STROUD FLOOD STUDY

FINAL
MARCH 2012

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<tr>
<td>Great Lakes Council</td>
<td>Mr Geoff Love</td>
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<table>
<thead>
<tr>
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<tr>
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# STROUD FLOOD STUDY

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FOREWORD

The NSW State Government’s Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any 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 Government 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 four sequential stages:

1. **Flood Study**
   - Determine the nature and extent of the flood problem.

2. **Floodplain Risk Management**
   - 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.

This study was funded jointly by the NSW Department of Environment, Climate Change and Water and by Great Lakes City Council on a 2:1 basis.
EXECUTIVE SUMMARY

Stroud lies near the confluence of Mill Creek and Lamans Creek, which join approximately 1km downstream of the centre of the township, and then flow into the Karuah River approximately 1km further downstream. Bucketts Way is the main thoroughfare through Stroud, crossing Mill Creek at the northern edge of town, and Lamans Creek to the south (Figure 1). Mill Creek has a catchment area of 120 km$^2$ and Lamans Creek an area of 20 km$^2$ at the Bucketts Way crossings. Mill and Lamans Creeks have experienced several significant floods in the past century, although no regular flood records exist. Some recorded flood levels exist for Mill and/or Lamans Creek from February 1956, October 1985 and June 2007, with the 1956 event remembered as the largest on record. A previous study documenting historical flooding in Stroud was undertaken in 1986 (Reference 3).

The present Flood Study has been commissioned by Great Lakes Council, whose local government area (LGA) includes the town of Stroud. This study considers flooding in Stroud from Mill and Lamans Creeks, as well as backwater flooding from the Karuah River and flooding of smaller catchments (at localised structures such as road crossings) within the township itself.

Stroud has a population approaching 700 and has undergone moderate growth over the last 10 years. Continued growth may result in expansion of existing urban areas and development of previously un-developed or rural land, some of which is likely to be on the fringes of the floodplain. It is therefore important that appropriate tools and information to assess flood risk are available for planning future development in the area.

OBJECTIVES

The key objective of this Flood Study is to develop a suitable hydraulic model that can be used to assist Great Lakes Council in the development of an updated Floodplain Risk Management Plan for the study area to consider both existing and future development. No hydraulic modelling of the study area has previously been completed, with the previous study in 1986 primarily comprising interpolation of historically recorded flood levels from Mill and Lamans Creeks.

The primary objectives of the study are:

- to determine the flood behaviour including design flood levels and velocities over the full range of flooding up to and including the PMF from the Mill and Lamans Creek catchments;
- to provide a model that can establish the effects on flood behaviour of future development;
- to undertake a flood damages assessment to assess the extent of the flood problem in Stroud;
- to assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities; and
- to assess the hydraulic categories and undertake provisional hazard mapping.
A glossary of flood related terms is provided in Appendix A.

**APPROACH**

In view of the above, the broad approach adopted for this study was to use a widely regarded hydrologic model to estimate catchment runoff using design rainfall patterns specified in Reference 1, and the runoff hydrographs were then used in an appropriate hydraulic model to estimate flood depths, velocities and hazard in the study area.

**CALIBRATION**

For this study there are insufficient pluviometer and streamflow records available to undertake a meaningful calibration of the hydrologic model. Although there are pluviometers at Chichester Dam and Gloucester, they are too far away to provide a reliable record of the temporal pattern at Stroud.

Although historic flood levels are available at several locations, there were insufficient historic rainfall data to undertake modelling of the historic flood events, since the inflows are unknown (refer to Section 5.2). In the absence of definitive information about historical flood events, the models were configured using typical or recommended parameters. The design flood behaviour estimated using this process was then compared to historical observed flood levels, to provide a limited “ball-park” validation of the modelling. The sensitivity of the model results to adopted model parameters was assessed to identify the level of uncertainty in the modelled flood behaviour. While this approach does not constitute a comprehensive calibration, it was considered to provide a reasonable check of the design flood results with the available historic information.

**HYDROLOGIC MODEL**

The Watershed Bounded Network Model (WBNM) was used to estimate catchment flows. The WBNM model is an event-based, lumped-catchment conceptual model that is based on an extensive empirical dataset of rainfall-runoff relationships for Australian catchments. The model was originally developed for natural catchments, and is therefore particularly suited for estimating inflows from the rural upper catchments of Mill and Lamans Creeks. The model requires very few parameters to describe the physical aspects of the catchment, and is therefore less sensitive to assumptions about catchment characteristics such as shape, steepness, and ground cover. WBNM was therefore considered a suitable tool for this study, in light of the lack of calibration data and detailed physical information about the catchment. WBNM has been widely adopted in Australia for use in similar studies.

**HYDRAULIC MODEL**

A hydraulic model was established for the study using the TUFLOW package. The upstream extents of the model are 3.5km upstream of the Bucketts Way crossing for the Mill Creek floodplain, and 2.5km upstream of the Bucketts Way crossing for the Lamans Creek floodplain.
A grid cell size of 5m x 5m was adopted, and the model was established from a combination of high density aerial survey for the terrain model, localised detail survey of hydraulic structures, and aerial photographs to delineate vegetation extents. The model includes a small reach of the Karuah River at the downstream end, to assess the effect of backwater floods from the Karuah River, and extends downstream approximately 0.8km beyond the Mill Creek/ Karuah River confluence. The model extent is indicated on Figure 8.

The following approach was adopted to incorporate co-incident flooding of the Karuah River in the design flood estimates:

<table>
<thead>
<tr>
<th>Flood (AEP)</th>
<th>Study Event</th>
<th>Mill Creek / Lamans Creek (AEP)</th>
<th>Karuah River Event (AEP)</th>
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<tr>
<td>PMF</td>
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SENSITIVITY ANALYSIS

From the sensitivity analysis, it was concluded that the principal factors that influence the modelled flood behaviour are the magnitude and timing of runoff flows and the Manning’s “n” roughness parameter. Peak flood levels were found to vary slightly as a result of variation of other model inputs, such as energy loss at bridge structures in the floodplain and Karuah River joint probability.

CLIMATE CHANGE

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events at Stroud under warmer climate scenarios.

In light of this uncertainty, the NSW State Government advice (Reference 6) recommends sensitivity analysis on flood modelling be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

The effect of increasing the design rainfalls by 10%, 20% and 30% has been evaluated for the 100 year ARI event, resulting in a relatively significant impact on peak flood levels in the study area. Generally speaking, each incremental 10% increase in flow results in a 0.15 m to 0.2 m
increase in peak flood levels on the Mill and Lamans Creek floodplains.

**RESULTS**

Peak flood level profiles for the creeks are presented in Figure 11 and Figure 12. The recorded flood levels from 1956, 1985 and 2007 are indicated on the plots to provide historical context for the estimated design flood results. Figure 13 shows design flood hydrographs just upstream of the Bucketts Way bridge in Mill Creek and Lamans Creek. Lamans Creek exhibits a faster rate of rise than Mill Creek, and is more significantly affected by backwater effects from the Karuah River in larger floods. This finding agrees with observations from Reference 3 and from the interviews with residents. Maps of estimated design flood depths, velocities and provisional hydraulic hazard are presented from Figure 14 to Figure 26.

It is considered that the design flood levels adopted reflect the best estimate of the model inputs with available information, and based on experience with other studies. However it is noted that variation of some of the above assumptions could result in localised changes to the estimated flood levels. Accuracy of the estimated flood levels is expected to be of the order of +/-0.5m. The accuracy can be expected to improve over time as data from future flood events is collected and evaluated, and used to validate the model results.

**FLOOD DAMAGES**

A flood damages assessment was undertaken for existing development within the study area for both residential and commercial properties. This was based on a detailed floor level survey and results from the TUFOLOW model. Damages to public structures have not been assessed. A summary of the damages estimates is provided in the table below.

<table>
<thead>
<tr>
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<th>Estimated Properties with Internal (Above Floor) Flood Damages</th>
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**AVERAGE ANNUAL DAMAGES** $20,000
1. INTRODUCTION

1.1. Background

Stroud lies near the confluence of Mill Creek and Lamans Creek, which join approximately 1km downstream of the centre of the township, and then flow into the Karuah River approximately 1km further downstream. Bucketts Way is the main thoroughfare through Stroud, crossing Mill Creek at the northern edge of town, and Lamans Creek to the south (Figure 1). Mill Creek has a catchment area of 120 km$^2$ and Lamans Creek an area of 20 km$^2$ at the Bucketts Way crossings. Mill and Lamans Creeks have experienced several significant floods in the past century, although no regular flood records exist. Some recorded flood levels exist for Mill and/or Lamans Creek from February 1956, October 1985 and June 2007, with the 1956 event remembered as the largest on record. A previous study documenting historical flooding in Stroud was undertaken in 1986 (Reference 3).

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Stroud has a population approaching 700 and has undergone moderate growth over the last 10 years. Continued growth may result in expansion of existing urban areas and development of previously un-developed or rural land, some of which is likely to be on the fringes of the floodplain. It is therefore important that appropriate tools and information to assess flood risk are available for planning future development in the area.

1.2. Objectives

The key objective of this Flood Study is to develop a suitable hydraulic model that can be used to assist Great Lakes Council in the development of an updated Floodplain Risk Management Plan for the study area to consider both existing and future development. No hydraulic modelling of the study area has previously been completed, with the previous study in 1986 primarily comprising interpolation of historically recorded flood levels from Mill and Lamans Creeks.

The primary objectives of the study are:

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- to undertake a flood damages assessment to assess the extent of the flood problem in Stroud;
- to assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities; and
• to assess the hydraulic categories and undertake provisional hazard mapping.

This report details the results and findings of the Flood Study investigations. The key elements include:

• a summary of available historical flood related data;
• establishment and validation of the hydrologic and hydraulic models;
• sensitivity analysis of the model results to variation of input parameters; and
• the definition of design flood behaviour for existing catchment conditions.

A glossary of flood related terms is provided in Appendix A.

1.3. Justification for Present Study

A limited desktop flood assessment of Mill and Lamans Creeks at Stroud was completed in 1986 (Reference 3), involving consideration of historical flood data only and without any modelling. The present Flood Study has been initiated for the following reasons:

• The availability of detailed topographic data from Airborne Laser Scanning (ALS) has enabled the use of two-dimensional (2D) models of flood behaviour, and accurate definition of topographic features in the floodplain such as flowpaths and storage areas;
• The continued development of computer technology and hydraulic modelling software has enabled the more widespread use of 2D computer models which can provide detailed flood extent and depth mapping for the entire study area;
• There are currently no design flood estimates for Stroud. Preliminary flood extent maps were defined in the late 1980s by the then Public Works Department, based on peak flood level profiles from collated historical flood level data, and using available ground survey to estimate inundation extents. However, these maps have limited application under current guidelines for planning development in flood-prone areas;
• There have been advancements in design rainfall and flood estimation that were not available at the time of the previous study;
• The previous Flood Study did not quantify potential risk of backwater flooding from the Karuah River, or other localised sources of flooding in Stroud; and
• The June 2007 flood provided a reminder of the flood risk at Stroud, and the importance of quantifying flood risk for the area. Photographs and peak flood levels provided by residents from the event can assist in the validation of flood models;
2. BACKGROUND

2.1. Catchment Description

The headwaters of Mill Creek are in the Myall River State Forest, some 15-20km north of Stroud, from which the creek flows southwards in a meandering fashion along a moderate gradient towards Stroud. There are several tributary creeks that converge in the upper parts of the catchment. Approximately 3km north of town, the bed slope of Mill Creek steepens and the channel straightens, before crossing through the northern part of Stroud via a bridge at Bucketts Way (known locally as Cowper Street). A flood runner (Mill Brook) breaks out of Mill Creek approximately 500m upstream of Bucketts Way and flows around the southern part of the town Recreation Centre, also crossing Bucketts Way via a large culvert, before rejoining Mill Creek. Mill Creek then discharges into the Karuah River approximately 2km to the south-west of Stroud.

Lamans Creek emerges approximately 3km east of Stroud, also from the Myall River State Forest, and follows a meandering course westwards towards Stroud. It crosses via a bridge at Bucketts Way in the southern part of town, before joining Mill Creek approximately 1km upstream of the confluence with the Karuah River.

The catchments of the two creeks are indicated on Figure 2.

The parts of Mill and Lamans Creek catchments located in the Myall River State Forest are predominantly natural bushland, and the remainder of the catchment areas are mainly rural properties, which are mostly cleared for grazing. The town of Stroud itself consists primarily of low-density residential development, and has a current population approaching 700.

2.2. Flood Behaviour

The main flooding mechanism at Stroud is due to runoff in Mill and Lamans Creeks exceeding the capacity of the defined channels and breaking out over the creek flats and floodplain, particularly in the vicinity of the Bucketts Way crossings. The bed slopes of both creeks are steeper upstream of the Bucketts Way bridges, leading to a more rapid rise of flooding in these areas.

Downstream of Stroud the bed slope of Mill Creek and Lamans Creek is relatively flat, and flood levels in the low-lying south-western areas downstream of the Mill and Lamans Creek confluence are primarily driven by backwater effects from the Karuah River in large flood events. In Lamans Creek, the backwater flood mechanism from the Karuah River plays a more significant role than for Mill Creek. The Karuah River has a major influence on Lamans Creek flood levels for the reach from Bucketts Way to the Mill Creek confluence, even in relatively small events.

Available records indicate that there has not been widespread inundation of houses in the township. Accounts of floods in the last 60 years primarily refer to flooding around Bucketts Way, with evidence that floodwaters from Mill Creek have inundated the showgrounds and
adjacent areas, overtopping Bucketts Way and inundating properties to the south, as well as flowing along the north-eastern part of Briton Court Road. There are also records of Bucketts Way being cut just north of the bridge at Lamans Creek, as happened in 2007, threatening nearby properties and resulting in damage to vehicles (Appendix B).

2.3. Previous Studies

2.3.1. Stroud Flood Study – 1986

The first Stroud Flood Study (Reference 3) by the NSW Water Resources Commission comprised a preliminary assessment of flood behaviour, based primarily on flood height data obtained from debris marks left during historical floods in the area. The purpose of the study was to define flood liable areas around the Stroud township to assist council in making decisions about planning and evaluation of development options in the vicinity of the creeks.

No modelling was undertaken for the Flood Study. A limited number of flood levels from the 1956 and 1985 floods were available from local anecdotal evidence and debris marks. The 1956 flood was considered to be the largest flood of the century based on available records. The approach of the Flood Study was to determine the peak flood level profile throughout the study area, based on the available surveyed flood levels. In areas where there were insufficient flood levels available from the 1956 flood to fully define the profile, the profile obtained from 1985 was adjusted upwards. In Lamans Creek, there was just a single recorded flood level on which to base the adjustment.

Based on the estimated 1956 peak flood profile in Mill and Lamans Creeks, estimates were made for the extent of flood inundation, the delineation of floodways, and potential flood hazards. No estimate was made for the exceedance probability of the 1956 event (that is, how likely it is for a similar or larger event to occur in any given year).

There is significant uncertainty involved with the outcomes of the study, due mainly to the limited amount of flood data available. The spatial mapping of flood inundation extents undertaken was based on substantial interpolation of the survey and recorded flood levels that were available at the time.

On the subject of flood damages Reference 3 states that “the highest known flood to date has been the 1956 flood. During this time no flood damage occurred to residential and business properties as no dwellings were flooded to above floor level. The only damage recorded to date has been to fencing at the Showground and minor damage to roads at the creek crossings.” However some of the recorded flood levels from 1956 and 1985 are higher than the surveyed floor levels for nearby properties, so it is considered likely that some inundation above floor level probably occurred in these events, even if it was not recorded (refer to interview with Mr Arkinstall, Section 3.6).

The recorded 1956 and 1985 peak flood levels from Reference 3 are shown on Figure 4.
2.3.2. Karuah River Flood Study – February 2010

This report (Reference 2) was undertaken on behalf of Great Lakes Council to define flood behaviour and design flood levels along the Karuah River, and to provide downstream flood levels for flood studies on tributaries to the Karuah, such as Mill Creek at Stroud.

At the time this study was undertaken, the Karuah River Flood Study was in the public exhibition stage, and largely finalised. The report estimates design flood level data over approximately 47km of the Karuah River from the township of Stroud Road to the mouth at Karuah. Inflows were estimated using the RORB hydrologic model, calibrated to recorded discharges at Booral in the 1977, 1978, 1990, 2001 and 2007 Karuah River floods.

Design flows were estimated using the calibrated RORB model with design rainfall depths and temporal patterns from ARR 87 (Reference 1). The peak flows at Booral were found to be comparable with those estimated from a flood frequency analysis of recorded annual maxima at that site. The estimated design peak flows at Stroud (Appendix D, Reference 4) and Booral (Tables 13 and 14, Reference 4) are reproduced in Table 1.

Table 1: Karuah River Design Peak Discharges at Stroud and Booral

<table>
<thead>
<tr>
<th>Flood Annual Exceedance Probability</th>
<th>Karuah Peak Discharge @ Stroud (m$^3$/s)</th>
<th>Karuah Peak Discharge @ Booral (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMF</td>
<td>7,860</td>
<td>12,713</td>
</tr>
<tr>
<td>0.5%</td>
<td>3,248</td>
<td>3,885</td>
</tr>
<tr>
<td>1%</td>
<td>2,785</td>
<td>3,313</td>
</tr>
<tr>
<td>2%</td>
<td>2,339</td>
<td>2,758</td>
</tr>
<tr>
<td>5%</td>
<td>1,983</td>
<td>2,106</td>
</tr>
<tr>
<td>10%</td>
<td>1,408</td>
<td>1,627</td>
</tr>
<tr>
<td>20%</td>
<td>1,091</td>
<td>1,244</td>
</tr>
<tr>
<td>50%</td>
<td>634</td>
<td>713</td>
</tr>
</tbody>
</table>

The primary relevance of the Karuah River Study to the Stroud study is to determine to what extent floods in the Karuah River affect floods in Mill and Lamans Creeks, and the extent of the threat posed to properties in Stroud due to backwater flooding from the Karuah River.

The study used a Mike-11 1D hydrodynamic model to calculate design flood levels and velocities. The model was established using twenty-eight surveyed river cross sections from upstream of Stroud Road to the Pacific Highway bridge at Karuah.

The estimated design flood levels in the Karuah River at the Mill Creek confluence are given in Table 2 (Table 23, Reference 4).

Table 2: Karuah River Design Flood Levels at Mill Creek
<table>
<thead>
<tr>
<th>Flood Annual Exceedance Probability</th>
<th>Peak Flood Level @ Mill Creek Confluence (mAHD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMF</td>
<td>32.05</td>
</tr>
<tr>
<td>0.5%</td>
<td>26.28</td>
</tr>
<tr>
<td>1%</td>
<td>25.67</td>
</tr>
<tr>
<td>2%</td>
<td>25.04</td>
</tr>
<tr>
<td>5%</td>
<td>24.61</td>
</tr>
<tr>
<td>10%</td>
<td>22.97</td>
</tr>
<tr>
<td>20%</td>
<td>22.07</td>
</tr>
<tr>
<td>50%</td>
<td>20.46</td>
</tr>
</tbody>
</table>

A brief comparison of the estimated flood levels from Table 2 with surveyed ground levels in Stroud indicates that some of the lower lying areas of Stroud may be inundated by larger Karuah River floods. In particular, the stated PMF level of 32.05 mAHD is higher than Bucketts Way at the Mill Creek and Lamans Creek crossings, and higher than several of the lower-lying properties in Stroud south of Lamans Creek.

It is noted that the highest recorded flood on the Karuah River at Booral occurred in 1971 with a recorded peak discharge of 2420 m³/s, which is between the estimated peak discharge for the 5% and 2% AEP (20yr and 50yr ARI) design event according to Table 1. The gauge was established in 1968, and in the forty years to 2008 there have been an additional five floods recorded between the estimated 10% and 5% AEP (10yr and 20yr ARI) events in 1978, 1985, 1990, 2001 and 2007. There have been no recorded floods on the Karuah River larger than the estimated 2% AEP design event, which is approximately the size above which significant backwater flooding at Stroud will begin to occur.
3. AVAILABLE DATA

Rainfall and streamflow data are required for the calibration of hydrologic models. Recorded rainfall levels are required as an input to the model. The runoff hydrograph estimated using the model is then generally assessed against measured streamflow (preferably at the bottom of the study catchment), and modelling assumptions and parameters can be adjusted to improve the fit.

For this reason a thorough search and review of rainfall and streamflow stations in the vicinity of Stroud was undertaken. Particular attention was focused on trying to find data records corresponding to dates of known floods in Stroud:

- 15\textsuperscript{th} April 1927;
- 25\textsuperscript{th} March and 19\textsuperscript{th} April 1946;
- 29\textsuperscript{th} February 1956;
- 19\textsuperscript{th} March 1978;
- 12\textsuperscript{th} October 1985; and
- 8\textsuperscript{th} June 2007.

3.1. Streamflow Stations

There are no historic streamflow records (manual or automated) in Mill Creek or Lamans Creek.

3.2. Rainfall

There is only one rainfall recording station within the study area (61071 – Stroud Post Office). The Stroud rainfall station is a daily-read gauge that commenced in 1889. While this gauge has records for all the dates of known floods listed above, the daily totals are of limited value for model calibration unless there is also some indication of the temporal pattern of the rainfall (such as sub-daily rainfall intensity data from a nearby station that recorded the same weather event).

Table 3 lists the automated continuous stations (pluviometers) within a 40km radius of Stroud Post Office, which have data available for each flood event.

**Table 3: Pluviometer Stations**

<table>
<thead>
<tr>
<th>Station</th>
<th>Name</th>
<th>Opened</th>
<th>Data Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>61151</td>
<td>Chichester Dam</td>
<td>30/05/1960</td>
<td>×</td>
</tr>
<tr>
<td>60112</td>
<td>Gloucester (Hiawatha)</td>
<td>29/11/1982</td>
<td>×</td>
</tr>
</tbody>
</table>

\(n = \text{data NOT available}, y = \text{data available}\)
Table 4 lists the daily read stations within a 40km radius of Stroud Post Office that had data available for at least one flood event.

Table 4: Daily Rainfall Stations

<table>
<thead>
<tr>
<th>Station</th>
<th>Name</th>
<th>Distance from Stroud Post Office (km)</th>
<th>Elevation (mAHD)</th>
<th>Opened</th>
<th>Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>61071</td>
<td>Stroud Post Office</td>
<td>0.0</td>
<td>44</td>
<td>29/04/1889</td>
<td></td>
</tr>
<tr>
<td>61184</td>
<td>Raglan</td>
<td>11.7</td>
<td>76</td>
<td>29/04/1960</td>
<td>29/12/1976</td>
</tr>
<tr>
<td>61022</td>
<td>Girvan State Forest</td>
<td>13.6</td>
<td></td>
<td>30/01/1936</td>
<td>29/12/1959</td>
</tr>
<tr>
<td>61106</td>
<td>Monkera Hill (Urimbirra)</td>
<td>15.9</td>
<td>91</td>
<td>28/01/2001</td>
<td></td>
</tr>
<tr>
<td>60089</td>
<td>Moana</td>
<td>17.0</td>
<td>15</td>
<td>30/08/1968</td>
<td>29/12/1979</td>
</tr>
<tr>
<td>61045</td>
<td>Redleaf</td>
<td>18.2</td>
<td></td>
<td>30/07/1914</td>
<td>29/12/1970</td>
</tr>
<tr>
<td>61059</td>
<td>Pine Brush</td>
<td>19.0</td>
<td></td>
<td>29/06/1902</td>
<td>29/12/1953</td>
</tr>
<tr>
<td>61017</td>
<td>Dungog Post Office</td>
<td>19.5</td>
<td>55</td>
<td>30/07/1897</td>
<td></td>
</tr>
<tr>
<td>61227</td>
<td>Cooreii</td>
<td>20.3</td>
<td></td>
<td>30/07/1886</td>
<td>29/12/1919</td>
</tr>
<tr>
<td>61170</td>
<td>Dungog - Main Ck (Yeranda)</td>
<td>21.0</td>
<td>154</td>
<td>29/04/1960</td>
<td></td>
</tr>
<tr>
<td>61340</td>
<td>Meroo</td>
<td>21.8</td>
<td>146</td>
<td>27/02/1970</td>
<td>29/12/1977</td>
</tr>
<tr>
<td>60002</td>
<td>Bulahdelah Post Office</td>
<td>22.7</td>
<td>10</td>
<td>30/10/1905</td>
<td></td>
</tr>
<tr>
<td>61302</td>
<td>Chichester State Forest</td>
<td>23.3</td>
<td></td>
<td>30/03/1938</td>
<td>29/12/1958</td>
</tr>
<tr>
<td>60008</td>
<td>Craven State Forest</td>
<td>23.4</td>
<td></td>
<td>1/01/1938</td>
<td>1/01/1956</td>
</tr>
<tr>
<td>61076</td>
<td>Wallaroo State Forest</td>
<td>25.0</td>
<td>75</td>
<td>30/03/1938</td>
<td></td>
</tr>
<tr>
<td>61122</td>
<td>Tillegra</td>
<td>25.3</td>
<td>61</td>
<td>28/02/1960</td>
<td>29/12/1986</td>
</tr>
<tr>
<td>61364</td>
<td>Dungog (Leawood)</td>
<td>26.9</td>
<td>155</td>
<td>1/01/1981</td>
<td></td>
</tr>
<tr>
<td>61010</td>
<td>Clarence Town (Grey St)</td>
<td>26.9</td>
<td>10</td>
<td>30/08/1895</td>
<td></td>
</tr>
<tr>
<td>61361</td>
<td>Wallaringa</td>
<td>27.5</td>
<td>85</td>
<td>28/02/1988</td>
<td>1/01/1998</td>
</tr>
<tr>
<td>61072</td>
<td>Carrington House</td>
<td>29.8</td>
<td>3</td>
<td>30/03/1887</td>
<td></td>
</tr>
<tr>
<td>61169</td>
<td>Durham Park</td>
<td>31.5</td>
<td>144</td>
<td>29/04/1960</td>
<td>29/12/1988</td>
</tr>
<tr>
<td>61332</td>
<td>Wangat</td>
<td>31.5</td>
<td></td>
<td>29/04/1912</td>
<td>29/12/1920</td>
</tr>
<tr>
<td>61160</td>
<td>Hilldale (Sundance)</td>
<td>31.6</td>
<td>82</td>
<td>30/05/1960</td>
<td>29/12/1976</td>
</tr>
<tr>
<td>61160</td>
<td>Hilldale (Sundance)</td>
<td>31.6</td>
<td>82</td>
<td>21/03/2006</td>
<td></td>
</tr>
<tr>
<td>61151</td>
<td>Chichester Dam</td>
<td>32.0</td>
<td>194</td>
<td>1/01/1942</td>
<td></td>
</tr>
<tr>
<td>60062</td>
<td>Waukivory (The Ranch)</td>
<td>32.1</td>
<td>340</td>
<td>30/07/1961</td>
<td></td>
</tr>
<tr>
<td>60123</td>
<td>Hawks Nest (Langi St)</td>
<td>35.8</td>
<td>8</td>
<td>27/02/1981</td>
<td></td>
</tr>
<tr>
<td>61303</td>
<td>Salamander Bay (Waratah Ave)</td>
<td>35.9</td>
<td>17</td>
<td>29/04/1971</td>
<td></td>
</tr>
<tr>
<td>61395</td>
<td>Tanilba Bay Wwtp</td>
<td>37.6</td>
<td>5</td>
<td>17/12/2001</td>
<td></td>
</tr>
<tr>
<td>61283</td>
<td>Eagleton</td>
<td>38.0</td>
<td>9.1</td>
<td>1/01/1912</td>
<td>1/01/1924</td>
</tr>
<tr>
<td>60143</td>
<td>Wang Wauk Rd</td>
<td>38.0</td>
<td>45</td>
<td>1/01/1995</td>
<td>29/10/1996</td>
</tr>
<tr>
<td>61038</td>
<td>Martins Ck</td>
<td>38.0</td>
<td></td>
<td>1/01/1933</td>
<td>1/01/1945</td>
</tr>
<tr>
<td>61258</td>
<td>Gostwyck House</td>
<td>38.3</td>
<td>25</td>
<td>30/10/1967</td>
<td>17/02/1971</td>
</tr>
<tr>
<td>61404</td>
<td>Torryburn (Little Acres)</td>
<td>38.5</td>
<td>34</td>
<td>18/04/2004</td>
<td></td>
</tr>
<tr>
<td>61054</td>
<td>Nelson Bay (Nelson Head)</td>
<td>38.7</td>
<td>25</td>
<td>29/04/1881</td>
<td></td>
</tr>
</tbody>
</table>

Rainfall gauge locations are indicated on Figure 2.
3.2.1. Analysis of Daily Read Data

The rainfall record for Stroud Post Office was analysed in order to provide an indication on the magnitude of historical rainfall events. This was undertaken by determining the maximum 1-day and 2-day totals. The results are provided in Table 8. It should be noted that there are many possible anomalies with this data, including:

- The rain may fall over the 9am period and thus be distributed over 2 days and thus may not pick up the 24-hour or even 48-hour peaks (it is likely that this happened on June 2007),
- For many events the gauge may have failed (vandalism, over flowed, out of service).
- There are periods in the record where it was customary to include rainfall over the weekend in the Monday reading, such that the Monday reading can include up to 3 days of rain.

Table 5: Maximum Recorded 1-day and 2-day Rainfall Depths

<table>
<thead>
<tr>
<th>Date</th>
<th>Rainfall in 24 hours to 9am (mm)</th>
<th>Date</th>
<th>Rainfall in 48 hours to 9am (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/03/1978</td>
<td>274</td>
<td>26/03/1946</td>
<td>385.1</td>
</tr>
<tr>
<td>16/04/1927</td>
<td>260</td>
<td>2/03/1956</td>
<td>330.2</td>
</tr>
<tr>
<td>1/03/1956</td>
<td>241</td>
<td>10/03/1893</td>
<td>307.3</td>
</tr>
<tr>
<td>26/03/1946</td>
<td>224</td>
<td>23/01/1895</td>
<td>300.8</td>
</tr>
<tr>
<td>13/10/1985</td>
<td>199</td>
<td>21/03/1978</td>
<td>293.4</td>
</tr>
<tr>
<td>12/11/1987</td>
<td>192</td>
<td>21/01/1971</td>
<td>278.1</td>
</tr>
<tr>
<td>18/06/1949</td>
<td>191</td>
<td>1/03/1956</td>
<td>267.7</td>
</tr>
<tr>
<td>20/04/1946</td>
<td>178</td>
<td>4/02/1990</td>
<td>267</td>
</tr>
<tr>
<td>22/01/1895</td>
<td>163</td>
<td>13/01/1968</td>
<td>239.8</td>
</tr>
<tr>
<td>25/03/1946</td>
<td>161</td>
<td>19/02/1957</td>
<td>238.2</td>
</tr>
</tbody>
</table>

There is some correlation between the maximum daily totals and large recorded floods at Stroud. The 1986 Flood Study (Reference 1) mentions floods from 1913, 1927, 1946, 1956 and 1985, and indicates that the 1956 flood was the largest in the 20th century according to local information and archival records. Table 5 shows that four of the top five recorded daily rainfalls were in corresponding years.

It is interesting to note that Reference 3 makes no mention of a flood occurring in 1978, when the maximum historical daily total was recorded, despite the study taking place only 8 years later. Nearly 200 mm was recorded at Chichester Dam during the same period, suggesting it was not an isolated or erroneous measurement. Conversely, on 7th April 1913 only 119 mm was recorded (the 47th highest), but flooding was observed.

In June 2007 an east-coast low-pressure system resulted in intense storm cells making landfall at Newcastle, before moving up the Karuah and Hunter Valleys. The storm is well documented, as it resulted in extensive flooding in Newcastle, and caused a bulk freighter (the Pasha Bulker)
to run aground near Newcastle. At Stroud Post Office, 126 mm was recorded in the 24 hours to 9am on 8th June, followed by 109 mm in the 24 hours to 9am on 9th June. Although these totals do not rank highly against the values from Table 5, significant flooding was observed at Stroud, particularly in Lamans Creek. Mr and Mrs Robards from Number 10 Laman Street (which was completely surrounded by water) indicated that it was the highest flood experienced in their 47 years at the premises since 1960 (Appendix B).

The critical duration storm event for the Mill and Lamans Creek catchments is in the order of 9 to 12 hours. It is therefore difficult to draw parallels between 24-hour rainfall totals at Stroud and the severity of flooding, which is more likely to be dependent on the sub-daily distribution of rainfall.

3.2.2. Analysis of Pluviometer Data

There are no continuous rainfall gauges in the immediate vicinity of the study area, with the closest being at Chichester Dam (32km away, opened in 1960) and Gloucester (39.2km away, opened in 1982). These gauges were not operational during most of the observed floods at Stroud. Even though the gauges were operational in 1985, they both failed in the period surrounding the October event. The only events for which data are available are March 1978 (Chichester Dam) and June 2007 (Chichester Dam and Gloucester). Since no records of flooding in Stroud are available for 1978, only the 2007 rainfall patterns were analysed in detail.

Records from Chichester Dam and Gloucester and other continuous rainfall stations in the region indicate that the majority of rainfall from the June 2007 storms fell in the 12 hours from 12am on 8th June. It is highly likely that a similar temporal pattern occurred at Stroud, as this would explain the significant flooding observed on this occasion.

An estimate of the relative severity of the June 2007 flood at Stroud can be obtained by distributing the total rainfall recorded at Stroud on the 8th and 9th June (235 mm) according to the temporal distributions recorded at Chichester Dam and Gloucester during the same period. The resulting rainfall intensities can be compared to the design IFD information (Section 3.2.3). Figure 3 shows the results of this analysis. If the rainfall at Stroud was distributed in a similar pattern to Chichester Dam then the rainfall intensity would have been close to the 20-year ARI intensity for the critical 9-hour duration. Using the Gloucester temporal pattern gives a 9-hour burst greater than the 100-year ARI storm intensity.

This analysis highlights that rainfall is subject to significant spatial and temporal variation, and that the closest pluviometers to the study area are too far away (both over 30km) to give a definitive record of historical rainfall patterns leading to known floods at Stroud.

3.2.3. Design Rainfalls

Design rainfall depths and temporal patterns for various storm durations at the study area were obtained from Australian Rainfall and Runoff 1987 (ARR87), for events up to and including the 0.2% AP event. Probable Maximum Precipitation estimates were derived according to Bureau of
Meteorology (BoM) guidelines (Reference 15). A summary of the design rainfall depths is provided in Table 6.

Table 6: Rainfall Intensity-Frequency-Duration Data

<table>
<thead>
<tr>
<th>DURATION</th>
<th>1 yr ARI</th>
<th>2 yr ARI</th>
<th>5 yr ARI</th>
<th>10 yr ARI</th>
<th>20 yr ARI</th>
<th>50 yr ARI</th>
<th>100 yr ARI</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 minute</td>
<td>82.7</td>
<td>107</td>
<td>137</td>
<td>155</td>
<td>179</td>
<td>210</td>
<td>234</td>
</tr>
<tr>
<td>10 minute</td>
<td>63.4</td>
<td>81.8</td>
<td>105</td>
<td>119</td>
<td>137</td>
<td>161</td>
<td>180</td>
</tr>
<tr>
<td>20 minute</td>
<td>46</td>
<td>59.3</td>
<td>76.3</td>
<td>86.2</td>
<td>99.4</td>
<td>117</td>
<td>130</td>
</tr>
<tr>
<td>30 minute</td>
<td>37.3</td>
<td>48.2</td>
<td>61.9</td>
<td>70</td>
<td>80.7</td>
<td>95</td>
<td>106</td>
</tr>
<tr>
<td>1 hour</td>
<td>25.5</td>
<td>32.8</td>
<td>42.3</td>
<td>47.9</td>
<td>55.3</td>
<td>65.1</td>
<td>72.6</td>
</tr>
<tr>
<td>2 hour</td>
<td>17</td>
<td>21.9</td>
<td>28.4</td>
<td>32.3</td>
<td>37.4</td>
<td>44.1</td>
<td>49.2</td>
</tr>
<tr>
<td>3 hour</td>
<td>13.3</td>
<td>17.3</td>
<td>22.5</td>
<td>25.5</td>
<td>29.6</td>
<td>35</td>
<td>39.2</td>
</tr>
<tr>
<td>6 hour</td>
<td>8.81</td>
<td>11.4</td>
<td>15</td>
<td>17.1</td>
<td>19.9</td>
<td>23.7</td>
<td>26.5</td>
</tr>
<tr>
<td>12 hour</td>
<td>5.83</td>
<td>7.59</td>
<td>10</td>
<td>11.5</td>
<td>13.4</td>
<td>16</td>
<td>17.9</td>
</tr>
<tr>
<td>24 hour</td>
<td>3.85</td>
<td>5.02</td>
<td>6.65</td>
<td>7.64</td>
<td>8.92</td>
<td>10.6</td>
<td>12</td>
</tr>
<tr>
<td>48 hour</td>
<td>2.48</td>
<td>3.24</td>
<td>4.3</td>
<td>4.95</td>
<td>5.78</td>
<td>6.9</td>
<td>7.78</td>
</tr>
<tr>
<td>72 hour</td>
<td>1.87</td>
<td>2.44</td>
<td>3.25</td>
<td>3.74</td>
<td>4.39</td>
<td>5.24</td>
<td>5.92</td>
</tr>
</tbody>
</table>

3.3. Flood Levels

There are no official flood level gauges (manual or automatic) on Mill Creek or Lamans Creek. The main source of flood level data for this study is from surveyed flood marks resulting from observations either during or after flood events. Reference 3 contained information about observed flood levels and debris marks for both Mill Creek and Lamans Creek from the 1956 and 1985 floods.

There is a high degree of uncertainty associated with some of these flood levels due to the passage of time since they were collected, and due to the slightly unclear descriptions of the locations. In the time since these flood levels were collected, the creek bed levels and widths may have changed due to geomorphologic processes. The density and type of riparian vegetation may also have changed. Debris marks often have additional uncertainty as floating debris can sometimes get lodged in trees or fences at a location higher than the actual water levels, or can be deposited during the receding limb of the flood at a level much lower than the peak. For this reason they are often only accurate to around ±0.5m or greater.

However some of the marks provide a reasonable level of confidence. The 1956 flood level marked by a nail in the telegraph pole on Briton Court Road should be quite reliable, and the level at the top of the first step at the Hawkins residence was verified by Ms Hawkins and Mr Daunt (Section 3.6). The recorded 2007 level at the top of the second step at 10 Laman Street is also likely to be quite accurate (within ±0.1m) due to the detailed location description.

After the June 2007 flood, Great Lakes Council undertook a data collection exercise that yielded a small number of relatively high quality flood marks (Appendix B). There is an increased level of confidence in these flood levels due to their relatively recent acquisition, and the detailed
Stroud Flood Study

locations supplied to surveyors.

The recorded levels of the available historic flood marks are reproduced in Table 7. The locations for the levels, as estimated by WMAwater based on the descriptions, are indicated on Figure 4.

Table 7: Recorded Historical Flood Levels

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Estimated Flood Level (mAHHD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1956 Observed Levels (Reference 3)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mill Creek at Showground</td>
<td>0.6 to 1.2m over showground</td>
<td>31.0 to 31.5</td>
</tr>
<tr>
<td>Mill Creek 100m upstream of bridge</td>
<td>Water just crossed Gloucester Road 50m NW of Briton Court Road Intersection</td>
<td>30.9</td>
</tr>
<tr>
<td>Mill Creek at bridge</td>
<td>Water over bridge handrail</td>
<td>31.2</td>
</tr>
<tr>
<td>Mill Creek 40m downstream of bridge</td>
<td>Top of first step Hawkins residence in Briton Court Road</td>
<td>30</td>
</tr>
<tr>
<td>Mill Creek at Lamans Street crossing</td>
<td>Top of fence near gate on left bank under water</td>
<td>26</td>
</tr>
<tr>
<td>Lamans Creek 60m downstream of Berkeley Street bridge</td>
<td>Top of second step of only house in Laman Street near creek</td>
<td>27</td>
</tr>
<tr>
<td><strong>1956 Observed Level (surveyed 2009)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Briton Court Road</td>
<td>Flood Mark Nail</td>
<td>30.68</td>
</tr>
<tr>
<td><strong>1985 Observed Levels (Reference 3)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downstream side of Bucketts Way near Swimming Pool</td>
<td>0.7m above ground</td>
<td>30.6</td>
</tr>
<tr>
<td>Upstream side of Bucketts Way near Swimming Pool</td>
<td>0.27m above ground</td>
<td>30.7</td>
</tr>
<tr>
<td>Swimming Pool car park</td>
<td>0.49m above ground</td>
<td>30.7</td>
</tr>
<tr>
<td>Downstream side of Showground Oval - Mexon Stalls</td>
<td>0.76m above ground</td>
<td>30.9</td>
</tr>
<tr>
<td>Briton Court Road intersection</td>
<td>0.41m above ground</td>
<td>30.9</td>
</tr>
<tr>
<td>40m downstream of Briton Court Road intersection</td>
<td>0.37m above ground</td>
<td>30.7</td>
</tr>
<tr>
<td><strong>1985 Debris Mark Levels (Reference 3)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mill Brook 400m upstream of Bucketts Way</td>
<td>Right bank</td>
<td>31.8</td>
</tr>
<tr>
<td>Mill Brook 400m upstream of Bucketts Way</td>
<td>Left bank</td>
<td>31.6</td>
</tr>
<tr>
<td>Mill Brook 400m upstream of Bucketts Way</td>
<td>40m from right bank</td>
<td>31.7</td>
</tr>
<tr>
<td>Mill Creek 150m downstream of Mayo Street</td>
<td>1.1m above ground</td>
<td>28.4</td>
</tr>
<tr>
<td>Mill Creek Erin-Scotia Streets corner</td>
<td>Left bank 0.45m above ground</td>
<td>27.7</td>
</tr>
<tr>
<td>Mill Creek 70m downstream of Erin-Scotia Streets corner</td>
<td>Left bank 1.1m above ground</td>
<td>27.6</td>
</tr>
<tr>
<td>Mill Creek 130m downstream of Erin-Scotia</td>
<td>Left bank 0.9m above ground</td>
<td>27.5</td>
</tr>
</tbody>
</table>
### Location Description Estimated Flood Level (mAHĐ)

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Estimated Flood Level (mAHĐ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streets corner</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mill Creek at Laman-Scotia Streets corner</td>
<td>Left bank 1.55m above ground</td>
<td>26.6</td>
</tr>
<tr>
<td>Mill Creek 100m downstream of Laman-Scotia Street crossing</td>
<td>Left bank 2.1m above ground</td>
<td>26.4</td>
</tr>
<tr>
<td>Mill Creek at Lamans Creek junction</td>
<td>Left bank 1.6m above ground</td>
<td>25.2</td>
</tr>
</tbody>
</table>

#### 2007 Observed Levels (surveyed 2007)

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Estimated Flood Level (mAHĐ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill Creek downstream of Bucketts Way</td>
<td>49_Cowper_St</td>
<td>28.2</td>
</tr>
<tr>
<td>Small local catchment at Erin St crossing</td>
<td>16_Erin_St</td>
<td>31.14</td>
</tr>
<tr>
<td>Lamans Creek downstream of Bucketts Way</td>
<td>10_Laman_St</td>
<td>25.8</td>
</tr>
</tbody>
</table>

The locations for data from 1956 and 1985 have been estimated based on the descriptions provided in Reference 3, and may therefore be subject to interpretation. The historic flood levels therefore do not provide a highly reliable description of past flood behaviour, but they are useful in developing a broader understanding of flood behaviour in the study area.

### 3.4. Flood Photographs

Photographs are available of flooding in Lamans Creek during the June 2007 flood, including pictures of Bucketts Way being overtopped (Appendix B). No aerial flood photographs or oblique photographs of flooding in Mill Creek were obtained for the study.

### 3.5. Survey

Airborne Light Detection and Ranging (LiDAR) survey of Stroud and its surroundings was provided for the study by Great Lakes Council. This data was verified against approximately 100 surveyed data points obtained across the study area and the accuracy confirmed as:

- The standard deviation of the error between the aerial survey and ground survey is no greater than 0.1m
- The mean of the error is not greater than +/- 0.15m

The points used for verification of the LiDAR were collected using a Real-Time-Kinematic (RTK) receiver attached to a vehicle, at locations with relatively flat, clear ground (Figure 5).

The LiDAR did not pick up below-water levels in the watercourses, so additional cross-section survey was obtained at key locations in the creeks. The cross-section data were interpolated to estimate the channel geometry at intermediate locations. Detailed survey was also obtained at key hydraulic structures such as bridges and culverts. These survey locations are indicated on Figure 6.

### 3.6. Site Inspection and Interviews

A site visit was undertaken on 21 May 2009 to inspect key hydraulic structures such as bridges
and culverts, and to assess the type and density of vegetation cover in the riparian zone and floodplain. Interviews were carried out with some of the residents near Mill Creek at Bucketts Way, the key outcomes of which are summarised below. Author comments are provided in square brackets.

**RESIDENT:** Mr M. Daunt  
**ADDRESS:** 43-45 Briton Court Road

- Mr Daunt grew up in Stroud around Briton Court Road.
- He indicated that during the June 2007 flood there was a lot of debris in Mill Ck pushed up against in the old timber bridge at Bucketts Way, including a tree trunk (Photo 1, following page) that had previously been located a few hundred metres upstream (Mr Daunt recalled playing on the trunk as a child);
- The resulting blockage at the bridge pushed water at high velocity along the right bank near his house, scouring the bank somewhat and threatening to undermine the trees at the top of the bank;
- Mr Daunt identified the flood mark nail from 1956 in the telegraph pole on the north side of Briton Court Road, which was later provided to surveyors (refer Table 7);
- He remembered that the 1956 flood reached the top of the front steps at Number 14 Briton Court Road (level not surveyed), but didn’t inundate the house above floor level (not surveyed), and that the showground was completely inundated;
- Mill Brook does not run frequently, with significant flows only being observed every couple of years at most on average;
- Mr Daunt indicated that in his experience, less rainfall falls at the township of Stroud itself than in the hills at the upper parts of the Mill Creek catchment [this may be possible, as a result of orographic rainfall effects].

**RESIDENT:** Mr G. Arkinstall  
**ADDRESS:** 49 Briton Court Road

- Mr Arkinstall has lived at his current address for about 6 years;
- Mr Arkinstall has not personally experienced inundation above floor level at the property, but indicated he was aware that inundation previously occurred with a depth of up to a few feet above floor level, possibly in 1956.
- The June 2007 flood inundated the fringes of the showground, but not the whole area, and was just below the level of the toilet block in the rest area adjacent to Mill Creek;
- The June 2007 flood reached the handle of the clothes line on Mr Arkinsall's property (see Appendix B);
- Another flood in Mill Creek in 2004 or 2005 came to a similar level as 2007 [a review of rainfall records shows that 154mm fell in Stroud on 24 March 2004, which may have produced similar flooding, particularly if higher rainfall occurred in the upper catchment. However WMAwater are not aware of additional records of this flood];
- The upgraded Bucketts Way (due to the changed approach to the new bridge) is higher than it used to be, with the old road passing through the rest area and along the old
timber bridge [this would generally cause flood levels to be higher upstream of the road and lower downstream of the road since the upgrade];

- Flooding in Mill Creek generally occurs with a relatively slow rate of rise compared to Lamans Creek.

**RESIDENT:** Ms C. Hawkins  
**ADDRESS:** 14 Briton Court Road

- Ms Hawkins grew up in the area and has lived at her present address for more than 15 years;
- Her parents indicated to her that the Briton Court Road had been flooded in 1956, but the higher area behind her house was dry [this agrees with Mr Daunt’s recollection that flooding came to the top of steps at the front of the property]. This level has not been surveyed but would be similar to the flood mark nail nearby that was surveyed;
- Ms Hawkins did not have significant personal recollections of flooding from Mill Creek.

Photo 1: Tree trunk washed down Mill Creek during the June 2007 flood, blocking the bridges at Bucketts Way (*looking downstream, taken 21 May 2009*)
4. STUDY METHODOLOGY

The approach adopted in flood studies to determine design flood levels largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc.). High quality survey datasets were available for this study, which enabled a detailed topographic model of the catchment to be established. However, as discussed in Section 3, the historical hydrologic data (such as rainfall patterns, streamflows and flood levels) are relatively limited.

The estimation of flood behaviour in a catchment is often conducted as a two-stage process, consisting of:

1. hydrologic modelling to convert rainfall estimates to stream runoff; and
2. hydraulic modelling to estimate overland flow distributions, flood levels and velocities.

Preferably there will be historic data available for both stages of the analysis, to allow calibration of the models, and increase confidence in the estimates. The calibration process is undertaken by altering model input parameters to improve the reproduction of observed catchment flooding. Recorded rainfall and streamflow data are required for calibration of the hydrologic model, while historic records of flood levels and inundation extents can be used for the calibration of hydraulic model parameters.

As discussed Section 3 there are no streamflow records in the catchment, so the use of a flood frequency approach for the estimation of design floods is not possible. Additionally, only daily measurements of rainfall depths are available, which restricts assessment of the relative severity of historic storms of shorter duration (such as 9 or 12 hours, which are more critical than 24 or 48 hour rainfalls for Mill and Lamans Creeks). A thorough calibration process for the hydrologic modelling component of the study was therefore not possible.

There are some historic flood levels available for the 1956, 1985 and 2007 floods at Stroud, although there are questions as to the consistency and reliability of the levels. The lack of detailed rainfall and streamflow data means that there is insufficient information to undertake hydraulic model calibration using these events, as the inflow boundary conditions required for the model are unknown.

In view of the above, the broad approach adopted for this study was to use a widely utilised and well-regarded hydrologic model to estimate catchment runoff using design rainfall patterns specified in Reference 1, and the runoff hydrographs were then used in an appropriate hydraulic model to estimate flood depths, velocities and hazard in the study area. In the absence of definitive information about historical flood events, the models were configured using typical or recommended parameters. The design flood behaviour estimated using this process was then compared to historical observed flood levels, to provide a limited “ball-park” validation of the modelling. The sensitivity of the model results to adopted model parameters was assessed to identify the level of uncertainty in the modelled flood behaviour.
4.1. Hydrologic Model

Australian Rainfall and Runoff (Reference 1) describes various techniques suitable for design flood estimation in rural and urban catchments. These techniques range from simple procedures to estimate peak flows (such as the Probabilistic Rational Method), to more complex rainfall-runoff routing models that estimate complete flow hydrographs.

In recent times, techniques have been developed to incorporate estimation of the rainfall-runoff relationship in a catchment directly into the hydraulic model. These techniques, often referred to as “direct rainfall on grid” approaches, remove the need for a hydrologic model entirely. However there is widespread uncertainty as to the validity of such methods, which can be highly sensitive to modelling assumptions, and therefore are highly dependent on good quality calibration data being available.

For the present study, the Watershed Bounded Network Model (WBNM) was used to estimate catchment flows. The WBNM model is an event-based, lumped-catchment conceptual model that is based on an extensive empirical dataset of rainfall-runoff relationships for Australian catchments. The model was originally developed for natural catchments, and is therefore particularly suited for estimating inflows from the rural upper catchments of Mill and Lamans Creeks. The model requires very few parameters to describe the physical aspects of the catchment, and is therefore less sensitive to assumptions about catchment characteristics such as shape, steepness, and ground cover. WBNM was therefore considered a suitable tool for this study, in light of the lack of calibration data and detailed physical information about the catchment. WBNM has been widely adopted in Australia for use in similar studies.

The flow estimates from WBNM were verified against alternative methods of estimating peak catchment flow.

4.2. Hydraulic Model

The availability of high quality ALS data means that the study area is suitable for 2D hydraulic modelling. Various 2D software packages are available (SOBEK, TUFLOW, Mike FLOOD) and the TUFLOW package (Reference 7) was adopted as it is widely used in Australia and WMAwater have extensive experience in the use of the TUFLOW model.

The model is capable of dynamically simulating complex overland flow regimes and interactions with sub-surface drainage systems. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short-duration events and a combination of supercritical and sub-critical flow behaviour.

For the hydraulic analysis of complex overland flow paths (such as those identified in the present study, particularly near the Bucketts Way crossings), a combined 1D/2D model such as TUFLOW provides several key advantages when compared to a traditional 1D only model. For example, in comparison to a purely 1D approach, a combined 1D/2D approach can:

- provide localised detail of any topographic and /or structural features that may influence
flood behaviour,
• better facilitate the identification of the potential overland flow paths and flood problem areas,
• dynamically model the interaction between hydraulic structures such as culverts and complex overland flowpaths, and
• inherently represent the available flood storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be readily incorporated into Council's planning activities. The model developed for the present study provides a flexible modelling platform to properly assess the impacts of any overland flow management strategies within the floodplain (as part of the ongoing floodplain management process).

In TUFLOW the ground topography is represented as a uniformly-spaced grid with a ground elevation and a Manning’s “n” roughness value assigned to each grid cell. The grid cell size is determined as a balance between the model result definition required, the dimensions of the river/creek channel (as a rough guide the channel should have over 4 cells widths in order to accurately define it) and the computer run time (which is relative to the number of grid cells).

4.3. Design Flood Modelling

Following validation of the peak inflows from upper catchment areas through the use of alternative calculation methods, the following steps were undertaken:
• Design inflows were obtained from the WBNM hydrologic model and included in the TUFLOW model;
• Sensitivity analysis was undertaken to assess the relative effect of changing various TUFLOW modelling parameters
• Design floods were modelled in TUFLOW using parameters selected to provide a sensible match between design flood levels and available recorded peak flood levels from historical events.
5. HYDROLOGIC MODELLING

5.1. WBNM

The WBNM hydrologic runoff-routing model was used to determine hydraulic model inflows, both from catchment areas upstream of the hydraulic model extent, and for the local sub-catchments within the study area. The catchment layout for the model is shown on Figure 7. The areas of the sub-catchments are given in Table 8.

Table 8: Sub-Catchment Areas

<table>
<thead>
<tr>
<th>Catchment (Upstream of Hydraulic Model)</th>
<th>Area (ha)</th>
<th>Local Catchment (Within Hydraulic Model)</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUB_1-6</td>
<td>613</td>
<td>Mill_02</td>
<td>82</td>
</tr>
<tr>
<td>SUB_1-5</td>
<td>613</td>
<td>Mill_01</td>
<td>66</td>
</tr>
<tr>
<td>SUB_1-4</td>
<td>1286</td>
<td>Mill_03</td>
<td>175</td>
</tr>
<tr>
<td>SUB_5-4</td>
<td>945</td>
<td>Mill_05</td>
<td>104</td>
</tr>
<tr>
<td>SUB_5-3</td>
<td>483</td>
<td>Mill_04</td>
<td>68</td>
</tr>
<tr>
<td>SUB_4-2</td>
<td>1010</td>
<td>Mill_07</td>
<td>20</td>
</tr>
<tr>
<td>SUB_4-1</td>
<td>938</td>
<td>Mill_06</td>
<td>30</td>
</tr>
<tr>
<td>SUB_5-2</td>
<td>793</td>
<td>Laman01</td>
<td>70</td>
</tr>
<tr>
<td>SUB_6-1</td>
<td>734</td>
<td>Laman02</td>
<td>136</td>
</tr>
<tr>
<td>SUB_5-1</td>
<td>324</td>
<td>Laman04</td>
<td>110</td>
</tr>
<tr>
<td>SUB_1-3</td>
<td>1301</td>
<td>Laman03</td>
<td>50</td>
</tr>
<tr>
<td>SUB_1-2</td>
<td>703</td>
<td>Laman05</td>
<td>55</td>
</tr>
<tr>
<td>SUB_3-1</td>
<td>804</td>
<td>Laman06</td>
<td>36</td>
</tr>
<tr>
<td>SUB_2-3</td>
<td>679</td>
<td>ErinSt</td>
<td>21</td>
</tr>
<tr>
<td>SUB_2-2</td>
<td>914</td>
<td>Mill_08</td>
<td>72</td>
</tr>
<tr>
<td>SUB_2-1</td>
<td>538</td>
<td>Mill_09</td>
<td>63</td>
</tr>
<tr>
<td>SUB_1-1</td>
<td>765</td>
<td>DS_01</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DS_02</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laman07</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laman09</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laman08</td>
<td>37</td>
</tr>
</tbody>
</table>

The model input parameters for each sub-catchment are:

- a lag factor (termed C), which can be used to accelerate or delay the runoff response to rainfall;
- a streamflow routing factor, which can speed up or slow down channelized flows occurring through each catchment;
- rainfall initial and continuing losses to represent infiltration; and
- the percentage of catchment area with a pervious/impervious surface.
5.2. Calibration

If data is available the model can be calibrated to historical flow records by including the historical rainfall data and adjusting the model parameters above until a good match to the recorded data is achieved. However for this study there are insufficient pluviometer and streamflow records available to undertake a meaningful calibration of the hydrologic model.

Streamflow records are essential for calibration of a hydrologic model as they provide measurements that can be compared to the model outputs. As discussed in Section 3.1, no streamflow records are available in the study area.

Pluviometer data is required to provide a temporal pattern to be applied to the daily rainfall records, for input into the hydrologic model. Even without streamflow records, historical storms could be modelled in the hydrologic model using typical or default catchment parameters if pluviometer data of historical events were available. The resulting runoff hydrographs could then be used to undertake a limited calibration of the hydraulic model through comparison with observed flood levels.

Although there are pluviometers at Chichester Dam and Gloucester, they are too far away to provide a reliable record of the temporal pattern at Stroud. It is known that the rainfall temporal patterns can vary greatly across even a small area and thus at distances of over 30km the available pluviometers allow only a limited description of the temporal distribution of large rainfall events in Stroud (see Section 3.2.2).

5.3. Design Event Modelling

Given the lack of calibration data for the hydrologic modelling, the input parameters were determined based on typical or default values, based where possible on experimental data for similar catchments

5.3.1. Lag Parameter

Lag times for runoff depend on several physical catchment characteristics, including area, planform shape and steepness (among others) for natural catchments. Experimental data for natural catchments in Australia has demonstrated that the dominant factor is catchment area, with other characteristics showing strong correlation with area such that there is a strong case for catchment lag to be determined on area alone. For WBNM, the adopted relationship is (Reference 8):

\[ \text{Lag time} = \text{Lag Parameter} \times \text{Area}^{0.57} \times \text{Discharge}^{-0.23} \]

Since the relationship includes the effect of catchment size and flood size, a similar value of the Lag Parameter should apply to a wide range of catchment and flood sizes (Reference 8). Experimental derivation of the Lag Parameter for 129 storms on 10 catchments in eastern NSW found that a value of 1.68 gave a good fit to all the data. Similar data has been obtained for
Queensland, Victoria, and South Australia, with estimated values of 1.47, 1.74, and 1.64 respectively. The recommended default value is 1.6, and this has value has been adopted for design flood modelling in this study.

5.3.2. Streamflow Lag Factor

The relationship of stream channel lag in WBNM is very similar to that of catchment runoff lag, and for natural catchments the default parameter value is 1.0. Since the Mill Creek and Lamans Creek channels are still in a largely natural state, without artificial lining or scour protection for most of their length, the default value was considered appropriate.

5.3.3. Rainfall Losses

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in AR&R. The methods are of varying complexity, with the more complex options only suitable if sufficient data are available (such as detailed soil properties). The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur, and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Initial and continuing losses are often used as the primary parameters for calibrating hydrologic models when observational data are available. For this study, typical values were adopted based on available data in similar catchments. Table 6.2 of Reference 1 recommends that for catchments east of the dividing range in New South Wales, an initial loss of 10mm to 35mm is appropriate, with a continuing loss of 2.5mm. For this study, the lower bound initial loss of 10mm was adopted, as it is the most conservative estimate (i.e. it will lead to increased runoff estimates), and as it will result in the minimum reduction in total volume from the AR&R design burst rainfall patterns, which do not contain antecedent rainfall (whereas real storm bursts are often preceded by a period of lower intensity rainfall, which would wet the catchment).

5.3.4. Impervious Areas

Runoff from impervious surfaces such as roads, gutters, roofs or concrete aprons occurs significantly faster than from natural surfaces, resulting in a faster concentration of flow at the bottom of a catchment, and increased peak flow in some situations. It is therefore necessary to estimate the proportion of a catchment area that is covered by such surfaces.

The upper parts of the Mill Creek and Lamans Creek catchments, as well as sections within and around the township, are either national park or rural areas. These areas have a negligible proportion of surface area covered by impervious surfaces (such as concrete) that prevent infiltration, and so were modelled as having a 0% impervious fraction.

The residential areas of town are low-density, with relatively large yards and grass verges adjacent to the roads. Based on a review of aerial photographs, these areas were assumed to be approximately 40% covered by impervious areas, mainly due to roads, pavements and roof-
gutter systems. The assumed impervious area for each sub-catchment is indicated on Figure 10.

5.3.5. Embedded Design Storm Approach

The traditional AR&R87 approach to design storm hydrology is based on the estimation of a peak flow generated by a critical duration peak burst rainfall pattern. The method assumed that antecedent rainfall prior to the critical duration burst does not impact upon the peak flow estimates (Reference 12). Several other studies indicate that a failure to incorporate antecedent conditions prior to the critical duration peak burst may result in the underestimation of peak flows for some catchments (References 13 and 14). This is particularly the case where the critical burst durations are much shorter than the duration of historic flood-producing rainfall events. For the Stroud catchment, there is a significant chance that high-intensity short duration storm bursts likely to cause flooding at culverts and other structures in the smaller urbanised catchments will occur during the course of a broader, longer duration storm of reduced intensity that will produce flooding in Mill and Lamans Creeks.

To address this issue, an alternative approach was adopted for this study whereby a shorter critical duration design storm burst is embedded within a longer duration storm of the same ARI. The shorter burst is used to replace the peak of the longer duration storm, and the intensity before and after the peak is adjusted so that the total rainfall depth is consistent with that of the original longer duration design storm. This procedure has been widely used since the publication of AR&R87, and is likely to be recommended in planned revisions to that document.

5.4. Outcomes

The AR&R burst design rainfall patterns were input into the WBNM model for a range of durations and recurrence intervals, to determine the critical storm duration for flooding in various parts of the study area. The Mill Creek and Lamans Creek catchments to Stroud both demonstrate critical storm duration (in terms of the highest peak flow) of 9 to 12 hours. Although the Mill Creek catchment is larger than the Lamans Creek catchment, its elongated shape results a similar peak flow being obtained for a wide range of storm durations. The smaller more urbanised catchments within Stroud were found to yield the highest peak flow for the 2 hours design storm burst.

Based on these outcomes, a 2-hour design burst embedded in a 12-hour design storm was selected for this study as the critical storm pattern for the flooding in the catchment. It is noted that the 6-hour and 9-hour storms both produce a similar peak flow to the 12-hour storm, but the 12-hour storm was adopted as the critical duration because it also involves a higher flood volume.

This duration (2-hour in 12-hour embedded storm) was adopted for all design events except the PMF, for which reliable estimates of the 12-hour rainfall depth are unavailable. For the PMF, a 2-hour burst embedded in a 6-hour design storm was adopted, using the Generalised Short-Duration Method (GSDM) developed by the Bureau of Meteorology (Reference 15). This was
considered reasonable, as the 6-hour peak flow is similar to the 12-hour peak flow for both creek systems in the other design events.

Estimated peak flows for the Mill and Lamans Creek catchments at the upstream extent of the TUFLOW hydraulic model for various storm durations are provided in Table 9. Plots of the corresponding discharge hydrographs are presented on Figure 7a (Mill Creek) and Figure 7b (Lamans Creek).

Table 9: Design Event Peak Inflow for Mill Creek and Lamans Creek

<table>
<thead>
<tr>
<th>Event AEP</th>
<th>Peak flow at upstream extent of TUFLOW model (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mill Creek</td>
</tr>
<tr>
<td>50%</td>
<td>197</td>
</tr>
<tr>
<td>20%</td>
<td>300</td>
</tr>
<tr>
<td>10%</td>
<td>365</td>
</tr>
<tr>
<td>5%</td>
<td>454</td>
</tr>
<tr>
<td>2%</td>
<td>571</td>
</tr>
<tr>
<td>1%</td>
<td>666</td>
</tr>
<tr>
<td>0.5%</td>
<td>765</td>
</tr>
<tr>
<td>0.2%</td>
<td>900</td>
</tr>
<tr>
<td>PMF*</td>
<td>2,820</td>
</tr>
</tbody>
</table>

*All except PMF are 120-minute burst in 720-minute embedded storm. The PMF is a 120-minute burst in 360-minute embedded storm.

5.5. Hydrologic Model Validation

Although there are insufficient data to undertake a comprehensive validation of the hydrologic model based on historic storms, there are alternative methods of estimating peak design flows which can be used to assess the validity of the model results. One widely used method is the Probabilistic Rational Method (PRM) as described in ARR87 (Reference 1), for which there is a specific approach for the eastern parts of NSW. The PRM was used to estimate peak flows for the 1% and 5% AEP events in Mill and Lamans Creeks to the inflow point at the upstream extent of the hydraulic model. The results are shown in Table 10 below.

The comparison indicates that the modelling results are reasonably consistent with the peak flow estimates from the PRM, with the PRM flows generally being approximately 5% lower than the peak flows from the WBNM modelling.

A discussion on the sensitivity of the modelling results to the estimated creek inflows is provided in Section 6.8.
Table 10: Comparison of Peak Inflow Estimates

<table>
<thead>
<tr>
<th>Event AEP</th>
<th>Catchment</th>
<th>WBNM Model Peak Flow (m³/s)</th>
<th>Probabilistic Rational Method Peak Flow (m³/s)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>Mill Creek</td>
<td>666</td>
<td>681</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Lamans Creek</td>
<td>138</td>
<td>143</td>
<td>4%</td>
</tr>
<tr>
<td>2%</td>
<td>Mill Creek</td>
<td>571</td>
<td>557</td>
<td>-2%</td>
</tr>
<tr>
<td></td>
<td>Lamans Creek</td>
<td>119</td>
<td>117</td>
<td>-2%</td>
</tr>
<tr>
<td>5%</td>
<td>Mill Creek</td>
<td>454</td>
<td>433</td>
<td>-5%</td>
</tr>
<tr>
<td></td>
<td>Lamans Creek</td>
<td>95</td>
<td>91</td>
<td>-4%</td>
</tr>
<tr>
<td>10%</td>
<td>Mill Creek</td>
<td>365</td>
<td>333</td>
<td>-9%</td>
</tr>
<tr>
<td></td>
<td>Lamans Creek</td>
<td>77</td>
<td>71</td>
<td>-8%</td>
</tr>
<tr>
<td>20%</td>
<td>Mill Creek</td>
<td>300</td>
<td>258</td>
<td>-14%</td>
</tr>
<tr>
<td></td>
<td>Lamans Creek</td>
<td>64</td>
<td>55</td>
<td>-14%</td>
</tr>
<tr>
<td>50%</td>
<td>Mill Creek</td>
<td>197</td>
<td>167</td>
<td>-15%</td>
</tr>
<tr>
<td></td>
<td>Lamans Creek</td>
<td>43</td>
<td>35</td>
<td>-19%</td>
</tr>
</tbody>
</table>
6. HYDRAULIC MODELLING

6.1. Model Extents

A hydraulic model was established for the study using the TUFLOW package. The upstream extents of the model are 3.5km upstream of the Bucketts Way crossing for the Mill Creek floodplain, and 2.5km upstream of the Bucketts Way crossing for the Lamans Creek floodplain. The model includes a small reach of the Karuah River at the downstream end, to assess the effect of backwater floods from the Karuah River, and extends downstream approximately 0.8km beyond the Mill Creek/ Karuah River confluence. The model extent is indicated on Figure 8.

A longer reach of the Karuah River was included in the model extent for the Probably Maximum Flood (PMF) than for the other design events, to assess the possibility of flooding over the saddle in Briton Court Road, upstream of the low level bridge at Gortons Crossing Road. For the smaller design events, this was not a possibility, so the model extent was reduced to reduce computation time.

6.2. Terrain Model

A grid cell size of 5m by 5m was adopted, as it provided an appropriate balance between providing sufficient detail in the waterways with practicable computational run-times. The model grid was established by sampling from a triangulation of filtered ground points from the LiDAR dataset.

Permanent buildings and other significant structures likely to act as significant flow obstructions were incorporated into the terrain model. These features were identified from the available aerial photography and modelled as impermeable obstructions to the flood flow (i.e. they were removed from the model grid).

Vegetation density is an important factor for the estimation of flood behaviour, particular in the riparian corridor. The extents of various vegetation groups were identified using aerial photography, and classified according to observations from site inspections. The floodplain within the study area has been largely cleared, except for isolated stands of trees without significant undergrowth. However the riparian vegetation is extremely thick, to the degree that access to the creek is difficult at many locations (Figure 30).

6.3. Joint Probability of Karuah River Floods

Flooding in the lower-lying parts of Stroud close to the Mill / Lamans Creek confluence is likely to be caused by a combination of local catchment flow and elevated Karuah River levels. To model the influence of Karuah River flooding at Stroud, a 2km reach of the Karuah River was included in the TUFLOW model, extending approximately 1km upstream and downstream from the Mill Creek confluence.

An approach was therefore required to make appropriate consideration of the relative magnitude
and timing of flows in the Karuah River that can be expected to occur in conjunction with floods of Mill Creek and Lamans Creek. While it is likely to be some correlation between Karuah River floods and Mill/Lamans Creek floods (due to large-scale weather events over the Karuah Valley), it is considered unlikely that a storm producing a 1% AEP flood in Mill Creek would also cause a 1% AEP flood in the Karuah River. This is primarily because the difference in catchment sizes means that a different event duration (and therefore weather system) is often required to produce extreme flood events in each catchment. Even if a weather event did produce equivalent floods in both systems, the peaks would be unlikely to arrive at the Mill Creek / Karuah River confluence at the same time, due to differences in time of concentration for the catchments. It is therefore likely that the joint probability of a 1% AEP Mill/Lamans Creek flood and a 1% AEP Karuah River flood peaking at the same time at Stroud would be smaller (less likely) than a 1% chance of occurring in a given year.

To date there is no standard approach that has been recommended for such circumstances. A detailed joint probability analysis based on historical events is not possible due to a lack of appropriate observed data to determine the correlation.

This study is primarily concerned with the effects of local (Mill and Lamans Creek) catchment events, as the Karuah Flood Study (Reference 4) has quantified backwater flood levels at Stroud (Table 2). Therefore the design floods for this study consisted of the appropriate design flood magnitude in Mill and Lamans Creeks, along with a smaller flood magnitude in the Karuah River. The following design flood matrix was used for this study:

Table 11: Adopted Design Flood Matrix – Karuah River Joint Probability

<table>
<thead>
<tr>
<th>lood Study Event AEP</th>
<th>Mill Creek / Lamans Creek AEP</th>
<th>Karuah River Event AEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMF</td>
<td>PMF</td>
<td>0.5%</td>
</tr>
<tr>
<td>0.2%</td>
<td>0.2%</td>
<td>1%</td>
</tr>
<tr>
<td>0.5%</td>
<td>0.5%</td>
<td>2%</td>
</tr>
<tr>
<td>1%</td>
<td>1%</td>
<td>5%</td>
</tr>
<tr>
<td>2%</td>
<td>2%</td>
<td>10%</td>
</tr>
<tr>
<td>5%</td>
<td>5%</td>
<td>20%</td>
</tr>
<tr>
<td>10%</td>
<td>10%</td>
<td>50%</td>
</tr>
<tr>
<td>20%</td>
<td>20%</td>
<td>50%</td>
</tr>
<tr>
<td>50%</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

For the issue of timing, the Karuah River design floods have a longer duration (36 hours) than the Mill / Lamans Creek design floods (12 hours). It was therefore considered appropriate to assume that for the design flood modelling, the peak of local catchment flows from Stroud would coincide with the peak of the Karuah River flow for the appropriate event magnitude.

The adopted joint-probability of events is largely subjective, and therefore the effect of variations in these assumptions was evaluated with sensitivity analysis (refer Section 6.8).
For the TUFLOW model, flows from the Karuah River flood study at Stroud (Table 1) were input into the model at a location approximately 1km upstream of the Mill Creek confluence. A rating curve was incorporated as the downstream boundary at a location approximately 1km downstream of the Mill Creek confluence, based on an assumed water level gradient at the boundary. The assumed water level slope was adjusted until the boundary produced similar tailwater levels as appropriate coincident flood levels in the Karuah River (Table 2). At both upstream and downstream boundary locations, the Karuah River is relatively confined between high banks (Figure 9).

6.4. Boundary Conditions

The hydraulic model several inflow boundaries, plus a downstream boundary where floodwaters leave the model. The runoff hydrographs estimated using WBNM were applied to the TUFLOW model as inflow hydrographs at the following locations:

- Mill Creek, just upstream of Mill Creek Road near the intersection with Greenhams Lane, 3.5km upstream of Bucketts Way;
- Lamans Creek, 2.5km upstream of Bucketts Way;
- Karuah River, 2.6km upstream of the Mill Creek confluence for the PMF, and 1.3km upstream for other design events; and
- the bottom of 22 local sub-catchments delineated inside the model boundary.

The downstream boundary condition was located at the Karuah River, 0.8km downstream of the Mill Creek confluence. This boundary used a constant tailwater condition, based on the appropriate co-incident Karuah River flood level from Table 11 (refer to Section 6.3 for discussion of the joint probability of Karuah River floods).

The model schematisation is illustrated on Figure 9, including the location of the streamflow boundary conditions. The inflow locations for the internal model sub-catchments are shown on Figure 10.

6.5. Hydraulic Structures

The behaviour of hydraulic structures like culverts, channels and bridges can have a significant influence on flood behaviour. When culverts are flowing near capacity or become blocked, backwater upstream of the culvert can flood properties or cause the road to be overtopped. The piers and deck of bridges over creeks can present an obstruction to flow, resulting in afflux (increased water level) upstream of the structure. It is therefore important to pay particular attention to the modelling of these features.

Key hydraulic structures were included in the hydraulic model, based on detailed survey undertaken in the study area. Culverts were modelled as 1D features embedded in the 2D model, since the majority of culverts of interest have dimensions smaller than the grid resolution. Bridges were modelled in the 2D domain using a TUFLOW feature specifically designed for this purpose, whereby the energy losses and blockage caused by the piers and deck can be applied directly to the grid cells.
The selection of modelling parameters for the culverts and bridges was based on the geometrical properties of the structures, which were obtained from detailed survey, and from photographs taken during site inspections.

Large obstructions such as houses and sheds were “nulled” from the model grid, such that flow is assumed not to occur through the buildings.

6.6. Validation Approach

There are a range of TUFLOW model input parameters that can be adjusted to modify the flow behaviour, including:

- Mannings “n” roughness, which primarily represents the retarding effect of surface friction on flood flow;
- energy loss coefficients at hydraulic structures; and
- eddy viscosity coefficients, which are used to represent the energy-loss due to turbulence on a sub-grid scale.

Typically Mannings “n” is the principal parameters used for calibration to adjust the model estimates to match historical flood levels. The other parameters can often be selected with a good degree of confidence using default values based on the geometry of hydraulic structures and the grid-cell size.

For this study although historic flood levels are available at several locations, there were insufficient historic rainfall data to undertake modelling of the historic flood events, since the inflows are unknown (refer to Section 5.2). Therefore the following approach was adopted to assess whether the model results were reasonable, to the extent which the available data allowed:

- design floods were modelled using the design flow hydrographs estimated with the WBNM model;
- sensitivity testing was undertaken to determine which model parameters were the most significant in influencing the estimated flood levels;
- design flood levels were compared to historic flood levels at key locations, as a check of the sensibility of results. For instance, if the flood level at a given location surpassed a certain mark in the 1956, 1985 and 2007 floods, it would be expected that this mark should be inundated in a relatively frequent event (such as the 5% AEP or smaller). If a given mark was only historically exceeded in the 1956 event, it might be more representative of a less frequent event (such as the 2% AEP or greater); and
- based on this comparison the model parameters were adjusted to produce more sensible results, primarily using the model parameters which were found to have more influence on model results during the sensitivity testing.

While this approach does not constitute a comprehensive calibration, it was considered to provide a reasonable check of the design flood results with the available historic information.
6.7. Design Flood Modelling

The adopted parameters for the design flood modelling, based on the above approach, are given in Table 12 and Table 13.

Table 12: Design Flood Mannings “n” Values

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Design event Mannings “n” value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creek beds</td>
<td>0.035</td>
</tr>
<tr>
<td>Creek banks</td>
<td>0.15</td>
</tr>
<tr>
<td>General floodplain / grazing land / low density</td>
<td>0.06</td>
</tr>
<tr>
<td>residential lots</td>
<td></td>
</tr>
</tbody>
</table>

The adopted roughness values are consistent with typical values in the literature (References 16 and 17) and previous experience with modelling similar catchment conditions. The roughness value of 0.15 is relatively high compared to most channels, and is due to the relatively high vegetation density on the channel banks. The spatial extent of areas delineated as “creek bank” and using a value of 0.15 is relatively limited. The sensitivity of model results to changes in the roughness values is discussed in Section 6.8.

Table 13: Design Flood Bridge Parameters

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Loss Parameter K</th>
<th>Blockage*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill Creek (old timber bridge)</td>
<td>0.3</td>
<td>10%</td>
</tr>
<tr>
<td>Mill Creek (new)</td>
<td>0.3</td>
<td>5%</td>
</tr>
<tr>
<td>Lamans Creek</td>
<td>0.3</td>
<td>5%</td>
</tr>
</tbody>
</table>

* Note this blockage is due to the estimated ratio of waterway area that is obstructed by the piers at each structure, and not an allowance for potential debris blockage at these locations.

Peak flood level profiles for the creeks are presented in Figure 11 and Figure 12. The recorded flood levels from 1956, 1985 and 2007 are indicated on the plots to provide historical context for the estimated design flood results.

Figure 13 shows design flood hydrographs just upstream of the Bucketts Way bridge in Mill Creek and Lamans Creek. Lamans Creek exhibits a faster rate of rise than Mill Creek, and is more significantly affected by backwater effects from the Karuah River in larger floods. This finding agrees with observations from Reference 3 and from the interviews with residents.

Maps of estimated design flood depths, velocities and provisional hydraulic hazard are presented from Figure 14 to Figure 26.

Hydraulic categorisations for the 5%, 1% and PMF events are provided on Figure 27 to Figure 29. There is no technical definition of hydraulic categorisation and different approaches are used by different consultants and authorities. For this study, hydraulic categories were defined by the following criteria:
• **Floodway** is defined as areas where the peak value of Velocity x Depth > 0.25 m²/s AND peak velocity > 0.25 m/s, OR where peak velocity > 1.0 m/s. The remainder of the floodplain is either Flood Storage or Flood Fringe,

• **Flood Storage** comprises areas outside the Floodway where peak depth > 1.0 m; and

• **Flood Fringe** comprises areas outside the Floodway where peak depth < 1.0 m.

### 6.8. Sensitivity Analyses

Due to lack of historical data suitable for undertaking a formal model calibration, a number of assumptions have been made for the selection of the design approach/parameters, primarily relying on default parameter values or values used in similar studies. The following sensitivity analyses were undertaken for the 1% AEP event to establish the variation in design flood level that may occur if different assumptions were made:

- **Mannings “n”**: The roughness values were increased and decreased by 20% at all locations;
- **Karuah River Joint Probability**: The tailwater level in the Karuah River was increased/reduced from the 5% AEP event to the 2% AEP / 10% AEP events respectively
- **Structure losses**: The energy loss at the bridge structures as a factor of dynamic head was increased/reduced to 0.5/0.1 respectively;
- **Temporal pattern**: A regular 12-hour temporal pattern from Reference 1 was modelled, to assess the difference from the embedded design storm approach. This storm has the same volume as the adopted embedded storm pattern, but the peak burst inside the storm is not as intense; and
- **Inflows / Climate Change**: Sensitivity to rainfall/runoff estimates was assessed by increasing the rainfall intensities by 10%, 20% and 30% as recommended under current guidelines. Refer to Section 6.8.5 below for discussion.

It should be noted that the parameters are not independent and adjustment of one parameter (Manning’s “n”) would generally require adjustment of other values (such as inflows) in order for the model to produce the same level at a given location.

### 6.8.1. Variation of Manning’s “n”

Flood levels are relatively insensitive to the adopted “n” value compared to other parameters. An increase of 20% to roughness values increases flood levels by around 0.1m generally for areas affected by Mill or Lamans Creek flooding, with negligible change to local catchment flood levels at culverts within Stroud township. A reduction of roughness values by 20% produces a similar reduction in flood levels.

The relatively small change to flood levels resulting from changes to Manning’s “n” gives increased confidence in the flood level estimates from the design flood modelling. Recommended values for Manning’s “n” based on land-use/ground cover are widely available, and suitable ranges have been verified through practice and experience in hydrodynamic modelling.
6.8.2. Variation of Karuah River Joint Probability

As indicated in Reference 4, flood levels in the Karuah River have not historically threatened the township of Stroud. However the estimated design flood levels of the Karuah River indicate that Karuah River flooding will affect Stroud in large events (around the 2% AEP Karuah flood and greater). A flood of this magnitude has not yet occurred since monitoring on the Karuah River commenced.

As discussed in Section 6.3, the approach adopted for the design 1% AEP flood event at Stroud was to model the 1% AEP event in Mill and Lamans Creeks with the 5% AEP in the Karuah River. For the sensitivity analysis, the joint probability was increased to the 2% AEP and reduced to the 10% AEP.

The results indicate that changing the magnitude of coincident Karuah River flooding has limited influence on design flood levels for the majority of the study area, with the exception being in the area downstream of Stroud around the Mill Creek / Lamans Creek confluence. At this location there is a transition from the two creeks being the primary flood mechanism the Karuah being the dominant flood risk. This area has relatively low levels of development compared to the main part of the Stroud township.

The effect of increasing the coincident Karuah tailwater to the 2% AEP level results in flood levels increasing by around 0.21m in the area downstream of Stroud near the Mill/Lamans Creek confluence. Flood levels Lamans Creek, Mill Creek and Mill Brook near Bucketts Way are not significantly affected.

Reducing the Karuah tailwater to the 10% AEP level results in a reduction of about 0.25m to flood levels at the Lamans / Mill confluence, but levels upstream of this location are not substantially changed.

6.8.3. Variation of Hydraulic Energy Losses at Structures

The abutments, piers, decks and railings of bridges cause an obstruction to flow which results in afflux upstream of the bridge, and potentially a change in floodplain flow distribution. The influence of bridges on flow in Mill and Lamans Creeks was included in the model through the use of energy loss parameters. The values used were based on typical bridge performance, and reflect assumptions about the hydraulic efficiency of the bridges.

The sensitivity of the model results to the assumed energy loss at bridges was tested by reducing and increasing the assumed loss parameters (roughly halved and doubled respectively). The peak flood levels were found not to vary significantly with the changes, with a change of less than 0.1 m generally observed over the floodplain, including immediately upstream of the bridges.

Sensitivity of blockage assumptions at bridges and culverts was not undertaken.
6.8.4. Temporal Pattern

Using the standard temporal pattern from AR&R produces generally lower flood levels than the embedded design storm approach adopted for the design events, and the difference is comparable to the difference between the 1% AEP and 2% AEP embedded storm floods. This difference is relatively significant compared to the other sensitivity tests, and emphasises the importance of assumptions about antecedent conditions in the catchment. The embedded storm approach is considered to provide a more reasonable approximation of real storm temporal characteristics and antecedent conditions than applying a single design burst to a “dry” model. Adopting the standard temporal pattern approach would require adjustments to other model parameters (such as roughness or losses) to increase flood levels to levels consistent with observations.

The results at culverts that drain smaller catchments within the study area (such as at Erin St and Bucketts Way) are affected more by the changed temporal pattern than other sensitivity analyses undertaken. This outcome is expected as one of the primary reasons for adopting the embedded storm approach is to ensure that flood levels near these culverts (where the critical duration is much shorter than for the rest of the catchment) are not underestimated.

6.8.5. Climate Change

BACKGROUND

The relative warmth of the earth’s surface temperature compared to space is due to the presence of certain greenhouse gases in the atmosphere which allow the sun’s rays to penetrate to the earth but reduce the amount of energy being radiated back. It is this trapping of the reflected heat which has enabled life to exist on earth.

Since the early 1980s there has been concern that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) resulting from human activity may be raising the average earth surface temperature. As a consequence, this may affect the climate and sea level. The extent of any permanent climatic or sea level change can only be established through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any mitigation works.

Based on the latest research by the United Nations Intergovernmental Panel on Climate Change evidence is emerging on the likelihood of climate change and sea level rise as a result of increasing “greenhouse” gasses. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase,
- the balance of evidence suggests human activity has resulted in climate change over the past century,
- global sea level has risen about 0.1 m to 0.25 m in the past century,
- many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.
The best available estimate of the projected sea level rise (including ice melt) along the NSW coast is from 0.18 m to 0.91 m between the years 2090 and 2100.

**DISCUSSION**

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO (Reference 6) that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less); however this information is not of sufficient accuracy for use as yet.

Any change in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions. The influence of dry catchment conditions on river runoff is observable in climate variability using the Indian Pacific Oscillation (IPO) index (Reference 11). Although mean daily rainfall intensity is not observed to differ significantly between IPO phases, runoff is significantly reduced during periods with fewer rain days.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events at Stroud under warmer climate scenarios.

In light of this uncertainty, the NSW State Government advice (Reference 6) recommends sensitivity analysis on flood modelling be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

The effect of increasing the design rainfalls by 10%, 20% and 30% has been evaluated for the 100 year ARI event, resulting in a relatively significant impact on peak flood levels in the study area. Generally speaking, each incremental 10% increase in flow results in a 0.15 m to 0.2 m increase in peak flood levels at several locations on the Mill and Lamans Creek floodplains. Flood levels at culverts from local catchment flooding within Stroud are not significantly affected (less than 0.1m for the 30% rainfall increase). The sensitivity analysis indicates that rainfall increases of 10% to 15% would be sufficient to make the 1% AEP flood levels from Mill Creek and Lamans Creek equivalent to the present day 0.5% flood levels.
The projected sea level increases will affect Karuah River flood levels at the river mouth, but the impacts will not extend up the estuary as far as Stroud.

6.9. Blockage

A detailed assessment of blockage scenarios is outside the scope of this study. However, WMAwater have identified locations where blockage of hydraulic structures (such as bridges or culverts) may have potentially adverse flood impacts on dwellings. The following five locations have been identified as potentially susceptible to adverse consequences from blockage, and should be the main focus if a blockage assessment is undertaken as part of a subsequent Floodplain Risk Management Study (refer to Figure 6 for locations):

1. **Mill Creek Bridge** (Bucketts Way) – the old timber bridge remains in place at this location, increasing the potential for blockage (as observed in the 2007 flood where a large tree trunk became lodged at this location). Increased blockage at the Mill Creek Bridge has the potential to exacerbate flooding across Bucketts Way and along Briton Court Road.

2. **Lamans Creek Bridge** – as for Mill Creek, the high density of riparian vegetation in the area could result in significant debris accumulation and blockage during a flood. Blockage at the Lamans Creek Bridge has the potential to exacerbate flooding across Bucketts Way and along Laman St.

3. **Bucketts Way Culvert #1** (250m north of Briton Court Road) – Blockage may potentially increase flood risk to adjacent houses on the upstream side.

4. **Bucketts Way Culvert #2** (400m south of Lamans Creek Bridge) – Blockage may potentially increase flood risk to adjacent houses on the upstream side.

5. **Erin St Culvert** (250m north of Briton Court Road) – The relatively small culvert diameters (600mm) may be susceptible to blockage and flooding of adjacent properties.

6.10. Summary

From the sensitivity analysis, it was concluded that the principal factors that influence the modelled flood behaviour are the magnitude and timing of runoff flows and the Manning’s “n” roughness parameter. Peak flood levels were found to vary slightly as a result of variation of other model inputs, such as energy loss at bridge structures in the floodplain and Karuah River joint probability.

It is considered that the design flood levels adopted reflect the best estimate of the model inputs with available information, and based on experience with other studies. However it is noted that variation of some of the above assumptions could result in localised changes to the estimated flood levels.

As mentioned above, there are limitless combinations of parameters, and a considerable effort was made to verify that the values used brought about a reasonable match of modelled design flood behaviour with the general flood behaviour from available historical flood records. There is a reasonable level of confidence in the design rainfall depths adopted due to the significant amount of regional rainfall data available. The Manning’s “n” values adopted were supported by
historical aerial photography.

Accuracy of the estimated flood levels is expected to be of the order of +/-0.5m. The accuracy can be expected to improve over time as data from future flood events is collected and evaluated, and used to validate the model results.

Table 14 on the following page provides a summary of peak flood level changes at various locations for the sensitivity scenarios. Yellow shading/text indicates that the magnitude of the change is greater than 0.1 m, with red shading/text to indicate changes greater than 0.2m in magnitude.

Peak flood level profiles for the sensitivity tests are provided on Figure 32.
### Table 14: Sensitivity of Design Peak Flood Levels at Selected Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>1% AEP depth</th>
<th>Mannings+20%</th>
<th>Mannings -20%</th>
<th>(K = 0.5 \cdot \frac{V^2}{2g})</th>
<th>(K = 0.1 \cdot \frac{V^2}{2g})</th>
<th>Karuah 2% AEP</th>
<th>Karuah 10% AEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Showground</td>
<td>0.88</td>
<td>0.08</td>
<td>-0.07</td>
<td>0.04</td>
<td>-0.07</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Briton Court Rd cnr Bucketts Way</td>
<td>0.27</td>
<td>0.07</td>
<td>-0.06</td>
<td>0.02</td>
<td>-0.04</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Mill Creek Picnic Area</td>
<td>2.55</td>
<td>0.08</td>
<td>-0.09</td>
<td>-0.04</td>
<td>-0.02</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Erin St cnr Scotia St</td>
<td>1.91</td>
<td>0.13</td>
<td>-0.16</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>U/S Erin St Culvert</td>
<td>0.41</td>
<td>0.02</td>
<td>-0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>U/S Bucketts Way Culvert 1</td>
<td>0.89</td>
<td>0.00</td>
<td>-0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>U/S Bucketts Way Culvert 2</td>
<td>1.15</td>
<td>0.01</td>
<td>-0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Laman St cnr Bucketts Way</td>
<td>0.46</td>
<td>0.04</td>
<td>-0.05</td>
<td>0.02</td>
<td>-0.03</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Lamans Ck /Mill Ck Confluence</td>
<td>4.15</td>
<td>0.15</td>
<td>-0.18</td>
<td>0.00</td>
<td>0.00</td>
<td>0.21</td>
<td>-0.26</td>
</tr>
<tr>
<td>Mill Brook U/S Bucketts Way</td>
<td>3.68</td>
<td>0.04</td>
<td>-0.04</td>
<td>0.00</td>
<td>-0.02</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Mill Brook D/S Bucketts Way</td>
<td>2.31</td>
<td>0.09</td>
<td>-0.10</td>
<td>-0.01</td>
<td>-0.01</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Mill Ck U/S Bucketts Way Bridge</td>
<td>7.09</td>
<td>0.09</td>
<td>-0.08</td>
<td>0.05</td>
<td>-0.13</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Lamans Creek U/S Bucketts Way Bridge</td>
<td>3.75</td>
<td>0.06</td>
<td>-0.05</td>
<td>0.06</td>
<td>-0.07</td>
<td>0.02</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Yellow highlighting indicates change of 0.1m to 0.2m
Red highlighting indicates change of greater than 0.2m

<table>
<thead>
<tr>
<th>Location</th>
<th>1% AEP depth</th>
<th>Rainfall +10%</th>
<th>Rainfall +20%</th>
<th>Rainfall +30%</th>
<th>Not Embedded</th>
<th>2% AEP</th>
<th>0.5% AEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Showground</td>
<td>0.88</td>
<td>0.21</td>
<td>0.40</td>
<td>0.56</td>
<td>-0.30</td>
<td>-0.25</td>
<td>0.23</td>
</tr>
<tr>
<td>Briton Court Rd cnr Bucketts Way</td>
<td>0.27</td>
<td>0.15</td>
<td>0.30</td>
<td>0.43</td>
<td>-0.18</td>
<td>-0.15</td>
<td>0.17</td>
</tr>
<tr>
<td>Mill Creek Picnic Area</td>
<td>2.55</td>
<td>0.15</td>
<td>0.29</td>
<td>0.42</td>
<td>-0.21</td>
<td>-0.18</td>
<td>0.16</td>
</tr>
<tr>
<td>Erin St cnr Scotia St</td>
<td>1.91</td>
<td>0.21</td>
<td>0.40</td>
<td>0.58</td>
<td>-0.29</td>
<td>-0.26</td>
<td>0.24</td>
</tr>
<tr>
<td>U/S Erin St Culvert</td>
<td>0.41</td>
<td>0.02</td>
<td>0.04</td>
<td>0.05</td>
<td>-0.10</td>
<td>-0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>U/S Bucketts Way Culvert 1</td>
<td>0.89</td>
<td>0.03</td>
<td>0.05</td>
<td>0.07</td>
<td>-0.09</td>
<td>-0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>U/S Bucketts Way Culvert 2</td>
<td>1.15</td>
<td>0.04</td>
<td>0.07</td>
<td>0.10</td>
<td>-0.46</td>
<td>-0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Laman St cnr Bucketts Way</td>
<td>0.46</td>
<td>0.12</td>
<td>0.20</td>
<td>0.30</td>
<td>-0.31</td>
<td>-0.17</td>
<td>0.13</td>
</tr>
<tr>
<td>Lamans Ck /Mill Ck Confluence</td>
<td>4.15</td>
<td>0.17</td>
<td>0.31</td>
<td>0.44</td>
<td>-0.24</td>
<td>-0.53</td>
<td>0.36</td>
</tr>
<tr>
<td>Mill Brook U/S Bucketts Way</td>
<td>3.68</td>
<td>0.15</td>
<td>0.30</td>
<td>0.44</td>
<td>-0.20</td>
<td>-0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Mill Brook D/S Bucketts Way</td>
<td>2.31</td>
<td>0.13</td>
<td>0.25</td>
<td>0.35</td>
<td>-0.20</td>
<td>-0.17</td>
<td>0.15</td>
</tr>
<tr>
<td>Mill Ck U/S Bucketts Way Bridge</td>
<td>7.09</td>
<td>0.21</td>
<td>0.41</td>
<td>0.58</td>
<td>-0.26</td>
<td>-0.21</td>
<td>0.24</td>
</tr>
<tr>
<td>Lamans Creek U/S Bucketts Way Bridge</td>
<td>3.75</td>
<td>0.15</td>
<td>0.30</td>
<td>0.43</td>
<td>-0.41</td>
<td>-0.26</td>
<td>0.19</td>
</tr>
</tbody>
</table>
7. FLOOD DAMAGES

The cost of flood damages and the extent of the disruption to the community depend upon many factors including:

- the magnitude (depth, velocity and duration) of the flood,
- land usage and susceptibility to damage,
- awareness of the community to flooding,
- effective warning time,
- the availability of an evacuation plan or damage minimisation program,
- physical factors such as erosion of creek banks, flood borne debris, sedimentation.

Flood damages can be defined as being “tangible” or “intangible”. Tangible damages are those for which a monetary value can be assigned, in contrast to intangible damages, which cannot easily be attributed a monetary value (stress, injury, loss to life, etc.).

While the total likely damages in a given flood are useful to get a “feel” for the magnitude of the flood problem, it is of little value for absolute economic evaluation. When considering the economic effectiveness of a proposed mitigation measure, the key question is what are the total damages prevented over the life of the measure? This is a function not only of the high damages which occur in large floods but also of the lesser but more frequent damages which occur in small floods.

Table 15 Summary of Flood Damages

<table>
<thead>
<tr>
<th>Design Flood (AEP)</th>
<th>Estimated Properties with Internal (Above-Floor) Flood Damages</th>
<th>Estimated Properties with External Flood Damages</th>
<th>Tangible Damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>0</td>
<td>2</td>
<td>$5,000</td>
</tr>
<tr>
<td>20%</td>
<td>0</td>
<td>5</td>
<td>$13,000</td>
</tr>
<tr>
<td>10%</td>
<td>0</td>
<td>6</td>
<td>$17,000</td>
</tr>
<tr>
<td>5%</td>
<td>0</td>
<td>7</td>
<td>$21,000</td>
</tr>
<tr>
<td>2%</td>
<td>2</td>
<td>18</td>
<td>$69,000</td>
</tr>
<tr>
<td>1%</td>
<td>2</td>
<td>23</td>
<td>$129,000</td>
</tr>
<tr>
<td>0.5%</td>
<td>5</td>
<td>25</td>
<td>$252,000</td>
</tr>
<tr>
<td>0.2%</td>
<td>9</td>
<td>30</td>
<td>$440,000</td>
</tr>
<tr>
<td>PMF</td>
<td>27</td>
<td>55</td>
<td>$1,782,000</td>
</tr>
</tbody>
</table>

AVERAGE ANNUAL DAMAGES $20,000
**Table 16 Flood Damages Categories**

**FINANCIAL**
Costs which can be expressed in dollars.

- **DAMAGE FROM FLOODING**
  - **TANGIBLE**
    - **DIRECT**
      - **INTERNAL**
        - RESIDENTIAL: Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances
      - **EXTERNAL**
        - RURAL: Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances
      - **STRUCTURAL**
        - COMMERCIAL: Contents of Buildings: Products, Stock, Fittings, Tools, Machinery, Raw Materials
      - **CLEANUP**
        - PUBLIC AUTHORITIES: Contents of Public Buildings and Facilities: Public Property and Facilities: Parks, Signs, Machinery, Equipment
    - **INDIRECT**
      - **INTERNAL**
        - SOCIAL: Costs which cannot be expressed in dollars, eg:
          - stress,
          - loss of life,
          - serious injury,
          - depression,
          - inconvenience,
          - insecurity.
      - **EXTERNAL**
        - **OPPORTUNITY**
      - **FINANCIAL**
        - OPPORTUNITY: Not Applicable
  - **TANGIBLE**
    - **DIRECT**
      - **INTERNAL**
        - RESIDENTIAL: Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances
      - **EXTERNAL**
        - RURAL: Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances
      - **STRUCTURAL**
        - COMMERCIAL: Contents of Buildings: Products, Stock, Fittings, Tools, Machinery, Raw Materials
      - **CLEANUP**
        - PUBLIC AUTHORITIES: Contents of Public Buildings and Facilities: Public Property and Facilities: Parks, Signs, Machinery, Equipment
    - **INDIRECT**
      - **INTERNAL**
        - SOCIAL: Costs which cannot be expressed in dollars, eg:
          - stress,
          - loss of life,
          - serious injury,
          - depression,
          - inconvenience,
          - insecurity.
      - **EXTERNAL**
        - **OPPORTUNITY**
      - **FINANCIAL**
        - OPPORTUNITY: Not Applicable

**DAMAGE CAUSED BY FLOODWATERS COMING INTO CONTACT WITH ITEMS.**
This can be expressed as "Potential" (max. damage) and "Actual" (reduced damage due to moving items).

**EXTERNAL**
These costs are associated with the flood event occurring, but not as readily quantifiable.

**INTERNAL**
These costs are associated with the flood event occurring, but not as readily quantifiable.

**STRUCTURAL**
These costs are associated with the flood event occurring, but not as readily quantifiable.

**CLEANUP**
These costs are associated with the flood event occurring, but not as readily quantifiable.

**FINANCIAL**
These costs are associated with the flood event occurring, but not as readily quantifiable.

**OPPORTUNITY**
These costs are associated with the flood event occurring, but not as readily quantifiable.
The standard way of expressing flood damages is in terms of average annual damages (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by taking into account the probability of a flood occurrence. Therefore the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods.

A flood damages assessment was undertaken for existing development within the study area for both residential and commercial properties. This was based on a detailed floor level survey and results from the TUFLOW model. Damages to public structures have not been assessed. The summary of flood damages for the lower catchment is provided in Table 15 with the building floors inundated shown on Figure 31.
8. ACKNOWLEDGEMENTS

This study was carried out by WMAwater and funded by Great Lakes City Council and the Department of Environment, Climate Change and Water. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Great Lakes City Council,
- Department of Environment, Climate Change and Water,
- Stroud Floodplain Management Committee,
- Residents of Stroud within the study area.
9. REFERENCES

1. Pilgrim H (Editor in Chief)
   Australian Rainfall and Runoff – A Guide to Flood Estimation

2. Floodplain Development Manual

3. Water Resources Commision of New South Wales
   Stroud Flood Study Reference Plan

4. Paterson Consultants Pty Ltd
   Karuah River Flood Study – Draft Report
   Great Lakes Council, May 2008

5. Pt Stephens, Dungog and Maitland City Council
   Paterson River Flood Study
   WBM Oceanics, February 1997

6. Department of Environment and Climate Change
   Practical Consideration of Climate Change
   Floodplain Risk Management Guideline

   BMT WBM, 2008.

   Watershed Bounded Network Model (WBNM) – Details of Theory
   2007

9. NSW Sea Level Rise Policy Statement
   NSW State Government, October 2009

    in flood risk assessments
    NSW State Government, October 2009

**Recent Developments in Climate Science: Implications for Flood Guidelines**  

12. Rigby, E., Boyd, M., Roso, S. and VanDrie, R.  

**Storms, Storm Bursts and Flood Estimation - A Need for Review of the AR&R Procedures**  

13. Rigby, E. and Bannigan, D.  

**The Embedded Design Storm Concept - A Critical Review**  


**Embedded Design Storms - An Improved Procedure For Design Flood Level Estimation**  

15. **The Estimation of Probable Maximum Precipitation in Australia: Generalised Short_Duration Method**  
Bureau of Meteorology, Melbourne, Australia, June 2003.

16. Chow, V. T.  

**Open Channel Hydraulics**  
McGraw Hill, 1959

17. Henderson, F. M.  

**Open Channel Flow**  
MacMillan, 1966
FIGURE 3
RAINFALL INTENSITY
DESIGNED RELATIONSHIPS AND
RECORDED JUNE 2007 RAINFALL

- Chichester
- Gloucester
- Stroud (Chichester Temporal Pattern)
- Stroud (Gloucester Temporal Pattern)
25.8 mAHD
28.2 mAHD
31.14 mAHD
30.7 mAHD
30.9 mAHD
30.9 mAHD
30.7 mAHD
27 mAHD
26 mAHD
30 mAHD
31.2 mAHD
31.3 mAHD
31.3 mAHD
25.2 mAHD
26 mAHD
26.6 mAHD
27.5 mAHD
27.6 mAHD
27.7 mAHD
28.4 mAHD
31.7 mAHD
31.6 mAHD
31.8 mAHD

2007 Observed Flood Levels
1985 Debris Flood Levels
1985 Observed Flood Levels
1956 Observed Flood Levels
FIGURE 5

LIDAR VERIFICATION OF SURVEY LOCATIONS

Note: The full extent of survey locations is not shown in this figure.
FIGURE 6
DETAIL SURVEY OF HYDRAULIC STRUCTURES
AND CROSS-SECTIONS
FIGURE 7a
DESIGN INFLOW HYDROGRAPHS
MILL CREEK
FIGURE 7
HYDROLOGIC MODEL CATCHMENT LAYOUT

Note: Shaded subcatchments are shown in greater detail in Figure 10.
The image shows an aerial view of a study area with various landmarks and streams marked. The study area is labeled as the "Additional Study Area (PMF)." The map includes the following features:

- **Karuah River:** A major waterway running through the area.
- **The Bucketts Way:** A road that runs parallel to the Karuah River.
- **Mill Creek:** A smaller stream marked on the map.
- **Mill Brook:** Another minor stream indicated.
- **Stroud:** A location or point of interest within the study area.

The area is zoomed in with a scale indicating distances in kilometers (km) ranging from 0 to 1 km.
HYDRAULIC MODEL SCHEMATISATION

FIGURE 9

Inflow Boundary

New Mill Creek Bridge
Old Mill Creek Bridge
Lamana Creek Bridge

Elevation (mAHD)
High : 47.7781
Low : 12.4666

HQ Rating Curve
LOCAL SUB-CATCHMENT INFLOW LOCATIONS

FIGURE 10

Routed Inflow Locations
Hydraulic Model Internal Subcatchments (0% Impervious)
Hydraulic Model Internal Subcatchments (40% Impervious)
Figure 11: Design peak height profiles for Mill Creek.

- 50% AEP
- 20% AEP
- 10% AEP
- 5% AEP
- 2% AEP
- 1% AEP
- 0.5% AEP
- 0.2% AEP
- PMF

- 2007 Levels
- 1985 Levels (Observed)
- 1985 Levels (Debris Marks)
- 1956 Levels

Legend:

- Karuah River Peak Flood Level PMF
- Karuah River Peak Flood Level 1% AEP
FIGURE 12
DESIGN PEAK HEIGHT PROFILES
LAMANS CREEK

Karuah River Peak Flood Level 1%
Karuah River Peak Flood Level PMF
Bucket's Way
Mill Creek

Peak Flood Level (mAHD)

Chainage (m)

50% AEP
20% AEP
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
0.2% AEP

PMF

2007 Levels
1956 Levels
FIGURE 13a
DESIGN FLOOD LEVEL HYDROGRAPHS
MILL CREEK UPSTREAM OF BUCKETTS WAY

- 50% AEP
- 20% AEP
- 10% AEP
- 5% AEP
- 2% AEP
- 1% AEP
- 0.5% AEP
- 0.2% AEP
- PMF

Level (mAHD)

Time (hr)
FIGURE 14
FLOOD CONTOURS AND DEPTHS
PMF

Water Surface Elevation (m AHD)
- 0.2m Interval
- 1.0m Interval
- Karuah River PMF Peak Flood Level (32.05m)

Depth (m)
- < 0.3
- 0.3 - 0.5
- 0.5 - 1.0
- 1.0 - 5.0
- > 5.0
FIGURE 15
FLOOD CONTOURS AND DEPTHS
0.2% AEP

Water Surface Elevation (m AHD)
- 0.2m Interval
- 1.0m Interval
- Karuah River 0.2% AEP Peak Flood Level (26.28m)

Depth (m)
- < 0.3
- 0.3 - 0.5
- 0.5 - 1.0
- 1.0 - 5.0
- > 5.0

J:\Jobs\28014\Arcview\ArcMaps\Figure14_0.2%AEP_Flood_Contours&Depths.mxd
0 0.4 0.8 1.2 1.6 0.2 km
FIGURE 16
FLOOD CONTOURS AND DEPTHS
0.5% AEP

Water Surface Elevation (m AHD)
- 0.2m Interval
- 1.0m Interval

Depth (m)
- < 0.3
- 0.3 - 0.5
- 0.5 - 1.0
- 1.0 - 5.0
- > 5.0
FIGURE 18
FLOOD CONTOURS AND DEPTHS
2% AEP

Water Surface Elevation (m AHD)

- 0.2m Interval
- 1.0m Interval

Depth (m)

- < 0.3
- 0.3 - 0.5
- 0.5 - 1.0
- 1.0 - 5.0
- > 5.0

Karuah River 2% Peak AEP Flood Level (25.04m)
FIGURE 19
FLOOD CONTOURS AND DEPTHS
5% AEP

Water Surface Elevation (m AHD)

- 0.2m Interval
- 1.0m Interval

Depth (m)
- < 0.3
- 0.3 - 0.5
- 0.5 - 1.0
- 1.0 - 5.0
- > 5.0

Karuah River 5% AEP Peak Flood Level (24.61m)
FIGURE 20
FLOOD CONTOURS AND DEPTHS
10% AEP

Water Surface Elevation (m AHD)

- 0.2m Interval
- 1.0m Interval
- Karuah River 10% AEP Peak Flood Level (22.97m)

Depth (m)
- < 0.3
- 0.3 - 0.5
- 0.5 - 1.0
- 1.0 - 5.0
- > 5.0
FIGURE 21
FLOOD CONTOURS AND DEPTHS
20% AEP

Water Surface Elevation (m AHD)

- 0.2m Interval
- 1.0m Interval
- Karuah River 20% AEP Peak Flood Level (22.07m)

Depth (m)

- < 0.3
- 0.3 - 0.5
- 0.5 - 1.0
- 1.0 - 5.0
- > 5.0
FIGURE 22
FLOOD CONTOURS AND DEPTHS
50% AEP

Water Surface Elevation (m AHD)
- 0.2m Interval
- 1.0m Interval
- Karuah River 50% AEP Peak Flood Level (20.46m)

Depth (m)
- < 0.3
- 0.3 - 0.5
- 0.5 - 1.0
- 1.0 - 5.0
- > 5.0
FIGURE 23
VELOCITY AT FLOOD PEAK
PMF

Velocity (m/s)
- 0 to 0.2
- 0.2 to 0.5
- 0.5 to 1
- > 1.0

km
0 0.2 0.4 0.8 1.2 1.6
FIGURE 24
VELOCITY AT FLOOD PEAK
1% AEP

Velocity (m/s)
- 0 to 0.2
- 0.2 to 0.5
- 0.5 to 1.0
- > 1.0

km
0 0.2 0.4 0.8 1.2 1.6
FIGURE 25
PROVISIONAL HYDRAULIC HAZARD CATEGORIES
PMF

Hydraulic Hazard Category

Low
High

km
0 0.2 0.4 0.8 1.2 1.6
FIGURE 26
PROVISIONAL HYDRAULIC HAZARD CATEGORIES
1% AEP

Hydraulic Hazard Category

- Blue: Low
- Red: High

km
FIGURE 27
HYDRAULIC CATEGORISATION

Hydraulic Categorisation

- Floodway
- Flood Depth
- Flood Fringe

Legend:
- Red: Floodway
- Blue: Flood Depth
- Yellow: Flood Fringe

Scale: 0 km - 1.6 km
FIGURE 28
HYDRAULIC CATEGORISATION
1% AEP

Hydraulic Categorisation
- Floodway
- Flood Storage
- Flood Fringe
FIGURE 30

AVERAGE ABOVE FLOOR INUNDATION FREQUENCY

Inundation Event
- Blue: 50y
- Green: 200y
- Yellow: 500y
- Red: PMF
FIGURE 31
VEGETATION PHOTOGRAPHS

(a) Mill Creek looking upstream from Bucketts Way bridge
(b) Mill Brook looking upstream from Bucketts Way
(c) Lamans Creek looking downstream towards Bucketts Way bridge
(d) Lamans Creek right bank, 250m downstream of Bucketts Way
FIGURE 32a
SENSITIVITY PROFILES
MILL CREEK
APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>acid sulfate soils</td>
<td>Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.</td>
</tr>
<tr>
<td>Annual Exceedance Probability (AEP)</td>
<td>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 m³/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m³/s or larger event occurring in any one year (see ARI).</td>
</tr>
<tr>
<td>Australian Height Datum (AHD)</td>
<td>A common national surface level datum approximately corresponding to mean sea level.</td>
</tr>
<tr>
<td>Average Annual Damage (AAD)</td>
<td>Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.</td>
</tr>
<tr>
<td>Average Recurrence Interval (ARI)</td>
<td>The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.</td>
</tr>
<tr>
<td>caravan and moveable home parks</td>
<td>Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.</td>
</tr>
<tr>
<td>catchment</td>
<td>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.</td>
</tr>
<tr>
<td>consent authority</td>
<td>The Council, government agency or person having the function to determine a development application for land use under the EP&amp;A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.</td>
</tr>
<tr>
<td>development</td>
<td>Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&amp;A Act).</td>
</tr>
<tr>
<td>infill development</td>
<td>Refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development.</td>
</tr>
<tr>
<td>new development</td>
<td>Refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.</td>
</tr>
</tbody>
</table>
**redvelopment**: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

**disaster plan (DISPLAN)**
A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

**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 for example, metres per second (m/s).

**ecologically sustainable development (ESD)**
Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.

**effective warning time**
The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

**emergency management**
A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

**flash flooding**
Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

**flood**
Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

**flood awareness**
Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

**flood education**
Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

**flood fringe areas**
The remaining area of flood prone land after floodway and flood storage areas have been defined.

**flood liable land**
Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>flood mitigation standard</td>
<td>The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.</td>
</tr>
<tr>
<td>floodplain</td>
<td>Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.</td>
</tr>
<tr>
<td>floodplain risk management options</td>
<td>The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.</td>
</tr>
<tr>
<td>floodplain risk management plan</td>
<td>A management plan developed in accordance with the principles and guidelines in this manual. 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.</td>
</tr>
<tr>
<td>flood plan (local)</td>
<td>A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.</td>
</tr>
<tr>
<td>flood planning area</td>
<td>The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the “flood liable land” concept in the 1986 Manual.</td>
</tr>
<tr>
<td>Flood Planning Levels (FPLs)</td>
<td>FPL’s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the “standard flood event” in the 1986 manual.</td>
</tr>
<tr>
<td>flood proofing</td>
<td>A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.</td>
</tr>
<tr>
<td>flood prone land</td>
<td>Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.</td>
</tr>
<tr>
<td>flood readiness</td>
<td>Flood readiness is an ability to react within the effective warning time.</td>
</tr>
<tr>
<td>flood risk</td>
<td>Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below.</td>
</tr>
<tr>
<td>existing flood risk</td>
<td>the risk a community is exposed to as a result of its location on the floodplain.</td>
</tr>
<tr>
<td>future flood risk</td>
<td>the risk a community may be exposed to as a result of new development on the floodplain.</td>
</tr>
<tr>
<td>continuing flood risk</td>
<td>the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.</td>
</tr>
<tr>
<td>flood storage areas</td>
<td>Those parts of the floodplain that are important for the temporary storage of</td>
</tr>
</tbody>
</table>
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.

**floodway areas**
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 flows, or a significant increase in flood levels.

**freeboard**
Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.

**habitable room**
in a residential situation: a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom.

in an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.

**hazard**
A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.

**hydraulics**
Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

**hydrograph**
A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

**hydrology**
Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

**local overland flooding**
Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

**local drainage**
Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

**mainstream flooding**
Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

**major drainage**
Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:
- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or
- water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These
conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or

- major overland flow paths through developed areas outside of defined drainage reserves; and/or

- the potential to affect a number of buildings along the major flow path.

**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.

The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.

**minor, moderate and major flooding**

Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

- **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

- **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.

- **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

**modification measures**

Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.

**peak discharge**

The maximum discharge occurring during a flood event.

**Probable Maximum Flood (PMF)**

The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, 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, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)  
The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.

probability  
A statistical measure of the expected chance of flooding (see AEP).

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 streamflow, also known as rainfall excess.

stage  
Equivalent to “water level”. Both are measured with reference to a specified datum.

stage hydrograph  
A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.

survey plan  
A plan prepared by a registered surveyor.

water surface profile  
A graph showing the flood stage at any given location along a watercourse at a particular time.

wind fetch  
The horizontal distance in the direction of wind over which wind waves are generated.
FLOOD DATA COLLECTION SURVEY

November 2007

for

Great Lakes Council

Prepared by:

34 King Street
Gloucester 2422
Phone: 6558 2255
Fax: 6558 2327
INTRODUCTION

The following report has been compiled for various sites throughout the Great Lakes Shire where flooding has been experienced. Particular focus has been given to the June 2007 storm event which affected much of the Central Coast, Hunter & Mid North Coast Regions.

Each of the subject sites have been surveyed to obtain levels (Australian Height Datum) which indicate the areas (including residences, properties, roads & other features) affected by the June 2007 storm event.

The data gathered for most sites has been supplemented with information from the local residents of each area. In addition, photographs were taken to assist in the analysis of each site.

METHODOLOGY

Field Survey included a combination of traditional theodolite and levelling procedures and G.P.S. measuring techniques.

Resultant levels (Australian Height Datum) are provided to an accuracy of +/- 0.05m.

Survey control was provided by Lands Department Permanent Survey Marks located in the vicinity of the nominated areas of interest. Extra marks were located to confirm/check the surveyed site levels.

Each nominated area was surveyed to establish the extent of flooding and the properties affected giving particular emphasis to the residences, roads, drainage & structures in the immediate vicinity.

Contact was made with the property owners of most areas to establish (at the time of flooding) characteristics including velocity, rate of rise and ebb of the flood & affect on property.
LOCATIONS COVERED:

- **Booral**
  - Booral Creek Bridge (Booral Road)
  - Cromarty Creek Bridge (Bucketts Way)
  - Washpool Creek Bridge (Washpool Road)

- **Bulahdelah**
  - Blanch Street/Stroud Street Intersection
  - Fry’s Creek Bridge (Markwell Road)

- **Darawank**
  - 31 Manns Road
  - 912 Lakes Way

- **Failford**
  - North of Failford Rd/Lakes Way Intersection
  - Bungwahl Creek Bridge (Failford Road)

- **Stroud**
  - 16 Erin Street
  - 49 Cowper Street (& Rest Area near Mill Ck Bridge)
  - 10 Laman Street (& approaches to Lamans Ck Bridge)

- **Tea Gardens**
  - 7 Marine Parade
  - 9 Budgeree Street
Plan of Levels in Vicinity of 16 Erin Street - Stroud

Client: Great Lakes Council

34 King Street, Gloucester
P.O. Box 194 Gloucester 2422
Ph. 02 6558 2255 Fax. 02 6558 2327
EMAIL - survey@calcosurveyors.com.au
<table>
<thead>
<tr>
<th>Property Owner</th>
<th>Mr. &amp; Mrs. George Cummings – 9 years residing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>16 Erin Street, STROUD</td>
</tr>
<tr>
<td>Ph No</td>
<td>4994 5666</td>
</tr>
<tr>
<td>Drawing Refs</td>
<td>DWG2491_ErinSt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flood</th>
<th>Date: Friday 8 June 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>Time: 12noon – 1pm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Speed of Rise and Fall</th>
<th>Unsure</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Which roads cut &amp; how long for?</th>
<th>No traffic impeded, however, 0.1 - 0.2m depth of water experienced across Erin Street at low point for most of the day.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Other comments</th>
<th>Drainage inlet blocks with debris even in smaller storm events.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Highest flood experienced in 9 years.</td>
</tr>
</tbody>
</table>
Site Locality Plan - Source: Dept of Lands

PLAN OF LEVELS IN VICINITY OF 49 COWPER STREET - STROUD

CLIENT: Great Lakes Council

CalCo
SURVEYORS PTY LTD

34 KING STREET, GLOUCESTER
P.O. BOX 194 GLOUCESTER 2422.
Ph. 02 6558 2255  Fax. 02 6558 2327
EMAIL - survey@calcosurveyors.com.au

SCALE: 1:1000
DATUM: A.H.D.
DATE: 14/11/2007
Job No.
2491
Drawing No.
DWG2491_CowperSt
<table>
<thead>
<tr>
<th>Property Owner</th>
<th>Mr. &amp; Mrs. G. Arkinstall – 6 years residing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>49 Cowper Street, STROUD</td>
</tr>
<tr>
<td>Ph No</td>
<td>4994 5643</td>
</tr>
<tr>
<td>Drawing Refs</td>
<td>DWG2491_CowperSt</td>
</tr>
<tr>
<td>Flood Date</td>
<td>Friday 8 June 2007</td>
</tr>
<tr>
<td>Peak Time</td>
<td>1pm – 2pm</td>
</tr>
<tr>
<td>Speed of Rise and Fall</td>
<td>Rose gradually &amp; fell quickly.</td>
</tr>
<tr>
<td>Which roads cut &amp; how long for?</td>
<td>Bucketts Way(i.e. Cowper Street) was not cut, however, rest area was inundated.</td>
</tr>
</tbody>
</table>
SITELOCALITYPLANSOURCEDepartmentofLands

- Photo reference
- Flood photo reference (incorrect date shown on photos)

Highest recorded flood level (June '07) as indicated by Mrs. Robards RL 25.8
(House was completely surrounded by water)

SECTION T
DP95908

Site Locality Plan - Source: Dept. of Lands

PLAN OF LEVELS IN VICINITY OF 10 LAMAN STREET - STROUD

CLIENT: Great Lakes Council

CalCo SURVEYORS PTY LTD

34 KING STREET, GLOUCESTER
P.O. BOX 194 GLOUCESTER 2422.
Ph. 02 6558 2255 Fax. 02 6558 2327
EMAIL - survey@calcosurveyors.com.au

SCALE: 1:1000
DATUM: A.H.D.
DATE: 14/11/2007
Job No. 2491
Drawing No. DWG2491_LamanSt
<table>
<thead>
<tr>
<th>Property Owner</th>
<th>Mr. &amp; Mrs. Robards – 47 years residing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>10 Laman Street, STROUD</td>
</tr>
<tr>
<td>Ph No</td>
<td>4994 5246</td>
</tr>
<tr>
<td>Drawing Refs</td>
<td>DWG2491_LamanSt</td>
</tr>
<tr>
<td>Flood Peak Date</td>
<td>Friday 8 June 2007</td>
</tr>
<tr>
<td>Flood Peak Time</td>
<td>10am – 11am</td>
</tr>
<tr>
<td>Speed of Rise and Fall</td>
<td>Rose quickly &amp; always does in any storm event.</td>
</tr>
<tr>
<td></td>
<td>If Mill Creek (downstream) floods first it forces Lamans Creek to back up even quicker.</td>
</tr>
<tr>
<td>Which roads cut &amp; how long for?</td>
<td>Both Bucketts Way (Berkeley Street) &amp; Laman Street were cut &amp; traffic along Bucketts Way was stopped for approx. 45mins. Flooding was less along Laman Street, however, Mr. &amp; Mrs. Robards car was stranded in garage for an hour or so.</td>
</tr>
<tr>
<td>Other comments</td>
<td>Highest flood experienced in 47 years.</td>
</tr>
</tbody>
</table>