6** and **7** in **Appendix D** show the flooding that occurred in several residential properties which are located between Ramsay Street and Hartley Valley Road.

The peak flow recorded by DPIOW's Mount Walker stream gauge of 174 m^3/s (refer RHS of **Figure 2.3**, **Sheet 2**) is similar to that recorded during the January 2011 storm and is the second highest over the period of record.

[7] Only one respondent to the Community Questionnaire made reference to flooding that occurred as a result of the January 2011 storm. This person stated that floodwater originating from State Mine Creek flowed down Guy Street.

2.4 Analysis of Available Stream Gauge Record

2.4.1. General

Table 2.3 lists the ten largest floods to have been recorded by DPIOW's Mount Walker stream gauge in terms of peak discharge, noting that the gauge was shifted a short distance upstream to a new location in 2007, meaning peak gauge heights recorded prior to this date cannot be compared to more recent data. Peak height and discharge data for the full period of record are provided in **Appendix E**.

DWR, 1988 identified that the hydrograph trace for the August 1986 storm event was not complete because condensation that occurred during the flood prevented the Stevens recorder pen from functioning and that the peak flow in Farmers Creek for this event was probably closer to 161 m^3/s than 146 m^3/s. The annual flood frequency analysis presented in **Section 2.4.2** incorporates the higher flow rate.

TABLE 2.3
HIGHEST RANKED ANNUAL FLOOD PEAKS AT LITHGOW
1980 TO DATE

Date of Flood [A]	Peak Height (m) [B]	Peak Discharge (m^3/s) [C]	Approximate Frequency (year ARI)[1,2] [D]
January 2011	2.498	183.7	55 [59]
February 2013	2.443	174.4	20 [22]
February 1981	2.351	153.3	13 [7]
August 1986[4]	2.307	145.8 [161]	9 [10]
August 1998	2.135	119.4	7 [6]
August 1990[3]	2.126	119.0	6 [5]
February 2009	1.809	74.1	5 [5]
March 2012	1.768	69.4	4 [4]
January 2008	1.685	60.3	4 [4]
January 2006	1.645	55.9	4 [3]

1. The approximate frequency of the historic floods is based on a log-Pearson Type 3 distribution which was fitted to the annual series of flood peaks with low flows omitted (refer **Figure 2.5** (RHS)).
2. The values in [ ] correspond to the approximate frequency of each flood should the adjusted peak flow rate of 161 m^3/s for the August 1986 storm event be adopted.
3. Note that a flood occurred in February 1990 that reached 2.04 on the Mount Walker stream gauge.
4. DWR, 1988 states that the gauge malfunctioned during the event and the peak discharge was more likely 161 m^3/s, placing it above the February 1981 storm.

2.4.2. Annual Flood Frequency Analysis

A log-Pearson Type 3 (**LP3**) distribution was fitted to the annual series of flood peaks for the 33 year period of record. The resulting frequency curves, along with 5% and 95% confidence limits are shown on **Figure 2.5** (LHS). Column B in **Table 2.4** over page gives the estimates of peak flows for various probabilities of occurrence as derived from the above analyses

TABLE 2.4
ESTIMATES OF PEAK FLOWS AT LITHGOW
VALUES IN m^3/s

Annual Exceedance Probability % AEP [A]	LP3 Distribution		GEV Distribution	
	Full Period of Record [B]	Low Flows Omitted [C]	Full Period of Record [D]	Low Flows Omitted [E]
20	76	80	75	82
10	118	119	109	116
2	256	245	224	211
1	337	320	293	263
0.5	433	445	380	324

Values at the low end of the observed range of flood peaks can distort the fitted probability distribution and affect the estimates of large floods. Deletion of these low values may improve the fitting of the remaining data. As the recorded flood peaks are only a small sample of peaks actually occurring over a longer duration, an expected probability adjustment was also made using the procedure set out in ARR, 1998. ARR, 1998 recommends implementing the expected probability adjustment to remove bias from the estimate.

Figure 2.5 (RHS) shows the results of omitting the fourteen annual flows less than 25 m^3/s from the analysis and applying the expected probability adjustment to the remaining data. By comparison of the peak flows given in columns B and C of **Table 2.4**, removal of low flows did not alter the flood frequency relationship for the Mount Walker stream gauge.

DWR, 1988 estimated that the peak flow in Farmers Creek at the gauge site was about 15 m^3/s greater than the 145.8 m^3/s which was recorded by the gauge for the August 1986 storm event. The sensitivity of the flood frequency relationship for the Mount Walker stream gauge was therefore tested by increasing the peak flow estimate for the August 1986 storm event to 161 m^3/s. By comparison of the values given in column D of **Table 2.3**, the flood frequency relationship is not sensitive to the minor increase in the peak flow estimate for this event.

DWR, 1988 also estimated that the peak flow in Farmers Creek at the gauge site was about 166 m^3/s for the March 1978 storm event, which ranks it above the August 1986 storm event. The flood frequency relationship that was derived by removing low flows from the record was updated assuming that the flow in Farmers Creek for the intervening period between the time of the storm event and the commencement of the stream gauge records (i.e. for the years of 1979 and 1980) did not exceed 25 m^3/s. The resulting flood frequency relationship did not yield significantly different flows from those presented in column C of **Table 2.4**.

A flood frequency analysis was also carried out fitting the annual peaks to the General Extreme Value (**GEV**) distribution using LH moments. **Figure 2.6** shows the results for both the full period of record (LHS) and after the fourteen annual flows less than 25 m^3/s are omitted from the analysis (RHS). Columns D and E in **Table 2.5** set out the estimates of peak flows for various probabilities of occurrence as derived from the above analysis.

The GEV distribution was found to provide lower peak flow estimates for the larger, less frequent floods. The estimated peak discharge of 293 m^3/s for the 1% AEP flood is 13 per cent less than the comparable LP3 distribution value given in column B of **Table 2.4**, while the estimated peak discharge of 263 m^3/s for the 1% AEP flood is 18 per cent less than the comparable LP3 distribution value given in column C of **Table 2.4**.

Based on the above findings, the peak flow estimates given in column C of **Table 2.4**, as well as those derived from the graph on the RHS of **Figure 2.5**, **Sheet 1** should be given greatest weight when deriving design discharge hydrographs for input to the hydraulic model. Refer **Section 5.3** in **Chapter 5** for further discussion.

3 HYDROLOGIC MODEL DEVELOPMENT AND CALIBRATION

3.1 Hydrologic Modelling Approach

The present investigation required the use of a hydrologic model which is capable of representing the rainfall-runoff processes that occur within the study catchments. For hydrologic modelling, the practical choice is between the models known as ILSAX, RAFTS, RORB and WBNM. Whilst there is little to choose technically between these models, ILSAX has been developed primarily for use in modelling the passage of a flood wave through urban catchments, whilst RAFTS, RORB and WBNM have been widely used in the preparation of rural flood studies.

Both the ILSAX and RAFTS modelling approaches were used to generate discharge hydrographs from urban and rural areas, respectively, as this combined approach was considered to provide a more accurate representation of the rainfall runoff process in the study catchments. The discharge hydrographs generated by ILSAX and RAFTS were applied to the TUFLOW hydraulic model as either point or distributed inflow sources.

3.2 Hydrologic Model Layout

Figure 3.1 (4 Sheets) shows the layout of the hydrologic models that were developed for the Farmer Creek (**Farmers Creek Hydrologic Model**) and Marrangaroo Creek (**Marrangaroo Creek Hydrologic Model**) catchments.

As the primary function of the hydrologic model was to generate discharge hydrographs for input to the TUFLOW hydraulic model, individual reaches linking the various sub-catchments were generally not incorporated in the model. However, it was necessary to develop a lumped model of the Farmers Creek catchment which was used to route the flow generated by several of the RAFTS sub-catchments to the upstream boundary of the hydraulic model, as well as to the location of DPIOW's Mount Walker stream gauge (**Farmers Creek Lumped Hydrologic Model**). The outlets of the sub-catchments in the Farmers Creek Lumped Hydrologic Model were linked and the lag times between each assumed to be equal to the distance along the main drainage path divided by an assumed flow velocity of 2.5 m/s.

Careful consideration was given to the definition of the sub-catchments which comprise the hydrologic models to ensure peak flows throughout the drainage system would be properly routed through the TUFLOW model. In addition to using the ALS-based contour data, the location of inlet pits and headwalls were also taken into consideration when deriving the boundaries of the various sub-catchments.

Percentages of impervious area were assessed using LCC's aerial photography and cadastral boundary data. Sub-catchment slopes used for input to the RAFTS component of the hydrologic models were derived using the vectored average slope approach, whilst the average sub-catchment slope computed by the Vertical Mapper software was used for input to the ILSAX component of the hydrologic models. The available contour data generated from the ALS survey was used as the basis for computing the slope for both methods.

3.3 Hydrologic Model Calibration

3.3.1. Historic Rainfall Data

While both rainfall and flood level data are available for the February 1990 and February 2013 storm events, calibration of the hydrologic model also included the storms that occurred in August 1986 and January 2011.

As the pluviographic stations which recorded the temporal variability of the rainfall are located external to the study catchments, it was necessary to adjust the pluviographic traces so that the total depth of rain in each storm matched that which was recorded by BoM's Lithgow (Birdwood Street) rain gauge (GS 63224) (pre-1998) and Lithgow (Cooerwull) rain gauge (GS 63226) (post-1998), both of which are located within the Farmers Creek catchment. The adjustments that were made to the pluviographic traces which were used for model calibration purposes were as follows:

- **August 1986 Storm** - The 5 minute rainfall depths recorded by BoM's Katoomba (Murri Street) pluviographic rain gauge on the rain days of 5, 6 and 7 August 1986 were factored down (Multiplication Factor = 103 / 162.6 = 0.63 for the rain day of the 5^{th}, 165.4 / 277.7 = 0.60 for the rain day of the 6^{th} and 42 / 76.7 = 0.55 for the rain day of the 7^{th}) so that the total depth of rainfall matched the daily total by the Birdwood Street rain gauge for the same 72 hour period. The adjusted pluviographic trace is shown dashed on the LHS of **Figure 2.3**, **Sheet 1**.
- **February 1990 Storm** - The 5 minute rainfall depths recorded by SWC's Lisdale State Forest pluviographic rain gauge on the rain day of 11 February 1990 were factored up (Multiplication Factor = 36.4 / 25 = 1.456) so that the total depth of rainfall matched the daily total recorded by the Birdwood Street rain gauge for the same 24 hour period. The adjusted pluviographic trace is shown dashed on the RHS of **Figure 2.3**, **Sheet 1**.
- **January 2011 Storm** - The 5 minute rainfall depths recorded by DPIOW's Mount Walker pluviographic rain gauge on the rain day of 6 January 2011 were factored up (Multiplication Factor = 83.2 / 19 = 4.38) so that the total depth of rainfall matched the daily total recorded by BoM's Lithgow (Cooerwull) rain gauge (GS 63226) for the same 24 hour period. The adjusted pluviographic traces are shown dashed on the LHS of **Figure 2.3**, **Sheet 2**.
- **February 2013 Storm** - The 5 minute rainfall depths recorded by DPIOW's Mount Walker and SWC's Mount Victoria pluviographic rain gauges on the rain day of 24 February 2013 were factored up (Multiplication Factor = 90.5 / 70.5 = 1.28) and down (Multiplication Factor = 90.5 / 95.5 = 0.95) respectively so that the total depth of rainfall matched the daily total recorded by BoM's Lithgow (Cooerwull) rain gauge (GS 63226) for the same 24 hour period. The adjusted pluviographic traces are shown dashed on the RHS of **Figure 2.3**, **Sheet 2**.

3.3.2. RAFTS Model Parameters

A Manning's n value of 0.08 was applied to the sub-catchments which describe the relatively steep heavily wooded areas which are located in the headwaters of the Farmers Creek and Marrangaroo Creek catchments. Depending on the degree of tree cover and development which could be observed in the aerial photography, Manning's n values of between 0.04 (representative of cleared pastoral land) and 0.08 were applied to the sub-catchments in the models.

Initial and continuing loss rates for impervious and pervious areas, as well as the Bx factor in RAFTS, which were found to give reasonable correspondence with the discharge hydrographs recorded at the Mount Walker stream gauge are given in **Table 3.1** over page.

3.3.3. Results of Model Calibration

While a reasonable fit could be achieved with the recorded discharge hydrographs for the four historic storms (refer **Figure 2.3**), differences in both the shape and timing of the modelled discharge hydrographs is attributed to the spatial and temporal variability of rainfall across the catchment which was not captured by the nearby pluviographic rainfall stations.

TABLE 3.1
ADOPTED RAFTS MODEL PARAMETERS
HISTORIC STORM EVENTS[(1)]

<table>
<tr><th rowspan="2">Historic Storm Event</th><th rowspan="2">Pluviographic Rainfall Station</th><th rowspan="2">Parameter Set</th><th colspan="2">Initial Loss (mm)</th><th colspan="2">Continuing Loss (mm/hr)</th><th rowspan="2">Bx</th></tr>
<tr><th>Impervious Area</th><th>Pervious Area</th><th>Impervious Area</th><th>Pervious Area</th></tr>
<tr><td>August 1986</td><td>Katoomba (Murri Street)</td><td>1986-1</td><td>0</td><td>193</td><td>0</td><td>1.0</td><td>0.8</td></tr>
<tr><td rowspan="2">February 1990</td><td rowspan="2">Lisdale State Forest</td><td>1990-1</td><td>0</td><td>0[(2)]</td><td>0</td><td>5.5</td><td>0.8</td></tr>
<tr><td>1990-2</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0.8</td></tr>
<tr><td>January 2011</td><td>Mount Walker</td><td>2011-1</td><td>0</td><td>50</td><td>0</td><td>2.5</td><td>0.8</td></tr>
<tr><td rowspan="2">February 2013</td><td>Mount Walker</td><td>2013-1</td><td>0</td><td>13</td><td>0</td><td>3.5</td><td>0.8</td></tr>
<tr><td>Mount Victoria</td><td>2013-2</td><td>0</td><td>32</td><td>0</td><td>0</td><td>0.8</td></tr>
</table>

1. Refer **Figure 2.3** (**2 Sheets**) for discharge hydrographs which were generated using the above parameters.
2. The storm that caused flooding in Lithgow occurred at the end of what had been a relatively wet period, when almost 200 mm of rain was recorded over the previous 8 days.

Note that a second set of values for initial and continuing loss were derived for the February 1990 storm, which gave a higher peak flow at the location of the stream gauge. As described in **Section 4.5.2**, it was necessary to reduce rainfall losses to zero in order to achieve a reasonable fit to the recorded flood marks. This finding suggests that the rainfall was concentrated in the upper reaches of the Farmers Creek catchment, with little or no rainfall experienced in the catchments which contribute to flow in the stream below the Geordie Street low level causeway.[8]

Table 4.2 on page 26 gives peak flows generated by the Farmers Creek Lumped Hydrologic Model at selected locations for the various parameter sets. Also provided is a comparison of peak flows for the January 1986 storm event with those presented in DWR, 1988.[9]

Further discussion on the ability of the hydraulic model to closely match observed flooding patterns along Farmers Creek for the storms that occurred in February 1990 and February 2013 is presented in **Chapter 4**.

[8] The hydrologic modelling which was undertaken for the February 1990 storm assumed the rainfall was uniform across the whole of the catchment.

[9] Kinhill, 1991 does not provide any peak flow data for the historic storms to allow a comparison to be made with the findings of the present investigation.

3.3.4. Recommended Set of Parameters for Design Flood Estimation

The RAFTS model parameters which were found to give a reasonable fit to the discharge hydrographs recorded by the Mount Walker stream gauge (i.e. Manning's n and BX values) are recommended for use in deriving design discharge hydrographs for input to the TUFLOW hydraulic model.

While historic flood data are not available to allow a formal calibration of the overland flow generator in the hydrologic model (i.e. ILSAX) to be undertaken, the following parameters are recommended for design flood estimation based on the findings of previous studies:

- Soil Type = 3.0
- AMC = 3.0
- Paved flow path roughness = 0.02
- Grassed flow path roughness = 0.07

Details in relation to the values of initial and continuing loss which have been adopted for design flood estimation are set out in **Chapter 5**.

4 HYDRAULIC MODEL DEVELOPMENT AND CALIBRATION

4.1 General

The present investigation required the use of a hydraulic model which is capable of analysing the time varying effects of flow in the creeks and the local stormwater drainage system and the two-dimensional nature of flow on both the floodplain and in the steeper parts of the study area that are subject to overland flow. The TUFLOW modelling software was adopted as it is one of only a few commercially available hydraulic models which contain all the required features.

This chapter deals with the development and calibration of the TUFLOW models that were then used to define both main stream and overland flow behaviour in the study area for a range of design storm events.

4.2 The TUFLOW Modelling Approach

TUFLOW is a true two-dimensional hydraulic model which does not rely on a prior knowledge of the pattern of flood flows in order to set up the various fluvial and weir type linkages which describe the passage of a flood wave through the system.

The basic equations of TUFLOW involve all of the terms of the St Venant equations of unsteady flow. Consequently the model is "fully dynamic" and once tuned will provide an accurate representation of the passage of the floodwave through the drainage system (both surface and piped) in terms of depth, velocity and distribution of flow.

TUFLOW solves the equations of flow at each point of a rectangular grid system which represent overland flow on the floodplain and along streets. The choice of grid point spacing depends on the need to accurately represent features on the floodplain which influence hydraulic behaviour and flow patterns (e.g. buildings, streets, changes in channel and floodplain dimensions, hydraulic structures which influence flow patterns, etc.).

Pipe drainage and channel systems can be modelled as one-dimensional elements embedded in the larger two-dimensional domain which typically represents the wider floodplain. Flows are able to move between the one and two-dimensional elements of the model depending on the capacity characteristics of the drainage system being modelled.

The TUFLOW models which have been developed as part of the present investigation will allow for the future assessment of potential flood management measures, such as detention storage, increased channel and floodway dimensions, augmentation of culverts and bridge crossing dimensions, diversion banks and levee systems.

4.3 TUFLOW Model Setup

4.3.1. Model Structure

The layout of the TUFLOW models that were developed of the Farmers Creek (**Farmers Creek TUFLOW Model**) and Marrangaroo Creek (**Marrangaroo Creek TUFLOW Model**) floodplains are shown on **Figure 4.1**. Within the urbanised areas of Lithgow, the model comprises the pit and pipe drainage system, while the inbank area of the various reaches of channel are represented by a series of cross sections normal to the direction of flow. Both out-of-bank and shallow “overland” flow are modelled by the rectangular grid.

The following sections provide further details of the model development.

Two-dimensional Model Domain

An important consideration of two-dimensional modelling is how best to represent the roads, fences, buildings and other features which influence the passage of flow over the natural surface. Two-dimensional modelling is very computationally intensive and it is not practicable to use a mesh of very fine elements without excessive times to complete the simulation, particularly for long duration flood events. The requirement for a reasonable simulation time influences the way in which these features are represented in the model.

A grid spacing of 3 m was found to provide an appropriate balance between the need to define features on the floodplain versus model run times, and was adopted for the investigation. Ground surface elevations for model grid points were initially assigned using a digital terrain model (**DTM**) derived from ALS survey data, and updated using ground survey data where such data were available.

The footprints of a large number of individual buildings located in the two-dimensional model domain were digitised and assigned a high hydraulic roughness value relative to the more hydraulically efficient roads and flow paths through allotments. This accounted for their blocking effect on flow while maintaining a correct estimate of floodplain storage in the model.

It was not practicable to model the individual fences surrounding the many allotments in the study area. For the purpose of the present investigation, it was assumed that there would be sufficient openings in the fences to allow water to enter the properties, whether as flow under or through fences and via openings at driveways. Individual allotments where development is present were digitised and assigned a high hydraulic roughness value (although not as high as for individual buildings) to account for the reduction in conveyance capacity which will result from fences and other obstructions stored on these properties.

One-dimensional Model Elements

Cross section survey was obtained along the inbank area of Farmers Creek, Oakey Park Creek, Vale of Clwydd Creek and State Mine Creek where it was considered that the ALS survey data were not adequate to define bed and bank levels. **Figure 4.1** shows the location of the 36 cross sections that were surveyed by Casey Surveying and Design in 2014. An additional 179 cross sections were also derived from the ALS survey data to improve the definition of the waterway area along the modelled reaches of Farmers Creek and its major tributaries.

No cross section survey was commissioned for the Marrangaroo Creek catchment. Rather, 49 cross sections were derived from the ALS survey data to define the inbank area of the channel system.

LCC's pit and pipe database was used to obtain details of the piped drainage system which were incorporated into the TUFLOW models. These data were supplemented with field survey of 88 major hydraulic structures that are located in the study catchments. **Table 4.1** over page summarises the pit and pipe data that were incorporated into the TUFLOW models.

Limited information was available on pipe invert levels. An assumed cover of 700 mm was therefore adopted for those drainage elements where invert levels or depth measurements were not available. Adjustments were made to the assumed invert levels where this approach resulted in a negatively graded reach of pipe or culvert.

TABLE 4.1
SUMMARY OF MODELLED DRAINAGE STRUCTURES

TUFLOW Model	Pipes		Box Culverts		Bridges		Inlet Pits / Headwalls	Junction Pits
	No.	Length (m)	No.	Length (m)	No.	Length (m)	No.	No.
Farmers Creek	1,640	20,739	58	2,704	20	258	1,447	334
Marrangaroo Creek	68	2,094	6	85	3	55	121	0

A substantial amount of checking and refinement of the pit and pipe data contained in LCC's asset database was also required to address the following issues:

- **Location** – Pits and pipes were shifted to ensure they were located along the gutter line of roads and along overland flow paths. The available aerial photography and ALS survey data, as well as Google Street View™ was used to determine the correct location of the stormwater pits.
- **Line Direction** – Adjustments were made to the pipe database to ensure that individual conduits were drawn in the downstream direction (a requirement of the TUFLOW software).
- **Inlet Type** - Several types of pits are identified on **Figure 4.1**, including junction pits which have a closed lid and inlet pits which are capable of accepting overland flow. LCC's asset database contained only limited information in regard to inlet pit types and dimensions. Inlet pit capacity relationships were incorporated in the TUFLOW models based on a visual inspection of the existing stormwater drainage system.
- **Data Gaps** – Checks were undertaken to locate and join a large number of disconnected drainage elements. Information contained on design drawings was supplemented by field measurements where possible.

Pit losses were modelled using the Engelhund approach in TUFLOW. This approach provides an automatic method for determining time-varying energy loss coefficients at pipe junctions that are recalculated each time step based on a range of variables including the inlet/outlet flow distribution, the depth of water within the pit, expansion and contraction of flow through the pit, as well as the horizontal deflection and vertical drop across the pit.

4.3.2. Model Parameters

The main physical parameter for TUFLOW is the hydraulic roughness. Hydraulic roughness is required for each of the various types of surfaces comprising the overland flow paths, as well as for the cross sections representing the geometric characteristics of the various watercourses. In addition to the energy lost by bed friction, obstructions to flow also dissipate energy by forcing water to change direction and velocity and by forming eddies. Hydraulic modelling traditionally represents all of these effects via the surface roughness parameter known as "Manning's n". Flow in the piped system also requires an estimate of hydraulic roughness.

Manning's n values along the channel and immediate overbank areas along the modelled length of Farmers Creek were varied, with the values in **Table 4.2** over the page providing reasonable correspondence between recorded and modelled flood levels.

TABLE 4.2
CALIBRATED HYDRAULIC ROUGHNESS VALUES
DERIVED FOR FARMERS CREEK

Surface Treatment	Manning's n Value	
	Historic Storms	Design Storms
[A]	[B]	[C]
Concrete block lined channel (Stage 1A, 1B and 2)	0.015	0.018
Concrete surfaces (including piped elements)	0.015	0.02
Asphalt or concrete road surface	0.02	0.02
Channel through Endeavour Park	0.025	0.025
Overbank area of Farmers Creek, including grass and lawns	0.045	0.045
Creek bed	0.05	0.05
Unmaintained creek banks	-	0.055
Macrophytes	0.06	0.06
Lightly vegetated areas	0.07	0.07
Vegetated creek banks, including trees and shrubs	0.08	0.08
Allotments (between buildings)	0.10	0.10
Buildings	10	10

The adoption of a value of 0.02 for the surfaces of roads, along with an adequate description of their widths and centreline/kerb elevations, allowed an accurate assessment to be made of their conveyance capacity. Similarly, the high value of roughness adopted for buildings recognised that these structures will completely block the flow but are capable of storing water when flooded.

Figure 4.2 is a typical example of flow patterns derived from the above roughness values. The left hand side of the figure shows the roads and inter-allotment areas, as well as the outlines of buildings which have all been individually digitised in the model. The right hand side shows the resulting flow paths in the form of scaled velocity vectors and the depths of inundation. The buildings with their high values of hydraulic roughness block the passage of flow, although the model recognises that they store floodwater when inundated and therefore correctly accounts for flood storage. The flow is conveyed via the road reserves and through the open parts of the allotments. Similar information to that shown on **Figure 4.2** may be presented at any location within the model domain (which is shown on **Figure 4.1**) and will be of assistance to LCC in assessing individual flooding problems in the floodplain.

4.4 Model Boundary Conditions

The locations where sub-catchment inflow hydrographs were applied to the TUFLOW model are shown on **Figure 4.1**. These comprise point-source inflows at selected locations around the perimeter of the two-dimensional model domain and also along the main arms of the major watercourses, as well as distributed inflows via "Rain Boundaries".

The Rain Boundaries act to "inject" flow into the TUFLOW model by distributing it across all inlet pits located within the sub-catchment. In the case where there are no pits, flow is evenly distributed along a defined flow path within the sub-catchment. The extent of each Rain Boundary matches the sub-catchment area defined in the RAFTS and ILSAX hydrologic models, resulting in the flows being applied as they would be in the real drainage system.

The downstream boundary of the TUFLOW models comprised a broad crested weir arrangement, the elevation of which was set equal to the invert level of the creek.

4.5 Hydraulic Model Calibration

4.5.1. General

The Farmers Creek TUFLOW Model was calibrated to the February 1990 and February 2013 storms using the available flood data. The calibrated model was run using discharge hydrographs that was generated by the Farmers Creek Hydrologic Model, parameters for which are set out in **Section 3.3.2** and **Table 3.1**.

Table 4.3 on page 26 gives peak flows which were generated by the calibrated Farmers Creek Lumped Hydrologic Model for the four historic storm events, as well as peak flows extracted from the calibrated Farmers Creek TUFLOW Model, inflows to which were generated by the Farmers Creek Hydrologic Model. Peak flows that were generated by the RAFTS model that was developed as part of DWR, 1988 for the August 1986 storm are also given for comparison purposes.[10]

Note that the version of the Farmers Creek TUFLOW Model used to define flooding patterns for the February 1990 storm did not incorporate the Stage 1A, 1B and 2 channel improvement works which had not been constructed at the time of the event.

4.5.2. February 1990 Flood

Figure 4.3 shows the TUFLOW model results for the February 1990 storm, while water surface profiles along the main arm of Farmers Creek and its major tributaries are shown on **Figure 4.5**. The plan location and elevation of several flood marks which are set out in Kinhill, 1991 are shown on **Figures 4.3** and **4.5**, respectively. **Table 4.4** on page 27 gives a comparison of modelled versus recorded peak flood levels for the February 1991 storm event.

Initial runs of the Farmers Creek TUFLOW Model using the discharge hydrographs generated using Parameter Set 1990-1 (refer **Table 3.1** for details) found that the computed water levels were over 1 m lower than several of the recorded flood marks. An improved fit to the recorded flood marks was achieved when the values of initial and continuing loss were reduced to zero (refer Parameter Set 1990-2 in **Table 3.1**). If losses in the catchment were effectively zero at the time of the storm (which is a reasonable assumption given that over 200 mm of rain fell in the 8 days prior to the storm), then it is likely that the rainfall was concentrated in the upper reaches of the catchment, as in order to match the peak flow recorded at the Mount Walker stream gauge, the Farmers Creek TUFLOW Model had to be run with zero inflows below the Geordie Street causeway.

[10] Kinhill, 1991 does not provide any peak flow data for the historic storms to allow a comparison to be made with the findings of the present investigation.

While the calibrated hydraulic model gave a reasonable fit to a large number of recorded data, there were a number of locations where the computed water surface profile was more than 300 mm above and below the recorded values. Reasons for the relatively large differences in modelled versus recorded flood levels could be:

- inaccuracies in the flood level data (both plan location and elevation);
- the effects of a partial blockage of hydraulic structures on peak flood levels, details of which are not documented in Kinhill, 1991;
- changes in the available waterway area and the level of the floodplain, details of which are not captured in the available data; and
- variations in the magnitude of flow which actually occurred along individual reaches of Farmers Creek due to spatial and temporal differences in the rainfall, the characteristics of which were not captured by BoM's Katoomba (Murri Street) pluviographic rain gauge which is located about 30 km to the south-east of Lithgow.

Given the time that has elapsed since the occurrence of this event, further refinement of the Farmers Creek TUFLOW Model and its parameters was not considered warranted.

4.5.3. February 2013 Flood

Figure 4.4 shows the TUFLOW model results for the February 2013 storm, while water surface profiles along the main arm of Farmers Creek and its major tributaries are shown on **Figure 4.5**. Also shown on **Figure 4.4** are the location of several respondents to the Community Questionnaire who observed flooding in or adjacent to their property

Note that the Farmers Creek TUFLOW Model was run using discharge hydrographs which were generated using Parameter Set 2013-2 (refer **Table 3.1** for details), given these values gave the best fit to the shape of the recorded hydrograph (refer RHS of **Figure 2.3**, **Sheet 1**).

A feature of the February 2013 storm event is that it generated similar water levels in Farmers Creek and its major tributaries to those that occurred during the February 1990 storm, which is also reflected in the peak flows which were also very similar in the various watercourses (refer peak flows given in **Table 4.3** over page).

Table 4.5 on page 28 summarises the comments that were made by several respondents to the Community Questionnaire in relation to flooding that they observed during the February 2013 storm. **Figure 4.4**, **Sheets 1** and **3** show the location of each respondent. In general, the model was able to reproduce flooding behaviour which was observed by the respondents (refer comments in column C of **Table 4.5**), with differences attributed to local features which influenced flooding patterns, details of which cannot practicably be incorporated into the structure of the Farmers Creek TUFLOW Model.

4.5.4. Concluding Remarks

While the Farmers Creek TUFLOW Model was able to reproduce observed flood behaviour for both the February 1990 and February 2013 storm events using the Manning's n values set out in column B of **Table 4.2**, a review of a preliminary set of results for the design flood events found that flow velocities along the concrete lined sections of channel were higher than would occur under prototype conditions. As a result, the hydraulic roughness values for the concrete lined elements of the drainage system were increased slightly, which had the effect of reducing flow velocities in the corresponding reach of the drainage system. The hydraulic roughness values which were used for modelling design flood events are set out in column C of **Table 4.2**.

TABLE 4.3
COMPARISON OF PEAK FLOWS
HISTORIC STORM EVENTS
(m^3/s)

<table>
<tr><th rowspan="4">Watercourse

[A]</th><th rowspan="4">Location

[B]</th><th colspan="2" rowspan="2">RAFTS Link No.</th><th colspan="12">Peak Flow</th></tr>
<tr><th>DWR, 1988</th><th colspan="7">Farmers Creek Lumped Hydrologic Model</th><th colspan="4">Farmers Creek TUFLOW Model</th></tr>
<tr><th rowspan="2">DWR, 1988

[C]</th><th rowspan="2">Present Investigation

[D]</th><th rowspan="2">August 1986 Storm

[E]</th><th>August 1986 Storm</th><th colspan="2">February 1990 Storm</th><th>January 2011 Storm</th><th colspan="2">February 2013 Storm</th><th>August 1986 Storm</th><th>February 1990 Storm</th><th>January 2011 Storm</th><th>February 2013 Storm</th></tr>
<tr><th>Parameter Set 1986-1
[F]</th><th>Parameter Set 1990-1
[G]</th><th>Parameter Set 1990-2
[H]</th><th>Parameter Set 2011-1
[I]</th><th>Parameter Set 2013-1
[J]</th><th>Parameter Set 2013-2
[K]</th><th>Parameter Set 1986-1
[L]</th><th>Parameter Set 1990-2
[M]</th><th>Parameter Set 2011-1
[N]</th><th>Parameter Set 2013-2
[O]</th></tr>
<tr><td rowspan="5">Farmers Creek</td><td>Upstream Boundary of TUFLOW Model</td><td>1.02</td><td>OF_016</td><td>55</td><td>45</td><td>27</td><td>46</td><td>58</td><td>54</td><td>45</td><td rowspan="8">Not Modelled</td><td>45</td><td rowspan="8">Not Modelled</td><td>45</td></tr>
<tr><td>Downstream of Confluence with Ida Falls Creek</td><td>1.03</td><td>OF_022</td><td>61</td><td>60</td><td>37</td><td>62</td><td>77</td><td>72</td><td>60</td><td>46</td><td>45</td></tr>
<tr><td>Upstream of Confluence with Vale of Clwydd Creek</td><td>1.05</td><td>OF_025</td><td>80</td><td>83</td><td>51</td><td>86</td><td>106</td><td>97</td><td>81</td><td>63</td><td>61</td></tr>
<tr><td>Geordie Street Causeway</td><td>1.10</td><td>OF_037</td><td>121</td><td>131</td><td>84</td><td>138</td><td>151</td><td>138</td><td>129</td><td>118</td><td>126</td></tr>
<tr><td>Mount Walker Stream Gauge</td><td>1.14</td><td>OF_out</td><td>161</td><td>165</td><td>107</td><td>138</td><td>176</td><td>169</td><td>167</td><td>115</td><td>161</td></tr>
<tr><td>Vale of Clwydd</td><td>Confluence with Farmers Creek</td><td>3.00</td><td>OF_024</td><td>-</td><td>15</td><td>9</td><td>15</td><td>20</td><td>18</td><td>15</td><td>13</td><td>15</td></tr>
<tr><td>State Mine Creek</td><td>Confluence with Farmers Creek</td><td>4.00</td><td>OF_038</td><td>-</td><td>16</td><td>10</td><td>16</td><td>23</td><td>23</td><td>17</td><td>13</td><td>16</td></tr>
<tr><td>Sheedys Gully Tributary</td><td>Confluence with Farmers Creek</td><td>5.0</td><td>OF_029</td><td>-</td><td>14</td><td>10</td><td>14</td><td>21</td><td>22</td><td>15</td><td>12</td><td>12</td></tr>
</table>

TABLE 4.4
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS[1]
FEBRUARY 1990 STORM EVENT

Point No.[2]	Location	Watercourse	Peak Flood Level (m AHD)		Difference (m)
			Recorded	Modelled	
3	Geordie Street centreline	Farmers Creek	904.3	904.5	0.2
4	No. 109 Coalbrook Street	Farmers Creek	905.4	905.2	-0.2
5	No. 103 Coalbrook Street	Farmers Creek	905.6	905.3	-0.3
6	No. 36 Coalbrook Street	Farmers Creek	905.7	905.7	0.0
7	No. 85 Coalbrook Street	Farmers Creek	906.5	906.5	0.0
8	No. 85 Coalbrook Street	Farmers Creek	906.2	906.4	0.2
9	Corner Davy and Coalbrook Street	Farmers Creek	906.3	906.2	-0.1
10	Upstream Lithgow State Mine Railway - the 'hump'	Farmers Creek	906.9	906.8	-0.1
11	Albert Street Bridge - Upstream side	Farmers Creek	907.2	906.9	-0.3
12	Glanmore Oval - Playground	Farmers Creek	907.2	907.3	0.1
13	No. 47 Coalbrook Street	Farmers Creek	907.3	907.1	-0.2
14	No. 47 Coalbrook Street	Farmers Creek	907.5	907.1	-0.4
18	Lot 3 Sandford Ave	Farmers Creek	912.2	912.0	-0.2
19	No. 9 Montague Street	Farmers Creek	913.7	913.2	-0.5
20	Just Downstream Tank Street Bridge	Farmers Creek	914.8	913.9	-0.9
22	No.28 Macauley Street	Farmers Creek	916.1	916.4	0.3
23	Corner Guy Street and Macauley Street	Farmers Creek	916.3	916.6	0.3
24	No. 14 Guy Street	State Mine Creek	917.2	917.2	0.0
25	No. 23 Guy Street	Farmers Creek	918	917.5	-0.5
26	No. 7 Burton Street	Farmers Creek	918.6	918.2	-0.4
27	No. 7 Burton Street	Farmers Creek	918.5	918.3	-0.2
28	Atkinson Street Bridge - Downstream side	Farmers Creek	919.2	919.1	-0.1
29	Atkinson Street Bridge - Upstream side	Farmers Creek	919.1	919.2	0.1
30	No. 21 - Laidley Street	Farmers Creek	919.6	919.3	-0.3
31	No. 4 Brook Street	Farmers Creek	926.2	926.4	0.2
32	No. 4 Brook Street	Farmers Creek	926	926.3	0.3
33	No. 7 Victoria Ave	Farmers Creek	928.2	927.8	-0.4
34	No.2 Hay Street	Farmers Creek	928.5	928.9	0.4
35	No. 56 Bells Road	Farmers Creek	929.3	929.4	0.1
36	No. 56 Bells Road	Farmers Creek	929.6	929.4	-0.2
37	No. 56 Bells Road	Farmers Creek	929.4	929.2	-0.2

1. Source of recorded peak flood levels and descriptors: Kinhill, 1990
2. Refer **Figure 4.3** for location of available flood marks.

TABLE 4.5
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR
FEBRUARY 2013 STORM EVENT

Response Identifier[1] [A]	Observed Flood Behaviour / Other Comment [B]	Model Verification Comments [C]
1	➢ Flooding occurred at lower end of Macaulay Street and Guy Street. ➢ Floodwater lapped against front yards in Macaulay Street.	➢ TUFLOW model shows water surcharging the right bank of Farmers Creek in the vicinity of its confluence with State Mine Creek and water ponding in Guy Street up to a maximum depth of about 500 mm. ➢ TUFLOW model shows shallow overland flow along Macaulay Street in front of properties.
2	➢ Property was flooded from Canal. ➢ Also knows of flooding at Montague Street, Vale of Clwydd and Main Street Viaduct	➢ TUFLOW model shows water surcharging the right bank of Farmers Creek into the backyard of the property. It also shows floodwater ponding in the property to a maximum depth of about 800 mm. ➢ TUFLOW model shows water surcharging the right bank of Farmers Creek into Montague Street to a maximum depth of about 400 mm. ➢ Location of reference to Vale of Clwydd unclear. ➢ Reference to Main Street viaduct is unclear. However, it is noted that the TUFLOW model shows 0.7 m^3/s of overland flow discharging through the George Coates Avenue viaduct at a maximum depth of about 300mm and 4.0 m^3/s of overland flow discharging through the James Street viaduct at a maximum depth of about 700 mm.
4	➢ Event eroded bank at rear of property and washed away trees. ➢ Observed water lapping up against fence of property across creek. ➢ Damage to property near Ida Falls Creek / Farmers Creek confluence. ➢ Water broke banks at Macaulay Street.	➢ TUFLOW model does not show floodwater encroaching on property. However, is does show velocities of up to 3.5 m/s in Farmers Creek behind property which may have contributed to bank erosion. ➢ TUFLOW model shows flood water surcharging the right bank of the creek on the opposite side of the creek. ➢ TUFLOW model shows floodwaters encroaching on property near Ida Falls Creek/Farmers Creek confluence. ➢ Refer comment to Response 1 regarding Macaulay Street.

1. Refer **Figure 4.4** for cross reference to Response Identifier

Cont'd Over

TABLE 4.5 (Cont'd)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHVIOUR
FEBRUARY 2013 STORM EVENT

Response Identifier[(1)] [A]	Observed Flood Behaviour / Other Comment [B]	Model Verification Comments [C]
5	➢ Open drain at western end of Andrew Street becomes deep and fast flowing. ➢ Drain off Cooerwull Street behind Roads and Maritime depot eroded and clogged.	➢ TUFLOW model shows about 0.4 m^3/s in the channel at the western end of Andrew Street at a velocity of up to 1.2 m/s. ➢ Location of drain off Cooerwull Street unclear– observed inundation may be a local drainage issue.
11	➢ Water pools in driveway originating from Atkinson Road bridge. ➢ Atkinson Road bridge subject to blockage from vegetation and rubbish (shopping trolleys).	➢ Blockage reference by respondent not included in TUFLOW modelling therefore results do not show ponding in driveway. ➢ Sensitivity analysis shows that the build up of debris on the bridge can cause major surcharge of the creek. Refer **Section 6.3.3** for details on the effects of blockage on flooding patterns.
12	➢ Back fence ruined and garden shed inundated. ➢ 0.4m deep on verandah of adjoining house.	➢ TUFLOW model shows floodwaters encroaching on the rear of the property. ➢ TUFLOW model shows water ponding up to a depth of about 300 mm adjacent to the front verandah of adjoining property.
16	➢ Water flows across driveway and down northern side of house.	➢ TUFLOW model shows water flowing along channel on northern side of property. ➢ TUFLOW model does not show water flowing across driveway – observed inundation is believed to be a local drainage issue.
19	➢ Property and house completely inundated. ➢ Peak occurred at around 20:00 hours.	➢ TUFLOW model shows water ponding up to a depth of about 400 mm in property. ➢ Peak flood levels occur at approximately 20:00 hours in TUFLOW model.

2. Refer **Figure 4.4** for cross reference to Response Identifier

Cont'd Over

TABLE 4.5 (Cont'd)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHVIOUR
FEBRUARY 2013 STORM EVENT

Response Identifier[(1)] [A]	Observed Flood Behaviour / Other Comment [B]	Model Verification Comments [C]
20	➢ Dense vegetation blocks Atkinson Street bridge.	➢ Refer comment to Response 11 regarding blockage of Atkinson Road bridge.
23	➢ Creek broke banks between No. 101-109 Coalbrook Avenue at around 22:45 hours.	➢ TUFLOW model shows water surcharges the right bank of Farmers Creek, inundating the backyard of the property to a maximum depth of about 400 mm. ➢ The peak of the flood occurs at approximately 21:00 hours in the TUFLOW model.
24	➢ Creek broke banks at bottom of Tank Street and inundated front yard. ➢ Flooding occurred during the night.	➢ TUFLOW model does not show Farmers Creek breaking its banks at Tank Street and inundating property. However, shallow overland flow inundates property along Union Street frontage.
25	➢ Water was eighteen (18) inches (450mm) deep in house and three (3) feet deep in garage. ➢ Water surcharged from pit in Ramsay Street where it ponded before flowing through properties to Hartley Valley Road.	➢ TUFLOW model shows water ponding up to a depth of about 300 mm in property. Local features such as fences may have further increased depths of overland flow beyond those predicted by the model. ➢ TUFLOW model shows water surcharging pit in Ramsay Street and ponding up to a depth of about 400 mm. It also shows water flowing in a westerly direction through properties between Ramsay Street and Hartley Valley Road.

1. Refer **Figure 4.4** for cross reference to Response Identifier

5 DERIVATION OF DESIGN FLOOD HYDROGRAPHS

5.1 Design Storms

5.1.1. Rainfall Intensity

The procedures used to obtain temporally and spatially accurate and IFD design rainfall curves for the Farmers Creek and Marrangaroo Creek catchment areas are presented in Book II of ARR, 1998. Design storms for frequencies of 5, 10, 50, 100 and 200 year ARI were derived for storm durations ranging between 25 minutes and 12 hours. The procedure adopted was to generate an IFD dataset for the catchment by using the relevant charts in Volume 2 of ARR, 1998. These charts included design rainfall isopleths, regional skewness and geographical factors.

5.1.2. Areal Reduction Factors

The rainfalls derived using the processes outlined in ARR, 1998 are applicable strictly to a point. In the case of a catchment of over tens of square kilometres area, it is not realistic to assume that the same rainfall intensity can be maintained. An areal reduction factor (**ARF**) is typically applied to obtain an intensity that is applicable over the entire catchment. Book II of ARR, 1998 shows curves relating the ARF to catchment area for various storm durations.

The ARF for a particular catchment area and given design rainfall burst duration and AEP, represents the ratio between the areal design rainfall and the representative point duration rainfall for the catchment. ARR, 1998 recommended ARF's based on studies in the United States, whilst *Jordan et al, 2011* describes the derivation of ARF equations for NSW and ACT. Data from the record at over 6000 sites across the two areas was used to derive ARF factors for durations between 1 and 5 days and AEP's between 1 in 2 and 1 in 100. For durations less than 1 day, short duration equations based on studies undertaken in Victoria were recommended.

Based on the *Jordan et al, 2011* relationships, ARF values for the Farmers Creek catchment at the location of the Mount Walker stream gauge would range between 0.87 and 0.91 for storm durations between 4.5 and 12 hours. This compares to values of between 0.95 and 0.97 for similar duration storms based on the curves given in Book II of ARR, 1998. **Table 5.1** over the page gives peak 100 year ARI flows generated by the Farmers Creek Lumped Hydrologic Model at the location of the Mount Walker stream gauge for various ARF values.

While application of the *Jordan et al, 2011* derived ARF values to the design rainfalls which were used as input to the Farmers Creek Lumped Hydrologic Model gave a peak 100 year ARI flow similar to the results of the flood frequency for the critical 9 hour storm duration (328 m^3/s versus 340 m^3/s), no areal reduction factors were applied to the design point rainfalls which were applied to the Farmers Creek and Marrangaroo Creek Hydrologic Models. This is because the intended use of these models is to generate inflow hydrographs which will be used to define flooding behaviour in the middle and upper reaches of the study catchments where higher ARF values would apply.

5.1.3. Temporal Patterns

Temporal patterns for various zones in Australia are presented in ARR, 1998. These patterns are used in the conversion of a design rainfall depth with a specific ARI into a design flood of the same frequency. Patterns of average variability are assumed to provide the desired conversion. The patterns may be used for ARI's up to 500 years where the design rainfall data is extrapolated to this ARI.

TABLE 5.1
COMPARISON OF PEAK FLOWS FOR VARIOUS ARF VALUES
100 year ARI[1,2]
(m^3/s)

ARF Values	Storm Duration (hours)			
	4.5	6	9	12
No ARF	337 [1.0]	354 [1.0]	372 [1.0]	316 [1.0]
ARF Values as per ARR, 1998	314 [0.95]	334 [0.96]	359 [0.97]	304 [0.97]
ARF Values as per Jordan et al, 2011	276 [0.87]	295 [0.88]	328 [0.90]	282 [0.91]

1 Numbers in [ ] refer to ARF values applied to the Farmers Creek Lumped Hydrologic Model.

2 Peak flows were derived adopting an initial loss of 15 mm and a continuing loss rate of 2.5 mm/hr.

The derivation of temporal patterns for design storms is discussed in Book II of ARR, 1998 and separate patterns are presented in Volume 2 of ARR for ARI's < 30 years and ARI's > 30 years. The second pattern is intended for use for rainfalls with ARI's up to 100 years, and to 500 years in those cases where the design rainfall data in Book II of ARR, 1998 are extrapolated to this ARI.

The Farmers Creek and Marrangaroo Creek catchments are located in the transition area between Zones 1 and 2. A method to overcome discontinuities as a result of differences in temporal patterns across zonal boundaries is outlined in ARR, 1998. However, the method requires that flows be calculated using both sets of temporal patterns and a weighted average applied based on the location of the catchment to the line dividing the two zones. As it is not practicable to calculate a weighted average peak flow for each individual sub-catchment comprising the hydrologic models, the temporal patterns presented in ARR, 1998 for Zone 1 were adopted for design flood estimation as this approach generated slightly higher flows in the drainage system when compared to those generated by application of the Zone 2 temporal patterns.

5.2 Probable Maximum Precipitation

Estimates of Probable Maximum Precipitation (**PMP**) were made using the Generalised Short Duration Method (**GSDM**) as described in BoM's update of Bulletin 53 (BoM, 2003). This method is appropriate for estimating extreme rainfall depths for catchments up to 1000 km^2 in area and storm durations up to 6 hours.

The steps involved in assessing PMP for the Farmers Creek and Marrangaroo Creek catchments are briefly as follows:

- Calculate PMP for a given duration and catchment area using depth-duration-area envelope curves derived from the highest recorded US and Australian rainfalls.
- Adjust the PMP estimate according to the percentages of the catchment which are meteorologically rough and smooth, and also according to elevation adjustment and moisture adjustment factors.
- Assess the design spatial distribution of rainfall using the distribution for convective storms based on US and world data, but modified in the light of Australian experience.
- Derive storm hyetographs using the temporal distribution contained in Bulletin 53, which is based on pluviographic traces recorded in major Australian storms.

Figure 3.1, **Sheet 1** shows the location and orientation of the PMP ellipses which were used to derive the rainfall estimates for each individual sub-catchment.

5.3 Design Rainfall Losses

Walsh et al, 1991 reported on the results of a study into the probabilistic derivation of losses, in particular initial losses, using stream flow data from 22 rural gauged catchments and design rainfalls from ARR. The design values of initial loss vary with the ARR rainfall zone, flood frequency and the degree of non-linearity assumed in the catchment flood hydrograph model. The recommended initial loss data for application when using a non-linear hydrologic model in Zones 1 and 2 are shown in **Table 5.2**, while **Table 5.3** over the page presents the initial loss values which were found to best fit the flood frequency analysis at the Mount Walker stream gauge.

TABLE 5.2
INITIAL LOSS DATA FOR PRACTICAL DESIGN FLOOD ESTIMATION IN NEW SOUTH WALES(1,2,3)
(mm)

Zone	ARI of Design Storm					
	2	5	10	20	50	100
1	50 [±20]	55 [±20]	60 [±20]	55 [±30]	50 [±30]	40 [±30]
2	25 [±15]	30 [±15]	30 [±15]	25 [±15]	20 [±15]	15 [±15]

1. Values taken from Table II presented in Walsh et al, 1991
2. Values in [ ] represent stated order of accuracy.
3. Initial loss values were derived using a continuing loss rate of 2.5 mm/hr.

As ILSAX uses the Hortonian loss modelling approach which does not require the user to input a continuing loss rate, the following initial loss values were adopted for generating flows in the urbanised parts of the study area:

- Paved area depression storage = 2 mm
- Grassed area depression storage = 10 mm

5.4 Derivation of Design Discharges

The various hydrologic models were run with the set of parameters recommended in **Section 3.3.4** to obtain design hydrographs for ARI's ranging between 5 and 200 years, together with the PMF, noting that the initial loss value for pervious areas within the Farmers Creek Lumped Hydrologic Model was varied for floods of different ARI to provide reasonable comparison with the peak flow estimates derived by the flood frequency analysis using an ARF value of 0.9.

Table 5.3 over page gives a comparison of peak flows derived by the flood frequency analysis (refer relationship shown on RHS of **Figure 2.5**) and those generated by the Farmers Creek Lumped Hydrologic Model for design storms of varying ARI. Note that peak flows generated by the model have been given for ARF values of 0.9 and 1.0, the latter being the value which was used to generate design discharge hydrographs for input to the hydraulic model. A comparison is also provided of peak flows derived using the Probabilistic Rational Method (**PRM**), procedures for which are set out in IEAust, 1998.

Note that initial and continuing loss rates of 0 mm and 0 mm/hr, respectively were adopted for generating discharge hydrographs for the PMF event.

TABLE 5.3
COMPARISON OF DESIGN PEAK FLOWS
MOUNT WALKER STREAM GAUGE

Design Storm Event	Peak Flow (m^3/s)						Initial Loss Value[2] (mm)	Continuing Loss Rate (mm/hr)
	PRM			Flood Frequency Analysis[1]	RAFTS			
	C_{10} = 0.25	C_{10} = 0.35	C_{10} = 0.40		ARF = 0.9	ARF = 1.0		
5 year ARI	53	73	84	80	100	112	40	2.5
10 year ARI	71	100	114	119	128	157	40	2.5
50 year ARI	146	204	235	245	235	285	40	2.5
100 year ARI	193	265	304	320	328	372	15	2.5
200 year ARI	214	294	337	445	370	418	15	2.5

1. Peak flows taken from relationship shown on RHS of **Figure 2.5**.
2. Initial loss values apply to pervious areas in Farmers Creek Lumped Hydrologic Model.

6 HYDRAULIC MODELLING OF DESIGN FLOODS

6.1 Presentation and Discussion of Results

6.1.1. General

Figures 6.1 to **6.6** show the TUFLOW model results for the 5, 10, 50, 100 and 200 year ARI floods, together with the PMF. These diagrams show the indicative extents and depths of inundation in the study area.

In order to create realistic results which remove most anomalies caused by inaccuracies in the ALS survey (which has a design accuracy such that 68 per cent of the points have an accuracy in level of +/- 150 mm), a filter was applied to remove depths of inundation over the natural surface of less than 100 mm. This has the effect of removing the very shallow depths which are more prone to be artefacts of the model, but at the same time giving a reasonable representation of the various overland flow paths. The depth grids shown on the figures have also been trimmed to the building polygons, as experience has shown that property owners incorrectly associate depths of above-ground inundation at the location of buildings with depths of above-floor inundation.

Design water surface profiles along Farmers Creek and its major tributaries, as well as for the main arm of Marrangaroo Creek are shown on **Figure 6.7**. **Figure 6.8** shows stage and discharge hydrographs at selected locations throughout the study area

Table F1 in **Appendix F** gives peak design flows at selected locations throughout the study area, while **Table G1** in **Appendix G** contains information in relation to the inundation of existing road and pedestrian crossings at Lithgow.

6.1.2. Accuracy of Hydraulic Modelling

The accuracy of results depends on the precision of the numerical finite difference procedure used to solve the partial differential equations of flow, which is also influenced by the time step used for routing the floodwave through the system and the grid spacing adopted for describing the natural surface levels in the floodplain. Channels are described by cross-sections normal to the direction of flow, so their spacing also has a bearing on the accuracy of the results. The results are also heavily dependent on the size of the two-dimensional grid, as well as the accuracy of the ALS survey data, which as noted above has a design accuracy based on +/- 150 mm.

Given the uncertainties in the ALS survey data and the definition of features affecting the passage of flow, maintenance of a depth of flow of at least 200 mm is required for the definition of a "continuous" flow path in the areas subject to shallow overland flow approaching the main arms of the study catchments. Lesser modelled depths of inundation may be influenced by the above factors and therefore may be spurious, especially where that inundation occurs at isolated locations and is not part of a continuous flow path. In areas where the depth of inundation is greater than the 200 mm threshold and the flow path is continuous, the likely accuracy of the hydraulic modelling in deriving peak flood levels is considered to be between 100 and 150 mm.

Use of the flood study results when applying flood related controls to development proposals should be undertaken with the above limitations in mind. Proposals should be assessed with the benefit of a site survey to be supplied by applicants in order to allow any inconsistencies in results to be identified and given consideration. This comment is especially appropriate in the areas subject to shallow overland flow, where the errors in the ALS or obstructions to flow would have a proportionally greater influence on the computed water surface levels than in the deeper flooded main stream areas.

Minimum floor levels for residential, commercial and industrial developments should be based on the 100 year ARI flood level plus appropriate freeboard (this planning level is defined as the *"Flood Planning Level" (**FPL**)*), to cater for uncertainties such as wave action, effects of flood debris conveyed in the overland flow stream and precision of modelling. Note that a freeboard of 500 mm has been adopted for defining the *Interim Flood Planning Levels* (***IFPL's***) pending the completion of the future *FRMS*. Derivation of an *Interim Flood Planning Area* (***IFPA***) based on the interim set of *IFPL's* is presented in **Section 6.5**.

The sensitivity studies and discussion presented in **Section 6.3** provide guidance on the suitability of the recommended allowance for freeboard under present day climatic conditions.

In accordance with OEH recommendations (DECC, 2007), sensitivity studies have also been carried out to assess the impacts of future climate change (refer **Section 6.4**). Increases in flood levels due to future increases in rainfall intensities may influence the selection of *FPL's*. However, final selection of *FPL's* is a matter for more detailed consideration in the future *FRMS*.

6.1.3. Main Stream Flooding Behaviour in the Farmers Creek Catchment

Flooding is generally confined to the inbank area of Farmers Creek and its major tributaries where they run through the urbanised parts of Lithgow up to about the 10 year ARI level of flooding. However, flooding is shown to occur within existing development at the 5 year ARI level of flooding at the following two locations:

- Along Coalbrook Street in Hermitage Flat, where floodwater is shown to extend into the rear of several residential properties that back onto Farmers Creek[11] (refer **Figure 6.1**, **Sheet 2**). Depths of inundation within the affected properties are generally less than 300 mm at the 5 year ARI level of flooding.
- Along Lockyer Street, Bowenfels where floodwater is shown to extend into the rear of several residential properties that are located a short distance downstream of the Great Western Highway bridge crossing of Farmers Creek (refer **Figure 6.1**, **Sheet 3**). The depths of inundation in these properties exceed 1 m at the 5 year ARI level of flooding.

The number of properties affected by floodwater increases significantly at the 50 year ARI level of flooding. Locations where both residential and commercial properties are affected the greatest include:

- on the right (northern) bank of Farmers Creek opposite the Jim Monaghan Athletics Track, where depths of inundation in several properties exceed 1 m (refer **Figure 6.3**, **Sheet 2**);
- on the right (northern) bank of Farmers Creek in the Hermitage Flat area, where depths of flow in a large number of residential properties exceed 600 mm (refer **Figure 6.3**, **Sheet 2**);
- on the right (northern) bank of Farmers Creek along Sandford Avenue between Crane Road and Tank Street, where depths of inundation in several residential properties exceed 600 mm (refer **Figure 6.3**, **Sheet 2**);

[11] Note that several of the affected properties are located along the reach of channel which was recently upgraded by LCC as part of the Stage 1A, 1B and 2 channel improvement works (refer **Figure 2.2**, Sheet 2 for extent of the works).

- on the left (southern) bank of Farmers Creek upstream of the Tank Street bridge crossing, where the depth of inundation in two residential properties exceeds 1 m (refer **Figure 6.3**, **Sheet 2**);
- on the left (southern) bank of Farmers Creek adjacent to the confluence of State Mine Creek, where maximum depths of inundation in several commercial properties range between 700 mm and 1 m (refer **Figure 6.3**, **Sheet 1**);
- on the right (northern) bank of Farmers Creek both upstream and downstream of the Atkinson Street bridge crossing, where depths of inundation in several residential properties exceed 1 m (refer **Figure 6.3**, **Sheet 1**);
- on the right (northern) bank of Farmers Creek at the southern end of Hay Street, where the depth of inundation in a residential property is a maximum of 500 mm (refer **Figure 6.3**, **Sheet 1**);
- on the left (western) bank of Vale of Clwydd Creek upstream of the Chifley Road culverts, where the maximum depth of inundation in a commercial property exceeds 400 mm (refer **Figure 6.3**, **Sheet 1**);
- on the left (eastern) bank of McKellers Park Tributary approximately 150-170 m upstream of the Sandford Avenue culverts, where maximum depths of inundation in the rear of several residential properties exceed 600 mm (refer **Figure 6.3**, **Sheet 2**); and
- on Sheedys Gully Tributary immediately south (upstream) of the Main Western Railway (refer **Figure 6.3**, **Sheet 2**).

A number of additional properties are affected by main stream flooding at the 100 year ARI level of flooding. These are principally located along the main arm of Farmers Creek at the following three locations:

- in the Hermitage Flat area;
- on the upstream side of the Tank Street bridge crossing; and
- in the vicinity of Hay Street.

While the number of properties affected by floods of between 100 and 500 year ARI does not increase significantly (refer **Section 6.4.2** for further discussion), there is a significant increase in the footprint of land which is affected by the PMF. The reason for this is that the upper envelope of flooding lies several metres above peak flood levels generated by floods of up to 500 year ARI (refer comparison of design water surface profiles shown on **Figure 6.7**). This finding will need to be taken into consideration when preparing the future *FRMS*, namely in regards the development of an appropriate set of flood related planning controls which takes this large flood range into account.

While the peak flows generated by the flood models developed as part of the present investigation are similar to those derived as part of Kinhill, 1991 at the 100 year ARI level, they are significantly lower for the more frequent flood events (refer comparison of peak flows given in **Table 6.1** over for the 5 year ARI design storm event). The reason for the large difference is the adoption of a zero initial and continuous loss model as part of Kinhill, 1991, which resulted in an overestimate of peak flows for the more frequent storm events. It is noted that the peak flows generated by the flood models which were developed as part of the present investigation more closely match the annual series flood frequency relationship which was derived for DPIOW's Mount Walker stream gauge, than do those presented in Kinhill, 1991.

TABLE 6.1
COMPARISON OF DESIGN PEAK FLOWS
(m^3/s)

Watercourse	Location	RAFTS Link No.		DWR, 1988	Kinhill, 1991				Present Investigation							
		DWR, 1988	Present Investigation						Farmers Creek Lumped Hydrologic Model				Farmers Creek TUFLOW Model			
				100 year ARI	5 year ARI	100 year ARI	200 year ARI	PMF	5 year ARI	100 year ARI	200 year ARI	PMF	5 year ARI	100 year ARI	200 year ARI	PMF
Farmers Creek	Upstream Boundary of TUFLOW Model	1.02	OF_016	91	65	116	119	790	35	112	126	990	35	112	126	990
	Downstream of Confluence with Ida Falls Creek	1.03	OF_022	103	74	132	136	910	48	150	169	1270	43	141	159	1100
	Upstream of Confluence with Vale of Clwydd Creek	1.05	OF_025	142	97	174	179	1200	67	206	232	1750	49	154	174	1120
	Geordie Street Causeway	1.10	OF_037	228	150	273	281	1900	103	310	349	2675	99	270	299	1420
	Mount Walker Stream Gauge	1.14	OF_out	294	189	347	357	2400	125 [80]	372 [320]	418 [445]	3090	113 [80]	330 [320]	370 [445]	2460
Vale of Clwydd	Confluence with Farmers Creek	3.00	OF_024	-	16	30	31	220	11	37	42	370	6	25	32	230
State Mine Creek	Confluence with Farmers Creek	4.00	OF_038	-	20	36	37	270	13	41	46	370	12	38	43	280
Sheedys Gully Tributary	Confluence with Farmers Creek	5.0	OF_029	-	13	23	24	170	12	36	42	315	10	31	34	290

1. Values in [ ] are based on the flood frequency analysis undertaken as part of the present investigation.

While there is a minor difference in peak flows generated by the Farmers Creek Lumped Hydrologic Model and those extracted from the Farmers Creek TUFLOW Model for events up to 200 year ARI, there is a significant difference in flow at the PMF level of flooding. The large difference in peak flows is attributed to the attenuating effects which result from flow being routed through the developed (and more hydraulically rougher) parts of Lithgow, a feature which is not incorporated in the hydrologic model.

Water levels in Farmers Creek and its major tributaries commence to rise within a few hours of the onset of heavy rain, as shown on **Figure 6.8**. In the upper reaches of the tributary arms, water levels typically rise to their peak within 1 hour, while on the main arm of Farmers Creek it can take up to 4 hours after the onset of heavy rain for water levels to reach their maximum height.[12] The height to which water levels reach relative to adjacent road and bridge deck levels is also shown on **Figure 6.8**.

By inspection of the values set out in **Table G1** in **Appendix G**, the road and pedestrians crossing will generally remain flood free for flood events up to about 50 year ARI, with the exception of the Mills Street and Geordie Street causeways on Farmers Creek, both of which will be inundated during freshes in the creek system. The Victoria Avenue crossing of Farmers Creek is overtopped in a 50 year ARI flood event, which will result in the isolation of the residents of Oakey Park. The Atkinson Street and Tank Street crossings of Farmers Creek are overtopped during a 100 year ARI flood event, as will the low point in Sandford Avenue immediately east of Crane Road. The State Mine Gully Road crossing of State Mine Creek will also be overtopped during a 100 year ARI storm event, isolating the residents of Morts Estate.

6.1.4. Main Stream Flooding Behaviour in the Marrangaroo Creek Catchment

Main stream flooding within the Marrangaroo Creek catchment is generally confined to undeveloped areas, with the following two notable exceptions:

- Within the Lithgow Correctional Centre, parts of which are shown to be inundated by floodwater at the 50 year ARI level of flooding (refer **Figure 6.3**, **Sheet 4**). It is noted that the access road into the Centre has a hydrologic standard of greater than 100 year ARI (refer **Figure 6.4**, **Sheet 4**). It is further noted that the Centre is located wholly on the floodplain of Marrangaroo Creek in an area where the depth of inundation will exceed 1 m during a PMF event (refer **Figure 6.6**, **Sheet 4**).
- In the vicinity of two rural residential properties which are located on the northern (downstream) side of Reserve Road along one of the tributary arms of Marrangaroo Creek (refer watercourse along which Peak Flow Identifier Q61 is located). While the watercourse meanders through these properties, a continuous overland flow path is shown to develop on its western (left) overbank at about the 50 year ARI level of flooding. It is noted that depths of flow along this continuous flow path generally do not exceed 300 mm at the 100 year ARI level of flooding.

Water levels in Marrangaroo Creek and its tributary arms generally commence to rise after about 1 hour after the commencement of heavy rain (refer **Figure 6.8**, **Sheets 4** and **5**). While long duration storms are generally critical for maximising peak flows (and hence flood levels) along the main arm of the creek (refer **Table F1** in **Appendix F** for critical storm durations), water levels along its tributary arms can reach their maximum within a 1-2 hour period after the commencement of heavy rain.

[12] Note that the longer duration storms are typically critical for maximising flows in Farmers Creek and its tributaries for the more frequent storm events. This is principally due to the increased initial loss associated with less intense rainfall events. **Table F1** in **Appendix F** gives the storm duration which is critical for maximising flows at various locations in the drainage system.

By inspection of the values set out in **Table G1** in **Appendix G**, the Great Western Highway will generally remain flood free for flood events up to about 50 year ARI, while Reserve Road will be inundated where it crosses two unnamed tributaries of Marrangaroo Creek during storms as frequent as 5 year ARI. It is noted that the inundation of Reserve Road will result in the isolation of several rural residential properties.

6.1.5. Areas Affected by Major Overland Flow

Areas affected by major overland flow within the Farmers Creek catchment are generally confined to the following areas:

- In the vicinity of Hartley Valley Road, Ramsay Street and Redgate Street in Vale of Clwydd (refer drainage line along which Peak Flow Identifier Q19 is located on Sheet 1 in the series). Several residential properties in this area are affected by major overland flow which occurs when the enclosed reach of a tributary arm of Vale of Clwydd Creek is surcharged. Surcharge of the enclosed reach of the drainage system commences at about the 5 year ARI level of flooding.
- Along the line of a stormwater drainage line which runs in a northerly direction from a location east of the Lithgow High School to the left (southern) bank of Farmers Creek downstream of the Tank Street bridge crossing (refer drainage line along which Peak Flow Identifiers Q27 and Q28 are located on Sheets 1 and 2 in the series). While ponding is shown to occur along the southern (upstream) side of the Main Western Railway line at the 5 year ARI level of flooding, major surcharge of the drainage line south (upstream) of this location does not occur until about the 50 year ARI level of looding, when several residential properties are affected by depths of overland flow greater than 100 mm. Major ponding is shown to occur along the southern (upstream) side of the Main Western Railway at the 100 year ARI level of flooding, with depths of inundation exceeding 1 m in several residential properties which back onto Gas Works Lane.
- In the upper reaches of the Sheedys Gully Tributary catchment where commercial development is affected by major overland flow which approaches the main arm of the watercourse north of Valley Drive (refer overland flow path east of Peak Flow Identifier Q33 on Sheet 2 in the series).
- Along the line of a stormwater drainage line which crosses the Main Western Railway line at Barton Street (refer drainage line along which Peak Flow Identifier Q37 is located on Sheet 2 in the series). Major ponding is shown to occur in Main Street and Barton Street at the 5 year ARI level of flooding. Several residential properties located to the south (upstream) of the Main Western Railway line between Academy Street and Laurence Street are also shown to be affected by overland flow at the 10 year ARI level of flooding.
- Along several stormwater drainage lines which control runoff in Littleton and South Littleton and cross the Main Western Railway line immediately south of the Jim Monaghan Athletics Track (refer overland flow paths along which Peak Flow Identifiers Q38, Q39, Q40, Q41, Q42 and Q43 on Sheet 2 in the series are located). While depths of overland flow along these flow paths are generally in the range 0-200 mm for storms up to 50 year ARI, major ponding is shown to occur along the southern (upstream) side of the Main Western Railway line at this level of flooding. At the 100 year ARI level of flooding, depths of overland flow exceed 500 mm in several residential properties that are located north (downstream) of Rabault Street.
- In the upper reaches of the Good Luck Hollow catchment, where several residential properties located immediately downstream of the detention basin which is located at the intersection of First Street and Munbinga Drive in South Littleton are affected by depths of

overland flow of up to 500 mm at the 100 year ARI level of flooding. The detention basin, which has been designed as an offline temporary storage area is surcharged at the 50 year ARI level of flooding.

- Along two overland flow paths which run through the developed part of South Bowenfels east (upslope) of the Great Western Highway (refer Sheet 3 in the series). Several residential properties are affected by overland flow which surcharges the road reserve along Bursaria Place at about the 50 year ARI level of flooding. Major ponding is also shown to occur at the 5 year ARI level of flooding in two residential properties that are located adjacent to the inlet of a transverse drainage line which crosses the Great Western Highway near Col Drewe Drive.

Several residential properties located to the south of the Lithgow Golf Club in the Marrangaroo Creek catchment are also affected by major overland flow at the 100 year ARI level of flooding (refer **Figure 6.4**, **Sheet 4**).

It will be necessary to develop an appropriate set of planning controls as part of the future *FRMS* which deal with future development in areas that are affected by major overland flow. The *IFPA* derived as part of the present investigation (refer **Section 6.5** for further details) includes areas which are affected by major overland flow.

6.2 Flood Hazard Zones and Floodways

6.2.1. Provisional Flood Hazard

Flood hazard categories may be assigned to flood affected areas in accordance with the procedures outlined in the Floodplain Development Manual (DIPNR, 2005). Flood prone areas may be provisionally categorised into *Low Hazard* and *High Hazard* areas depending on the depth of inundation and flow velocity. Flood depths as high as a metre, in the absence of any significant flow velocity, could be considered to represent Low Hazard conditions. Similarly, areas of flow velocities up to 2.0 m/s, but with small flood depths could also represent Low Hazard conditions.

A Provisional Hazard diagram for the 100 year ARI event in the study area based on Diagram L2 of DIPNR, 2005 is presented on **Figure 6.9**.

For the 100 year ARI, high hazard flooding along the tributary arms of both Farmers Creek and Marrangaroo Creek is generally confined to the inbank area of the channel system and areas where the depth of ponding exceeds 1 m. Along the main arms of the two creeks, high hazard flooding extends out onto the overbank area and in the case of Farmers Creek impacts existing development, principally in the Hermitage Flat area.

In areas affected by overland flow, high hazard flooding is present in the road network where relatively shallow but fast moving floodwater is present.

The Flood Hazard assessment presented herein is based on considerations of depth and velocity of flow and is *provisional* only. As noted in DIPNR, 2005, other considerations such as rate of rise of floodwaters and access to high ground for evacuation from the floodplain should also be taken into consideration before a final determination of Flood Hazard can be made. These factors would be taken into account in the future *FRMS* for the study catchments.

6.2.2. Floodways

According to DIPNR, 2005, the floodplain may be subdivided into the following three hydraulic categories:

- Floodways;
- Flood storage; and
- Flood fringe.

Floodways are those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with obvious naturally defined channels. Floodways are the areas that, even if only partially blocked, would cause a significant re-distribution of flow, or a significant increase in flood level which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow of areas where higher velocities occur.

Flood storage areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.

Flood fringe is the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.

Floodplain Risk Management Guideline No. 2 Floodway Definition, offers guidance in relation to two alternative procedures for identifying floodways. They are:

- **Approach A**. Using a *qualitative approach* which is based on the judgement of an experienced hydraulic engineer. In assessing whether or not the area under consideration was a floodway, the qualitative approach would need to consider; whether obstruction would divert water to other existing flow paths; or would have a significant impact on upstream flood levels during major flood events; or would adversely re-direct flows towards existing development.
- **Approach B**. Using the hydraulic model, in this case TUFLOW, to define the floodway based on *quantitative experiments* where flows are restricted or the conveyance capacity of the flow path reduced, until there was a significant effect on upstream flood levels and/or a diversion of flows to existing or new flow paths.

One quantitative experimental procedure commonly used is to progressively encroach across either floodplain towards the channel until the designated flood level has increased by a significant amount (for example 0.1 m) above the existing (un-encroached) flood levels. This indicates the limits of the hydraulic floodway since any further encroachment will intrude into that part of the floodplain necessary for the free flow of flood waters – that is, into the floodway.

The *quantitative assessment* associated with **Approach B** is technically difficult to implement. Restricting the flow to achieve the 0.1 m increase in flood levels can result in contradictory results, especially in unsteady flow modelling, with the restriction actually causing reductions in computed levels in some areas due to changes in the distribution of flows along the main drainage line.

Accordingly the *qualitative approach* associated with **Approach A** was adopted, together with consideration of the portion of the floodplain which conveys approximately 80% of the total flow. The findings of *Howells et al, 2004* who defined the floodway based on velocity of flow and depth were also taken into consideration. For example, Howells et al suggested the following criteria for defining those areas which operate as a "floodway" in a 100 year ARI event:

- Velocity x Depth greater than 0.25 m^2/s **and** Velocity greater than 0.25 m/s; or
- Velocity greater than 1 m/s.

Flood storage areas are identified as those areas which do not operate as floodways in a 100 year ARI event but where the depth of inundation exceeds 1 m. The remainder of the flood affected area was classified as flood fringe.

Figure 6.10 shows the division of the floodplain into floodway, flood storage and flood fringe areas at the 100 year ARI level of flooding.

As the main arm of Farmers Creek upstream of the Sandford Avenue road bridge is incised and of relatively high hydraulic capacity, the majority of the area affected by main stream flooding in a 100 year ARI event functions as a floodway. . The tributary arms of the Farmers Creek are similarly incised and of relatively high hydraulic capacity, resulting in these areas also functioning as a floodway.

The hydraulic capacity of Farmers Creek reduces downstream of the Sandford Avenue road bridge, with the result that areas which lie on its overbank also functioning as a floodway during a 100 year ARI event.

The areas of "flood storage" are confined to the major ponding areas which are located on the southern (upstream) side of the Main Western Railway line and also within the detention basins that have been constructed to control runoff in several parts of Lithgow.

In the Marrangaroo Creek catchment, the flood fringe areas are more pronounced given the flatter nature of the overbank area, especially on the portion of the floodplain which lies to the north of Reserve Road.

6.3 Sensitivity Studies

6.3.1. General

The sensitivity of the hydraulic model was tested to variations in model parameters such as hydraulic roughness and the partial blockage of hydraulic structures, including the local piped drainage system. The main purpose of these studies was to give some guidance on the freeboard to be adopted when setting floor levels of development in flood prone areas, pending the completion of the future *FRMS* for Lithgow. The results are summarised in the following sections.

6.3.2. Sensitivity to Hydraulic Roughness

Figure 6.11 shows the difference in peak flood levels (i.e. the "afflux") for the 100 year ARI storm resulting from an assumed 20% increase in hydraulic roughness compared to the values given in **Table 4.1**. The afflux is given in colour coded increments in metres and is shown along the creeks and stormwater drains, as well as in areas throughout the study area subject to overland flow. The sheets also identify areas where land is rendered flood free, or where additional areas of land are flooded.

The typical increase in peak flood level along the main arm of Farmers Creek is in the range 100 to 200 mm, with increases of up to 300 mm present at several locations. Increases in the range 300 to 500 mm are also present in the reach of channel which runs along the northern side of Marjorie Jackson Oval.

Increases in peak flood levels along the tributary arms of Farmers Creek are generally in the range 10 to 50 mm, with increases in the range 50 to 100 mm present in isolated locations. Increases in the depth of overland flow in the urbanised parts of Lithgow are typically in the range 10 to 50 mm.

The typical increase in peak flood level along the main arm of Marrangaroo Creek is in the range 100 to 200 mm, with increases of up to 300 mm present at several locations. Increases in peak flood levels in the range 10 to 50 mm are present along the tributary arms.

6.3.3. Sensitivity to Partial Blockage of Hydraulic Structures

The mechanism and geometrical characteristics of blockages in hydraulic structures and piped drainage systems are difficult to quantify due to lack of recorded data and would no doubt be different for each system and also vary with flood events. Realistic scenarios would be limited to waterway openings becoming partially blocked during a flood event (no quantitative data are available on instances of blockage of the drainage systems which may have occurred during historic flood events).

EA, 2013 includes guidance on modes of blockage which are likely to be experienced for different hydraulic structures. Bridge structures with clear opening heights up to 3 m are considered to be susceptible to blockage in streams where large floating debris is conveyed by floodwater, due to debris becoming lodged in the clear opening of the bridge. For bridges of all heights, EA, 2013 considers that debris is likely to also wrap around the bridge piers.

The impact on flood behaviour of an accumulation of debris at bridge structures was assessed assuming a 1 m thick raft of debris lodges beneath the underside of the deck and a 4 m wide raft of debris lodges on the upstream side of each bridge pier over the full height of the clear opening. Analyses were also carried out with the cross sectional areas of all pipes and culverts reduced by 50 per cent of their unobstructed areas. These blockage scenarios represent a case which is well beyond a blockage scenario which could reasonably be expected to occur and is presented for illustrative purposes.

Figure 6.12 shows the afflux for the 100 year ARI storm resulting from a partial blockage of hydraulic structures. The effects of blockage are greatest immediately upstream of hydraulic structures and in several locations results in a redistribution of flood flows across the floodplain. The increase in the volume of temporary flood storage upstream of major hydraulic structures also has the effect of reducing peak flows (and hence peak flood levels) in the downstream reach of the drainage system.

6.4 Climate Change Sensitivity Analysis

6.4.1. General

At the present flood study stage, the principal issue regarding climate change is the potential increase in flood levels and extents of inundation throughout the study area. In addition it is necessary to assess whether the patterns of flow will be altered by new floodways being developed for key design events, or whether the provisional flood hazard will be increased.

OEH recommends that its guideline *Practical Considerations of Climate Change, 2007* be used as the basis for examining climate change induced increases in rainfall intensities in projects undertaken under the State Floodplain Management Program and DIPNR, 2005. The guideline recommends that until more work is completed in relation to the climate change impacts on rainfall intensities, sensitivity analyses should be undertaken based on increases in rainfall intensities ranging between 10 and 30 per cent. On current projections the increase in rainfalls within the service life of developments or flood management measures is likely to be around 10 per cent, with the higher value of 30 per cent representing an upper limit. Under present day climatic conditions, increasing the 100 year ARI design rainfall intensities by 10 per cent would produce a 200 year ARI flood; and increasing those rainfalls by 30 per cent would produce a 500 year ARI event.

The impacts of climate change and associated effects on the viability of floodplain risk management options and development decisions may be significant and will need to be taken into account in the *FRMS* using site specific data.

In the *FRMS* it will be necessary to consider the impact of climate change on flood damages to existing development. Consideration will also be given both to setting floor levels for future development and in the formulation of works and measures aimed at mitigating adverse effects expected within the service life of development.

Mitigating measures which could be considered in the *FRMS* include the implementation of structural works such as levees and channel improvements, improved flood warning and emergency management procedures and education of the population as to the nature of the flood risk.

6.4.2. Sensitivity to Increased Rainfall Intensities

As mentioned, the investigations undertaken at the flood study stage are mainly seen as sensitivity studies pending more detailed consideration in the *FRMS*. For the purposes of the investigation, the design rainfalls for 200 and 500 year ARI events were adopted as being analogous to flooding which could be expected should present day 100 year ARI rainfall intensities increase by 10 and 30 per cent, respectively.

Figures 6.13 and **6.14** show the afflux resulting from an increase in 100 year ARI rainfall intensities by 10 and 30 per cent, respectively, while **Figure 6.15** shows the increase in the extent of land affected by overland flow should 100 year ARI rainfall intensities increase by either 10 and 30 per cent.

In general terms, peak 100 year ARI flood levels along the main arms of Farmers Creek and Marrangaroo Creek would be increased in the range 50 to 200 mm as a result of a 10 per cent increase in rainfall intensities and in the range 100 to 300 mm as a result of a 30 per cent increase in rainfall intensities. However, increases in peak 100 year ARI flood levels in the range 300 to 500 mm are shown to occur along the reach of Farmers Creek which runs around the northern side of Marjorie Jackson Oval and in parts of the Marrangaroo Creek catchment for the case where rainfall intensities are increased by 30 per cent. It is noted that increases in peak 100 year ARI flood levels do not translate into a significant increase in the extent of land affected by flooding.

No new major flow paths are shown to develop along the main arms of Farmers Creek and Marrangaroo Creek under the two assessed climate change scenarios. This is principally due to the well-defined nature of the floodplain at Lithgow.

Consideration of the abovementioned changes in flood behaviour will need to be given during the preparation of the future *FRMS*.

6.5 Selection of Interim Flood Planning Area and Levels

After consideration of the TUFLOW results and the findings of sensitivity studies outlined in **Section 6.3**, a freeboard allowance of 500 mm was adopted for determination of the *IFPL*'s for both main stream flooding and major overland flow. The associated *IFPA* for main stream flooding and major overland flow is shown on **Figure 6.16**.

Further consideration will need to be given during the preparation of the future *FRMS&P* to the setting of an appropriate freeboard for areas subject to major overland flow, given that the adopted value of 500 mm may be found to be too conservative. The adoption of an allotment based approach to the identification of individual properties subject to major overland flow related planning controls should also be considered.

7 REFERENCES

Austroads, 1994. *"Waterway Design. A Guide to the Hydraulic Design of Bridges, Culverts and Floodways"*.

Bewsher (Bewsher Consulting Pty Ltd), Bewsher, 1996. *"Flood Mitigation Works – Hermitage Flat, Lithgow – Stage 1 Report – Detailed Analysis of Flood Mitigation Options".*

Bewsher (Bewsher Consulting Pty Ltd), 2001. "*Flood Mitigation Works - Hermitage Flat, Lithgow – Options Assessment"*

Bewsher (Bewsher Consulting Pty Ltd), 2002. *"Flood Mitigation Works – Hermitage Flat, Lithgow – Review of Environmental Factors"*

Bewsher (Bewsher Consulting Pty Ltd), 2003. *"Flood Mitigation Works – Hermitage Flat, Lithgow – Environmental Documentation and Approvals"*

BOM (Bureau of Meteorology), 2003. *"The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"*.

CSIRO, 2007. *"Climate Change in the Hawkesbury Nepean Catchment".*

DECC (Department of Environment and Climate Change), 2007. *"Practical Consideration of Climate Change". Floodplain Risk Management Guideline.*

DWR (Department of Water Resources), 1988. *"Lithgow Flood Study"*

EA (Engineers Australia), 2013. *"Australian Rainfall & Runoff - Revision Projects – Project 11 – Blockage of Hydraulic Structures"*. Stage 2 Report P11/S2/021 dated February 2013.

IEAust (The Institution of Engineers Australia), 1998. *"Australian Rainfall and Runoff – A Guide to Flood Estimation"*, Volumes 1 and 2.

Jordan et al. (Jordan, P.W, Sih, K, Hill, P.I, Nandakumar, N, Weinmann, P.E, Nathan, R.J) (2011), *"Areal Reduction Factors for the Estimation of Design Rainfall Intensities for New South Wales and the Australian Capital Territory"* Hydrology and Water Resources Symposium, Brisbane

Kinhill (Kinhill Engineers Pty Ltd), 1991. *"Lithgow Floodplain Management Study"*

DIPNR (Department of Infrastructure, Planning and Natural Resources), 2005. *"Floodplain Development Manual – The Management of Flood Liable Land"*.

O'Loughlin, 1993. *"The ILSAX Program for Urban Stormwater Drainage Design and Analysis (User's manual for Microcomputer Version 2.13)"*, Civil Engineering Monograph 93/1, University of Technology, Sydney (5th printing, 1st version 1986).

Slaven, 1995. *"An Assessment of Vegetation in the Riparian Zones of Farmers Creek, Lithgow, NSW"*

Walsh et al (Walsh, M.A, Pilgrim, D.H, Cordery, I) (1991). *"Initial Losses for Design Flood Estimation in New South Wales"* Intn'l Hydrology & Water Resources Symposium, Perth.

8 FLOOD-RELATED TERMINOLOGY

Note: For an expanded list of flood-related terminology, refer to glossary contained within the Floodplain Development Manual, NSW Government, 2005).

TERM	DEFINITION
Afflux	Increase in water level resulting from a change in conditions. The change may relate to the watercourse, floodplain, flow rate, tailwater level etc.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger events occurring in any one year (see average recurrence interval).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The average period in years between the occurrence of a flood of a particular magnitude or greater. In a long period of say 1,000 years, a flood equivalent to or greater than a 100 year ARI event would occur 10 times. The 100 year ARI flood has a 1% chance (i.e. a one-in-100 chance) of occurrence in any one year (see annual exceedance probability).
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving (e.g. metres per second [m/s]).
Flood fringe area	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood Planning Area (FPA)	The area of land inundated at the Flood Planning Level.
Flood Planning Level (FPL)	A combination of flood level and freeboard selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans.
Flood prone land	Land susceptible to flooding by the Probable Maximum Flood. Note that the flood prone land is synonymous with flood liable land.
Flood storage area	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
Floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event (i.e. flood prone land).

TERM	DEFINITION
Floodplain Risk Management Plan	A management plan developed in accordance with the principles and guidelines in the *Floodplain Development Manual, 2005*. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
Floodway area	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	A factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted Flood Planning Level and the peak height of the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such and wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as “greenhouse” and climate change. Freeboard is included in the flood planning level.
High hazard	Where land in the event of a 100 year ARI flood is subject to a combination of flood water velocities and depths greater than the following combinations: 2 metres per second with shallow depth of flood water depths greater than 0.8 metres in depth with low velocity. Damage to structures is possible and wading would be unsafe for able bodied adults.
Low hazard	Where land may be affected by floodway or flood storage subject to a combination of floodwater velocities less than 2 metres per second with shallow depth or flood water depths less than 0.8 metres with low velocity. Nuisance damage to structures is possible and able bodied adults would have little difficulty wading.
Main Stream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
Merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well-being of the State’s rivers and floodplains.
Overland flow	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
Peak discharge	The maximum discharge occurring during a flood event.

TERM	DEFINITION
Peak flood level	The maximum water level occurring during a flood event.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land (i.e. the floodplain). The extent, nature and potential consequences of flooding associated with events up to and including the PMF should be addressed in a floodplain risk management study.
Probability	A statistical measure of the expected chance of flooding (see annual exceedance probability).
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall which actually ends up as stream flow, also known as rainfall excess.
Stage	Equivalent to water level (both measured with reference to a specified datum).

APPENDIX A
COMMUNITY NEWSLETTER AND QUESTIONNAIRE

LITHGOW FLOOD STUDY

Lithgow City Council has engaged consultants to undertake a *Flood Study* that will define flooding patterns along the main arms of the various creeks which run through the urbanised parts of Lithgow, as well as those located in future growth areas. The investigation will also define drainage patterns which arise as a result of surcharge of the local stormwater drainage system. The investigation will build upon the findings of previous studies which have been undertaken by Council in recent years, namely in relation to the flood mitigation works which are currently being implemented in the lower reaches of Farmers Creek in the Hermitage Flat area.

The *Flood Study* is an important step in the Floodplain Management Process for this area and will be managed by Council according to the NSW Government's Flood Prone Lands Policy. The Floodplain Management Process aims to build community resilience towards flooding through informing better planning of development, emergency management and community awareness.

The various stages of the *Flood Study* will be as follows:

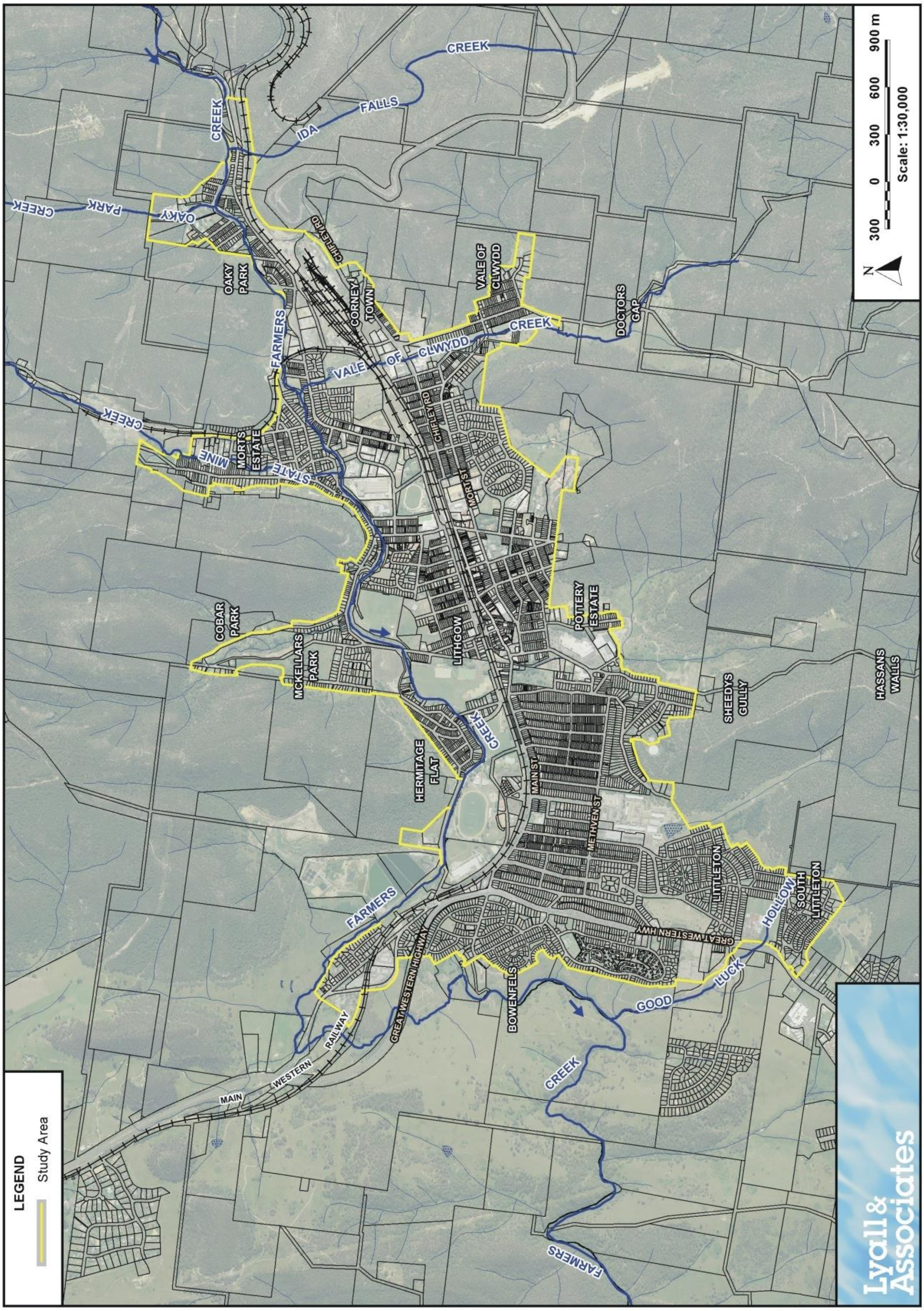
- Survey along the creek and collection of data on historic flooding.
- Preparation of computer models of the catchments to determine flows for both historic storms and design floods.
- Preparation of computer based hydraulic models of the creeks and floodplain to determine flooding and drainage patterns, flood levels and depths of overland flow.
- Preparation of a *Flood Study* report that will document the findings of the investigation. The draft *Flood Study* report will be placed on public exhibition following completion of the investigation seeking community feedback on its findings.

Whilst much of Lithgow has not been impacted by major flooding in recent years, surcharge of the local stormwater drianage system during storms which occurred in January 2011 and March 2013 did result in damage to property in several locations. To assist the consultant, information on historic flooding which you as a resident or business owner may have experienced in any part of Lithgow is being sought. Several questions relating to flooding and drainage paterns in the study area are set out on the attached Questionnaire. Please take a minute or two to read these questions and provide responses where you can. Please return your completed questionnaire by **Tuesday 17th December 2013** to one of the following:

- IN PERSON: LITHGOW CITY COUNCIL 180 MORT STREET LITHGOW
- BY MAIL: LITHGOW CITY COUNCIL PO BOX 19 LITHGOW NSW 2795
- BY EMAIL: MADDISON.BAILEY@LITHGOW.NSW.GOV.AU
- INFORMATION SESSIONS: FRIDAY 6/12/13 AND SATURDAY 7/12/13 IN COOK STREET PLAZA, AND SATURDAY 7/12/13 LITHGOW VALLEY PLAZA

Any information you provide will remain confidential and will only be used as statistical data for the *Flood Study.*

Community Newsletter


LEGEND
Study Area
N
300 0 300 600 900 m
Scale: 1:30,000
FARMERS CREEK
IDA FALLS CREEK
OAKY PARK CREEK
OAKY PARK
CHIFLEY RD
CORNEY TOWN
VALE OF CLWYDD
VALE OF CLWYDD CREEK
DOCTORS GAP
MORTS ESTATE
STATE MINE CREEK
MORT ST
COBAR PARK
MCKELLARS PARK
LITHGOW
POTTERY ESTATE
SHEEDYS GULLY
HASSANS WALLS
HERMITAGE FLAT
MAIN ST
METHVEN ST
LITTLETON
SOUTH LITTLETON
HOLLOW
GREAT WESTERN HWY
GREAT WESTERN HIGHWAY
BOWENFELS
GOOD LUCK CREEK
MAIN WESTERN RAILWAY
Lyall & Associates

STUDY AREA

LITHGOW
FLOOD STUDY

Lithgow CITY COUNCIL

Community Questionnaire

1. Contact Name: ______________________________

   Address: ______________________________

   Home Phone Number: ______________________________

   Mobile Number: ______________________________

   Email: ______________________________

2. How long have you lived in this location?

   _________ years

3. Has your property ever been inundated by stormwater from the streets or channels in the past?

   [ ] Yes [ ] No

   If yes, when did it occur and which part(s) of your property was affected? (Please provide a short description such as: duration of flooding, source of water, flow directions, etc. Refer example below.)

	Location	Date / Time / Description
[✓]	**EXAMPLE ONLY** Driveway	9 May 2013 @ 2 pm – driveway flooded from direction of street, continued for 10 – 15 minutes. Floodwaters continued through property down northern side of house.
[ ]	Driveway	
[ ]	Water level below floor level in building	
[ ]	Water level above floor level in building	
[ ]	Garage	
[ ]	Front yard	
[ ]	Backyard	
[ ]	Shed	
[ ]	Other (please specify)	

4. If stormwater flooding and local stormwater affected your property in the past, what damages occurred as a result?

____

____

____

5. Are you aware of any other flooding or local stormwater problems in the study area? (The attached map may be useful to mark the location of any problem areas).

____

____

____

6. Please provide dates of historic flooding, even if it is only the year in which the event occurred. Rank the floods from the most severe to the least severe.

1. __________ 2. __________ 3. __________ 4.__________

7. For the floods you have listed, do you have any records of the height the floodwaters reached? For example, a flood mark on a building, shed, fence, light pole, etc.

[ ] Yes [ ] No

If yes, please provide a short description of the location of the flood mark(s), maximum depth of flooding, source and or direction of water, etc. Refer example below.

	Location	**Maximum Depth (m)**	**Description**
[✓]	**EXAMPLE ONLY** Residential	0.3 m	9 May 2013, just after 2 pm - depth of floodwaters along northern side of house reached 0.3 m adjacent to front steps.
[ ]	Residential		
[ ]	Commercial		
[ ]	Park		
[ ]	Road/ Footpath		
[ ]	Other (please specify)		

8. Do you have any photos, videos or other evidence of the flood marks that you have identified?

[ ] Yes [ ] No

If yes, could you please provide as much detail as possible, including whether you would be willing to provide Council with electronic copies of any photos/videos? You may wish to email any flood data that you have directly to Council (refer email address below).

____

____

____

____

9. Do you have any information on pipe blockage or the inundation of local roads due to water surcharging the local stormwater drainage system?

[ ] Yes [ ] No

If yes, could you please identify the location? Could you also comment on the nature of the blockage and/or the duration and depth of the flooding in the local road network?

____

____

____

____

10. If you have any additional information which you believe would assist Council in completing the *Flood Study*, please provide details of such below. (Note that additional space is provided on the back of this page should you need it).

____

____

____

Thank you for your assistance in completing this Questionnaire.

For any further enquiries, please contact Ms Maddison Bailey on 6354 9999 or email

Maddison.Bailey@lithgow.nsw.gov.au

COMMENTS

Please write any further comments you may have here:

APPENDIX B
DETAILS OF AVAILABLE DATA

B1. COLLECTION OF MISCELLANEOUS DATA

B1.1 Airborne Laser Scanning Survey and Aerial Photography

The Lithgow City LGA was flown by Land and Property Information (**LPI**) in August 2013 for the purpose of preparing a DTM based on ALS survey. The Lithgow City LGA was flown at an unspecified altitude to the International Committee on Surveying and Mapping (ICSM) guidelines for digital elevation data with a 95% confidence interval on horizontal accuracy of ±800 mm and an unspecified vertical accuracy.

The DTM was sampled at regular intervals along the major watercourses to generate cross sections normal to the direction of flow. The ALS derived cross sections were then used as input to the Farmers Creek and Marrangaroo Creek TUFLOW models.

B1.2 Stormwater Pit and Pipe Network

At the commencement of the study, LCC provided a copy of its then current stormwater pit and pipe database in MAPINFO format. The database was generally limited to pipe/culvert dimensions and pit type. No information on grate or pipe invert levels were contained in the database. **Figure 2.2** (4 sheets) shows the extent of the stormwater pit and pipe network in Lithgow.

A review of the database showed that there were a large number of gaps in the data. Missing pit and pipe data were generally populated based on detailed structure survey and design drawings, supplemented by site inspections where possible. In some cases, assumptions were made regarding the size and alignment of missing pipes. Further details on the adjustments that were made to LCC's pit and pipe database are given in **Section 4.3.1** of the report.

B1.3 Cross Section and Structure Survey

Casey Surveying and Design Pty Ltd were engaged to undertake a cross section survey in areas where dense tree cover was judged to reduce the accuracy of the DTM derived cross sections.

Cross section data was provided as tabulations of offset versus elevation in an Excel spreadsheet. An AutoCAD file was also provided in the MGA co-ordinate system showing the extent of each cross section. A photographic record of each cross section was also compiled by the surveyor.

The cross sections which have been used to define the waterway area of the major watercourses in the study area have been colour coded on **Figure 2.1** (4 sheets) to differentiate between those that were surveyed by Casey Surveying and Design Pty Ltd (refer orange coloured lines) and those that were derived using the ALS survey data (refer yellow coloured lines).

Casey Surveying and Design Pty Ltd were also engaged to undertake survey of the hydraulic structures that are located along the major watercourses. Pipe and box culvert structure survey was provided as tabulations of invert location (in MGA co-ordinate system), elevation, size and number of barrels in an Excel spreadsheet. Where the structure was a bridge, the survey was provided in a similar format as the cross sections. A photographic record of each structure was compiled by the surveyor.

B1.4 Stormwater Drainage Works

LCC provided design plans of drainage lines at various locations throughout the study area. The plans were used to fill in the gaps contained in LCC's stormwater pit and pipe database.

LCC provided detailed design plans of the Farmers Creek Stage 2 Channel Upgrade works. The plans provided details of the enlarged waterway area of Farmers Creek in the vicinity of Hermitage Flat.

B1.5 Historic Stream Data

DPIOW's Mount Walker stream gauge (GS 212042) is located on Farmers Creek approximately 7 km (by creek) downstream of the Great Western Highway road bridges. Historic flows in Farmers Creek have been recorded at the gauge site since it was first installed in September 1980.

Appendix E contains annual peak height and discharge data for DPIOW's Mount Walker stream gauge for the period 1981 to 2013. It is noted that the stream gauge was shifted upstream a short distance in September 2007 while the zero on the gauge, which is to an assumed datum, was maintained. Due to flood slope in Farmers Creek, direct comparison should not be made of recorded gauge heights either side of this date.

B1.6 Historic Rainfall Data

There was no BoM or SWC operated pluviographic stations located in or immediately adjacent to the study catchments. However, rainfall data were available for five pluviographic rain gauges operated by SWC at various periods of time after 1990 within a 20 km radius of Lithgow. These gauges, the locations of which some are shown on **Figure 1.1**, are:

- Lisdale State Forest (GS 563048), which is located 11 km north-west of Lithgow;
- Newnes State Forest (East Boundary Road) (GS 563074), which is located 14 km north-east of Lithgow;
- Lowther (Duddawarra) (GS 563073), which is located 15 km south of Lithgow; and
- Mt Victoria STP (GS 563148) and Mt Victoria (GS 563149), which are located 15 km south-east of Lithgow.

In addition to the above, rainfall data were available for seven BoM operated pluviographic rain gauges that area located within a 16 – 45 km radius of Lithgow. These gauges, the locations of which some are also shown on **Figure 1.1**, are:

- Newnes Junction Old Mill Site (GS 63268), which is located 16 km north of Lithgow;
- Mount Boyce AWS (GS 63292), which is located 20 km south of Lithgow; and
- Katoomba (Murris St) (GS 63039), which is located 30 km south-east of Lithgow;
- Oberon (Springbank) (GS 63063), which is located 35 km south-west of Lithgow;
- Kurrajong Heights (Bells Line of Road) (GS 63043) which is located 40 km east of Lithgow;
- Oberon (Jenolan Caves) (GS 63293), which is located 38 km south-west of Lithgow; and
- Bathurst Airport AWS (GS 63291), which is located 45 km west of Lithgow.

A pluviographic rain gauge has also been in operation at the location of DPIOW's Mount Walker stream gauge (GS 212042) since December 2000.

Daily rainfall totals were available for various gauge sites in the vicinity of Lithgow which gave an indication of the spatial distribution of rainfall for historic events.

B1.7 Previous Reports

Historic flood data, including several flood marks were extracted from the following reports:

- Lithgow Flood Study (DWR, 1988).
- Lithgow Floodplain Management Study (Kinhill, 1991).
- Flood Mitigation Works at Hermitage Flat, Lithgow – Options Assessment (Bewsher, 2001).

APPENDIX C
PLATES SHOWING HISTORIC FLOODING BEHAVIOUR IN LITHGOW – FEBRUARY 1990 STORM

	
Plate 1 – Farmers Creek. View from rear of No. 47 Coalbrook Street looking downstream towards Albert Street.	**Plate 2** - View across Farmers Creek from No. 47 Coalbrook Street at Glanmire Oval.
	
Plate 3 – Water ponding in the rear of No. 47 Coalbrook Street.	**Plate 4** – Farmers Creek behind No. 47 Coalbrook Street.

APPENDIX D

PLATES SHOWING HISTORIC FLOODING BEHAVIOUR IN LITHGOW – FEBRUARY 2013 STORM

Plate 5 – Water ponding in Ramsay Street after flood peak.

Plate 6 – Flooding in front of Nos. 63 and 65 Hartley Valley Road.

Plate 7 – Floodwaters between Nos. 61 and 63 Hartley Valley Road.

APPENDIX E
FARMERS CREEK AT MOUNT WALKER STREAM GAUGE (GS 212042) DATA

TABLE E1
RECORDED ANNUAL PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER MOUNT WALKER STREAM GAUGE[(1)]

Year	Peak Height (m)	Peak Discharge (m^3/s)
1981	2.351	153
1982	0.839	4
1983	1.519	38
1984	1.279	21
1985	0.982	8
1986	2.307	146
1987	1.062	10
1988	1.667	54
1989	1.332	24
1990	2.126	119
1991	0.953	9
1992	1.536	44
1993	1.127	16
1994	1.119	15
1995	1.131	16
1996	1.095	14
1997	1.001	11
1998	2.135	119
1999	1.404	33
2000	1.585	50
2001	0.996	10
2002	1.425	35
2003	1.253	23
2004	1.378	31
2005	1.268	24
2006	1.645	56
2007	1.403	33
2008	1.685	60
2009	1.809	74
2010	1.492	41
2011	2.498	184
2012	1.768	69
2013	2.443	174

1. Note that the stream gauge was shifted upstream a short distance in September 2007 while the zero on the gauge, which is to an assumed datum, was maintained. Due to flood slope in Farmers Creek, direct comparison should not be made of recorded gauge heights either side of this date.

TABLE E2
RECORDED ANNUAL PEAK HEIGHT AND DISCHARGE DATA IN ORDER OF MAGNITUDE MOUNT WALKER STREAM GAUGE(1)

Year	Peak Height (m)	Peak Discharge (m^3/s)
2011	2.498	184
2013	2.443	174
1981	2.351	153
1986	2.307	146
1998	2.126	119
1990	2.135	119
2009	1.809	74
2012	1.768	69
2008	1.685	60
2006	1.645	56
1988	1.667	54
2000	1.585	50
1992	1.536	44
2010	1.492	41
1983	1.519	38
2002	1.425	35
1999	1.404	33
2007	1.403	33
2004	1.378	31
1989	1.332	24
2005	1.268	24
2003	1.253	23
1984	1.279	21
1995	1.127	16
1993	1.131	16
1994	1.119	15
1996	1.095	14
1997	1.001	11
1987	1.062	10
2001	0.996	10
1991	0.953	9
1985	0.982	8
1982	0.839	4

1. Note that the stream gauge was shifted upstream a short distance in September 2007 while the zero on the gauge, which is to an assumed datum, was maintained. Due to flood slope in Farmers Creek, direct comparison should not be made of recorded gauge heights either side of this date.

APPENDIX F
PEAK FLOWS DERIVED BY TUFLOW MODEL

TABLE F1
SUMMARY OF PEAK FLOWS
(m^3/s)

ID	Tributary	Location	Type	5 year ARI		10 year ARI		50 year ARI		100 year ARI		200 year ARI		PMF	
				Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)
Q01	Farmers Creek	Inflow to TUFLOW Model	Total	35.0	720	47.1	540	89.3	540	112.4	540	126.7	540	988	90
Q02	Farmers Creek	Brewery Lane	Total	43.7	720	58.6	540	111.4	540	140.7	540	159.0	540	-	-
Q03	Farmers Creek	Mills Street Causeway	Total	46.5	720	60.5	540	115.1	540	147.8	540	167.1	540	-	-
Q04	Farmers Creek	Victoria Avenue	Total	47.0	720	62.3	540	116.9	540	149.1	540	168.6	540	-	-
Q05	Farmers Creek	Lithgow State Mine Railway	Total	48.8	720	63.8	540	122.6	540	153.6	540	173.5	540	-	-
Q06	Farmers Creek	Atkinson Street	Total	63.1	720	79.3	540	148.8	540	190.0	540	214.2	540	-	-
Q07	Farmers Creek	Tank Street	Total	75.6	720	97.1	540	180.3	540	230.0	540	258.7	540	-	-
Q08	Farmers Creek	Sandford Avenue	Total	85.7	720	107.8	540	197.1	540	249.2	540	301.2	540	-	-
Q09	Farmers Creel	Albert Street	Total	99.6	720	123.9	540	220.0	540	279.1	540	323.8	540	-	-
Q10	Farmers Creek	Geordie Street	Total	105.4	720	130.5	540	222.7	540	281.2	540	320.6	540	-	-
Q11	Farmers Creek	Cooerwull Road	Total	115.4	720	141.9	540	250.5	540	320.8	540	366.5	540	-	-
Q12	Farmers Creek	Great Western Highway	Total	117.1	720	144.4	540	255.5	540	329.3	540	374.7	540	2340	180
Q13	Farmers Creek	Downstream Extent of Two-Dimensional Model	Total	124.3	720	154.2	540	273.7	540	354.5	540	399.1	540	2611	180
Q14	Lithgow Valley Gully	Bells Road	Total	5.0	720	6.6	540	13.0	540	16.6	540	18.8	540	163	90
Q15	Ida Falls Creek	Main Western Railway Corridor	3060 mm Wide Brick Arch	5.0	720	7.2	540	14.1	540	17.1	360	19.9	360	98	90
Q16	Oakey Park Creek	Upstream Farmers Creek Confluence	Total	5.1	540	7.3	720	10.1	540	17.7	120	21.1	120	-	-
Q17	Unnamed Tributary	Main Western Railway Corridor	1 off 900 RCP	1.5	540	1.6	720	1.6	720	1.7	120	1.7	120	2	15
Q18	Vale of Clwydd Creek	Inflow to TUFLOW Model	Total	6.5	720	8.5	540	16.4	540	21.6	540	24.5	540	213	90
Q19	Vale of Clwydd Tributary	Upstream Redgate Street	Total	3.7	540	5.0	720	8.4	720	12.5	120	14.9	120	94	30
Q20	Vale of Clwydd Creek	Mort Street	Total	10.1	720	13.0	540	23.3	540	29.0	540	32.6	540	-	-
Q21	Vale of Clwydd Creek	Chifley Road	Total	12.0	720	16.0	540	30.9	540	42.9	540	50.3	120	390	90
Q22	Vale of Clwydd Creek	Main Western Railway Corridor	3 off 3330 x 2200 RCBC's	11.9	720	16.0	540	28.4	540	35.3	540	39.6	540	83	90
Q23	Unnamed Tributary	Main Western Railway Corridor	1 off 500 RCP	0.4	90	0.5	90	0.5	120	0.5	120	0.5	120	1	45
Q24	State Mine Creek	State Mine Gully Road	Total	7.2	720	9.6	540	18.5	540	24.1	540	27.2	540	236	90
Q25	State Mine Creek	550 m Downstream State Mine Gully Road	Total	10.5	720	14.2	540	26.8	540	34.3	540	38.4	540	320	90

TABLE F1 (Cont'd)
SUMMARY OF PEAK FLOWS
(m^3/s)

ID	Tributary	Location	Type	5 year ARI		10 year ARI		50 year ARI		100 year ARI		200 year ARI		PMF	
				Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)
Q26	State Mine Creek	Laidley Street	Total	11.7	720	16.3	540	30.2	540	38.2	720	43.3	720	-	-
Q27	Unnamed Tributary	Lithgow High School	Total	3.0	720	4.0	720	5.4	720	11.3	120	13.4	120	79	15
Q28	Unnamed Tributary	Main Western Railway Corridor	1 off 1500 RCP	3.5	540	3.9	540	4.9	540	5.1	540	5.4	540	7	45
Q29	Unnamed Tributary	Main Western Railway Corridor	1 off 1500 RCP	1.1	540	1.5	540	1.9	540	2.0	540	2.1	540	5	45
Q30	McKellars Park Tributary	Downstream Gell Street	Total	4.5	540	6.0	540	9.9	720	14.3	120	16.6	120	102	45
Q31	McKellars Park Tributary	Upstream Sandford Avenue	1 off 450 RCP	9.5	540	12.9	540	21.5	720	32.0	120	38.0	120	240	90
Q32	Unnamed Tributary	Main Western Railway Corridor	Pipe	0.3	540	0.4	540	0.4	60	0.4	120	0.4	120	-	-
Q33	Sheedys Gully Tributary	Upstream Valley Drive	Total	5.5	720	7.3	540	14.1	540	17.7	540	19.7	360	-	-
Q34	Sheedys Gully Tributary	Queen Elizabeth Park	Total	9.5	720	12.5	540	23.7	540	28.8	540	32.4	360	295	90
Q35	Sheedys Gully Tributary	Main Western Railway Corridor	1 off 2100 RCP	8.1	720	8.6	540	9.7	540	10.0	540	10.2	540	12	90
			Overland	2.3	720	5.0	540	15.5	540	20.7	540	24.2	540	280	90
Q36	Unnamed Tributary	Main Western Railway Corridor	1 off 1000 RCP	1.2	540	1.3	90	1.7	90	1.7	120	1.8	120	2	45
Q37	Unnamed Tributary	Main Western Railway Corridor	1 off 750 RCP	1.0	90	1.0	90	1.0	90	1.0	120	1.1	120	1	90
			Overland	1.4	90	2.1	90	4.5	90	6.0	120	7.6	120	66	90
Q38	Unnamed Tributary	Finlay Avenue	Total	3.1	540	4.5	540	7.5	720	9.4	120	10.8	120	54	60
Q39	Unnamed Tributary	Upstream Amiens Street	1 off 600 RCP	0.5	720	0.6	720	0.7	720	0.8	120	0.8	120	1	30
			Overland	0.8	720	1.2	720	2.4	720	4.5	120	5.6	120	39	30
Q40	Unnamed Tributary	Endeavour Park	Total	2.8	540	3.8	540	5.6	720	7.4	120	8.8	120	41	45
Q41	Unnamed Tributary	Downstream Martini Parade	1 off 1150 x 1000 RCBC	3.0	540	3.3	540	3.8	540	3.8	360	3.8	360	4	60
			Overland	0.8	540	2.0	540	4.1	540	4.7	360	5.4	360	-	-
Q42	Unnamed Tributary	Enfield Avenue	1 off 1700 x 1050 RCBC	3.4	90	4.5	540	4.7	540	4.8	360	4.8	120	5	45
			Overland	0.3	90	0.6	540	3.8	540	5.4	360	8.5	120	-	-
Q43	Unnamed Tributary	Main Western Railway Corridor	Total	7.8	540	10.3	540	16.2	540	19.2	540	21.5	360	-	-
Q44	Unnamed Tributary	Downstream Great Western Highway	Total	6.3	540	8.4	720	12.2	720	17.5	120	22.1	120	90	180
Q45	Good Luck Hollow	James O'Donnell Drive	Culvert	2.1	540	2.5	540	3.5	540	4.8	360	6.3	540	44	45

TABLE F1 (Cont'd)
SUMMARY OF PEAK FLOWS
(m^3/s)

ID	Tributary	Location	Type	5 year ARI		10 year ARI		50 year ARI		100 year ARI		200 year ARI		PMF	
				Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)	Discharge (m^3/s)	Critical Duration (min)
Q46	Good Luck Hollow	Upstream Confluence with Farmers Creek	Total	3.9	540	4.8	540	7.2	720	12.9	120	14.5	120	93	180
Q47	South Bowenfels Tributary	Upstream Confluence with Farmers Creek	Total	1.0	720	1.3	90	3.1	90	3.7	90	4.0	90	26	15
Q48	Marrangaroo Creek	Local Access Road	Total	68.2	720	86.6	540	162.0	540	215.0	540	242.3	540	2040	120
Q49	Marrangaroo Creek	-	Total	73.6	720	93.1	540	169.0	540	227.9	540	257.0	540	-	-
Q50	Marrangaroo Creek	Disused Railway Line	Total	75.6	720	95.3	540	173.3	540	236.4	540	267.1	540	-	-
Q51	Marrangaroo Creek	-	Total	85.0	720	108.6	540	187.4	540	255.2	540	287.1	540	-	-
Q52	Marrangaroo Creek	Great Western Highway	Total	91.7	720	113.9	540	201.7	540	271.0	540	300.7	540	2400	150
Q53	Marrangaroo Creek	Downstream Extent of Two-Dimensional Model	Total	91.2	720	113.5	540	203.0	540	280.9	540	320.8	540	2467	180
Q54	Unnamed Tributary	-	Total	3.4	540	5.2	540	8.8	540	11.9	270	14.0	270	109	60
Q55	Unnamed Tributary	-	Total	1.4	540	2.0	720	2.9	540	4.8	120	5.7	120	35	30
Q56	Unnamed Tributary	-	Total	5.4	540	7.9	540	13.4	540	18.6	120	22.6	120	162	45
Q57	Unnamed Tributary	-	Total	5.5	540	8.3	540	15.1	540	20.9	120	25.2	120	183	45
Q58	Unnamed Tributary	-	Total	2.4	540	3.5	540	5.8	540	8.8	270	10.6	120	82	30
Q59	Unnamed Tributary	-	Total	2.5	540	3.7	540	6.3	540	9.7	120	11.8	120	93	45
Q60	Unnamed Tributary	-	Total	1.5	540	2.3	540	4.4	540	6.2	270	7.0	270	68	45
Q61	Unnamed Tributary	Upstream Reserve Road	Total	9.1	540	13.7	540	27.1	540	37.7	120	45.5	120	357	45
			Total	1.9	540	2.7	540	4.4	540	6.6	120	8.0	120	69	45
Q63	Unnamed Tributary	Upstream Confluence with Marrangaroo Creek	Total	8.9	720	15.3	540	32.5	540	44.3	120	52.9	120	400	120
Q64	Unnamed Tributary	-	Total	1.5	540	2.1	720	3.0	540	5.5	120	6.6	120	37	30
Q65	Unnamed Tributary	-	Total	5.8	540	8.0	540	13.0	540	18.6	120	22.5	120	182	30
Q66	Unnamed Tributary	-	Total	6.4	540	9.3	540	16.8	540	23.3	120	28.1	120	157	150
Q67	Unnamed Tributary	Reserve Road	Total	6.6	720	10.2	540	18.2	540	22.1	540	24.9	540	175	150
Q68	Unnamed Tributary	Parallel to Great Western Highway	Total	1.2	540	1.7	720	2.4	540	4.7	120	5.4	120	28	30
Q69	Unnamed Tributary	-	Total	0.8	540	0.9	540	1.1	540	1.7	120	2.0	120	19	30

APPENDIX G
FLOOD DATA FOR INDIVIDUAL ROAD AND PEDESTRIAN CROSSINGS

TABLE G1
FLOOD DATA FOR INDIVIDUAL ROAD AND PEDESTRIAN CROSSINGS AT LITHGOW

ID[1]	Tributary	Location	Road Level	5 year ARI			10 year ARI			50 year ARI			100 year ARI			200 year ARI			PMF		
				Time at Which Overtopping Occurs	Maximum Duration of Inundation	Maximum Depth of Inundation	Time at Which Overtopping Occurs	Maximum Duration of Inundation	Maximum Depth of Inundation	Time at Which Overtopping Occurs	Maximum Duration of Inundation	Maximum Depth of Inundation	Time at Which Overtopping Occurs	Maximum Duration of Inundation	Maximum Depth of Inundation	Time at Which Overtopping Occurs	Maximum Duration of Inundation	Maximum Depth of Inundation	Time at Which Overtopping Occurs	Maximum Duration of Inundation	Maximum Depth of Inundation
			(m AHD)	(hr:min)	(hr:min)	(m)	(hr:min)	(hr:min)	(m)	(hr:min)	(hr:min)	(m)	(hr:min)	(hr:min)	(m)	(hr:min)	(hr:min)	(m)	(hr:min)	(hr:min)	(m)
Q02	Farmers Creek	Brewery Lane	931.7	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	1:45	0:45	0.1	0:15	3:45	3.2
Q03		Mills Street Causeway	927.9	0:00	> 12	1.5	0:00	> 12	1.7	0:00	> 12	2.2	0:00	> 12	2.3	0:00	> 12	2.4	0:00	> 5	6.1
-		Hay Street Pedestrian Bridge	932.0	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	0:30	2:15	1.9
Q04		Victoria Avenue	927.8	NF	NF	NF	NF	NF	NF	2:30	3:45	0.5	0:45	4:30	0.6	0:45	4:45	0.7	0:15	4:30	3.8
Q06		Atkinson Street	920.2	NF	NF	NF	NF	NF	NF	NF	NF	NF	2:00	0:45	0.1	1:30	1:15	0.2	0:15	3:45	3.5
Q07		Tank Street	915.2	NF	NF	NF	NF	NF	NF	5:00	0:45	0.1	1:30	1:45	0.4	1:15	2:00	0.6	0:15	4:15	4.9
Q08		Sandford Avenue	914.3	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	1:00	1:30	0.7
Q09		Albert Street	908.4	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	0:15	3:45	4.2
-		Coalbrook Street Pedestrian Bridge	907.1	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	0:30	3:15	2.3
Q10		Geordie Street	901.1	0:30	> 12	1.5	0:30	> 12	1.7	0:15	> 12	2.3	0:15	> 12	2.6	0:15	> 12	2.8	0:00	> 5	5.8
Q11		Cooerwull Road	897.6	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	0:45	3:00	3.7
Q12		Great Western Highway	903.4	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF
Q20	Vale of Clwydd Creek	Mort Street	941.1	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	0:15	1:30	0.9
Q21		Chifley Road	931.2	NF	NF	NF	NF	NF	NF	4:00	1:30	0.5	0:45	2:15	0.6	0:30	2:45	0.7	0:15	4:00	1.8
Q22		Main Western Railway Corridor	930.4	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	0:15	3:00	1.8
Q24	State Mine Creek	State Mine Gully Road	951.9	NF	NF	NF	NF	NF	NF	NF	NF	NF	1:15	1:15	0.1	1:00	1:30	0.2	0:00	3:45	1.5
-		State Mine Gully Road	945.5	NF	NF	NF	NF	NF	NF	NF	NF	NF	1:30	0:45	0.2	1:15	1:15	0.3	0:15	3:30	1.7
Q26		Laidley Street	919.0	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF	0:15	3:30	3.2
Q31	McKellars Park Tributary	Sandford Avenue	913.7	NF	NF	NF	NF	NF	NF	3:45	1:00	0.1	0:30	1:15	0.2	0:30	1:30	0.3	0:00	3:45	4.1
Q52	Marrangaroo Creek	Great Western Highway	910.4	NF	NF	NF	NF	NF	NF	6:30	1:15	0.1	2:00	2:30	0.6	1:45	3:45	0.8	0:30	4:15	7.5
Q56	Unnamed Tributary	Reserve Road	921.8	9:30	0:00	0.1	7:30	1:45	0.2	7:30	1:45	0.2	1:00	4:30	0.7	0:45	4:15	0.7	0:15	3:45	1.4
Q57		Reserve Road	912.6	NF	NF	NF	10:15	0:00	0.1	10:15	0:00	0.1	1:00	2:30	0.8	1:00	3:15	0.8	0:30	4:15	5.5

1. Refer **Figures 6.1** to **6.6** for location of road crossings.
2. Times relate to time (hr:min) after the onset of heavy rain.
3. Times rounded to nearest 15 minutes.
4. Depths rounded to nearest 0.1 m.
5. NF = Not Flooded.