

Halls Gap Flood Study Study Report



Report No. J521/R01

June 2008



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Front cover photo: Halls Gap Valley floor- Flooding in 1996 (Source Margo Sietsma)

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EXECUTIVE SUMMARY

This report details the input data, approach and outcomes for the Halls Gap Flood Study.

The study has been initiated by Wimmera Catchment Management Authority (Wimmera CMA) and Northern Grampians Shire Council (NGSC) with funding provided under the Natural Disaster Risk Management Studies Programme by the Australian and Victorian Governments, and NGSC. The study provides information on flood levels and flood risks within the township for riverine and stormwater flooding.

The study team was lead by Water Technology with sub-consultants, Michael Cawood and Associates, Price Merrett Consulting, MPMedia Solutions, Planning and Environmental Design and AAMHatch.

Community consultation was undertaken with three community information sessions held. A number of residents provided photos and recollections of past flood events. The flood information provided by the residents was invaluable in the development of the study outcomes.

The township is subject to flash flooding with significant flood events occurring in 1946, 1992, 1996, 2003 and 2005. The steep terrain contributes to the generation of significant runoff volumes from relatively minor rainfall events. Further, the steep terrain combined with the absence of formal drainage infrastructure may lead to nuisance flooding in minor rainfall events (2 – 5 year average recurrence interval (ARI) events). Based on this minor rainfall event threshold (2 – 5 year), a daily rainfall total of 35 – 40 mm may lead to nuisance flooding. However, rainfall intensity is a major determining factor in runoff quantity.

Considerable uncertainty surrounds the design flood estimates developed by this study. Rigorous calibration and/or validation of the approach was restricted by the absence of a lengthy streamflow record. The absolute reliability of design estimates is unknown, however, the relativity of design estimates is considered reasonable.

Digital terrain models were developed from field and aerial surveys. Using the digital terrain models, hydraulic models were established to simulate flood behaviour within the study area. Due to the steep terrain and ill defined waterways, the hydraulic analysis was limited to the east of Grampians Road except for Stony Creek.

The study team supports the proposed NGSC drainage scheme. The construction of small bunds/landscaping may prevent flooding from overland flows and should be further considered by NGSC.

Draft flood related planning overlays (FO and LSIO) have been prepared to reflect the study outcomes. Also, revisions to the Design Development Overlay (DDO) have been made to control building techniques to reduce overland flow flooding, and enable the incorporation of the study outcomes in the Northern Grampians Planning Scheme, draft Planning Scheme Amendment documentation has been prepared.

With significant residential development occurring along the base of the Mount Difficult Range and within the Halls Gap Valley floor region (many at ground level), a major flood event is likely to cause significant damages. Many owners of such properties are likely to be unaware of the flooding risks as most have been built post the last significant flood event and many owners live permanently outside of Halls Gap. In addition to raising flood awareness amongst property owners, there is a need to inform the significant number of tourists that are exposed to flooding, particularly campers who are more highly exposed to this risk.

The study team recommends the preparation of community flood awareness material to communicate the understanding of flood risk developed by this study. Such material would provide residents and business owners an overview of flood risk at their property, and outline preparedness measures aimed reducing flood damages.

The study team recommends that the NGSC adopt all aspects of the revised Flood Sub-plan as an integral part of the Municipal Emergency Management Plan (MEMP). This includes measures aimed at 'keeping the Plan alive' and relevant to the community.

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I INTRODUCTION

The Halls Gap Flood Study has been initiated by Wimmera Catchment Management Authority (Wimmera CMA) in conjunction with Northern Grampians Shire Council (NGSC). The study provides information on flood levels and flood risks within the township of Halls Gap. This information underpins the development of appropriate measures aimed at reducing flood related inconvenience and damages into the future.

The study was funded under the Natural Disaster Risk Management Studies Programme by the Australian and Victorian Governments with a contribution from the NGSC.

The study team was lead by Water Technology with sub-consultants Michael Cawood and Associates, Price Merrett Consulting, MPMedia Solutions, Planning and Environmental Design and AAMHatch providing specialist input.

The township lies on Fyans Creek, a tributary of the upper Wimmera River. The creek rises in the southern Grampians before flowing to the north through Lake Bellfield. The lake is primarily used for water storage and is operated by Grampians Wimmera Mallee Water (GWMWater). Halls Gap is located some 2-3 km downstream from the Lake. Numerous drainage lines (gullies) along the Mount Difficult Range flow from the west to east through the township. Stony Creek is the largest of these drainage lines. The township has been subject to flash flooding on a number of occasions with a significant flood event in December 1992.

Figure I-1 displays the study area and the contributing catchments.

The flood study involved a hydrologic analysis of Fyans Creek and significant gullies, and a hydraulic assessment of flood behaviour in the township and surrounding floodplain areas. The flood behaviour was assessed for a range of design events up to the 1 in 200 year ARI flood event. Assessment of flood related damages and potential mitigation measures were also undertaken.

The structure of this report is as follows:

- Section 2 – provide a brief study background
- Section 3 – outlines the input data gathered for use in the study
- Section 4 – details the community consultation process
- Section 5 – outlines approach and outcomes from the hydrologic analysis
- Section 6 – discuss the hydraulic analysis for the existing conditions
- Section 7 – summarises the flood damage assessment
- Section 8 – outlines preliminary assessment of mitigation measures
- Section 9 - provides a summary of the study key conclusions

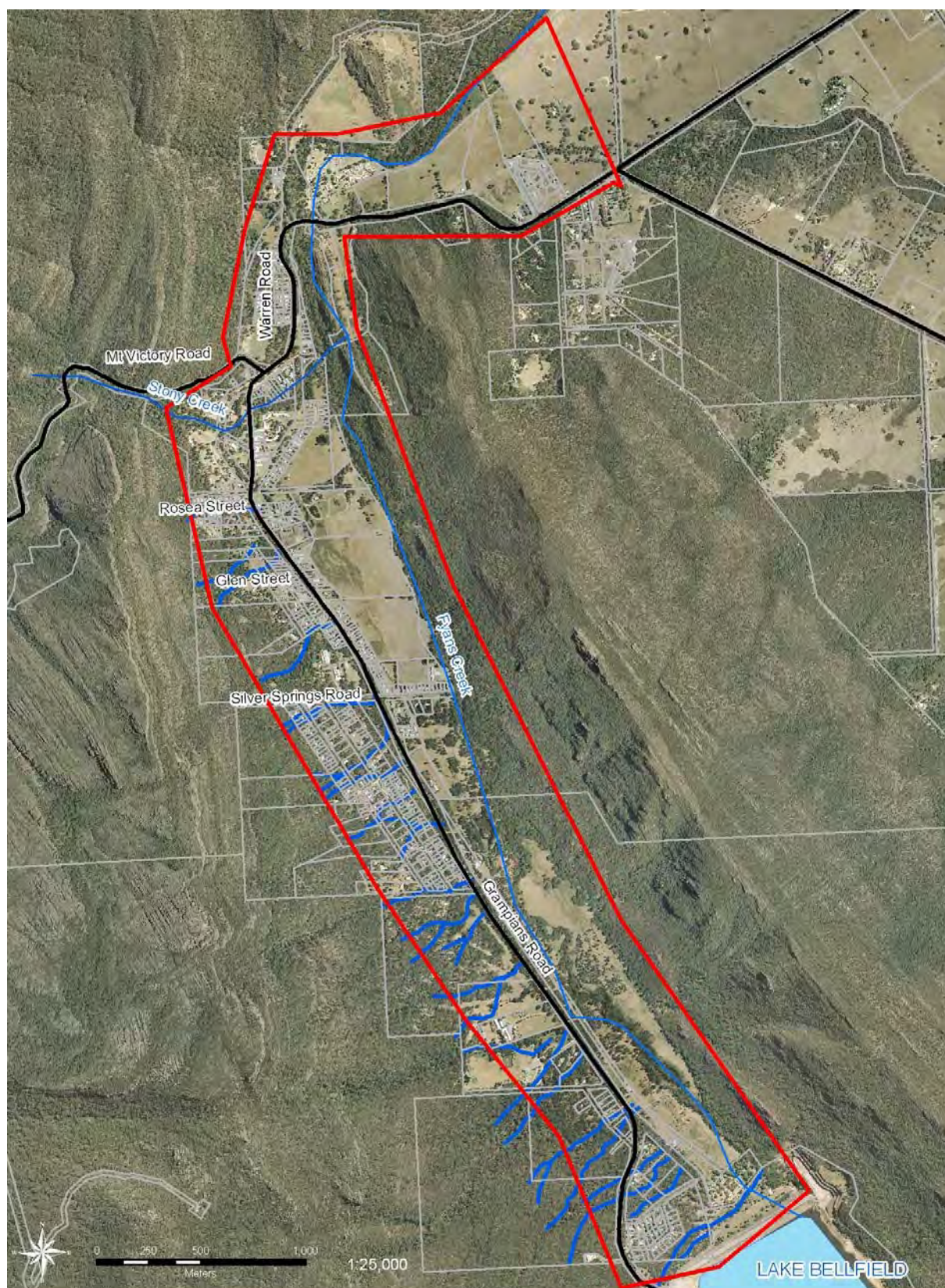


Figure I-I Study area and contributing catchments

2 STUDY AREA FEATURES

This section briefly describes the key features which influence flood behaviour within the study area. The study area has been broken into the following four waterways:

- Fyans Creek
- Mount Difficult gullies south of Glen Street
- Valley floor south of Hemley Court
- Mount Difficult Range gullies Glen Street to Stony Creek

The following sub-sections outline the key features along each waterway.

2.1 Fyans Creek

Halls Gap is located in a confined valley between the Mount William Range to the east and the Mount Difficult Range to the west. Fyans Creek flows to the east of the township in a northerly direction along the valley floor. Lake Bellfield, located some 2 - 3 kilometres upstream (to the south) of the township is a major water supply dam for the Wimmera Mallee Stock and Domestic Water Supply System. The storage is operated by GWMWater. Since the construction of Lake Bellfield, the flow regime of Fyans Creek has been significantly altered. Significant incision of the Fyans Creek channel has occurred. This incision has considerably increased the bankfull flow capacity of Fyans Creek. As a result, flooding of the valley floor due to Fyans Creek flows is limited from rare to extreme flood events, excess of 1 in 200 year ARI events. Figure 2-1 and Figure 2-2 show the large dimensions of the Fyans Creek channel.



Figure 2-1 Fyans Creek Channel downstream of Lake Bellfield (Note the cable way used for streamflow gauging)



Figure 2-2 Fyans Creek Channel immediately upstream from Delley's Bridge

2.2 Mount Difficult gullies south of Glen Street

Downstream of Lake Bellfield, numerous gullies drain the Mount William and Mount Difficult Ranges. In particular, the gullies draining along the Mount Difficult Range flow through developed areas of the Halls Gap township. During a heavy rainfall event, considerable runoff is generated from the steep escarpments of the Mount Difficult Range. Figure 2-3 displays the major gully lines to the south of Glen Street.

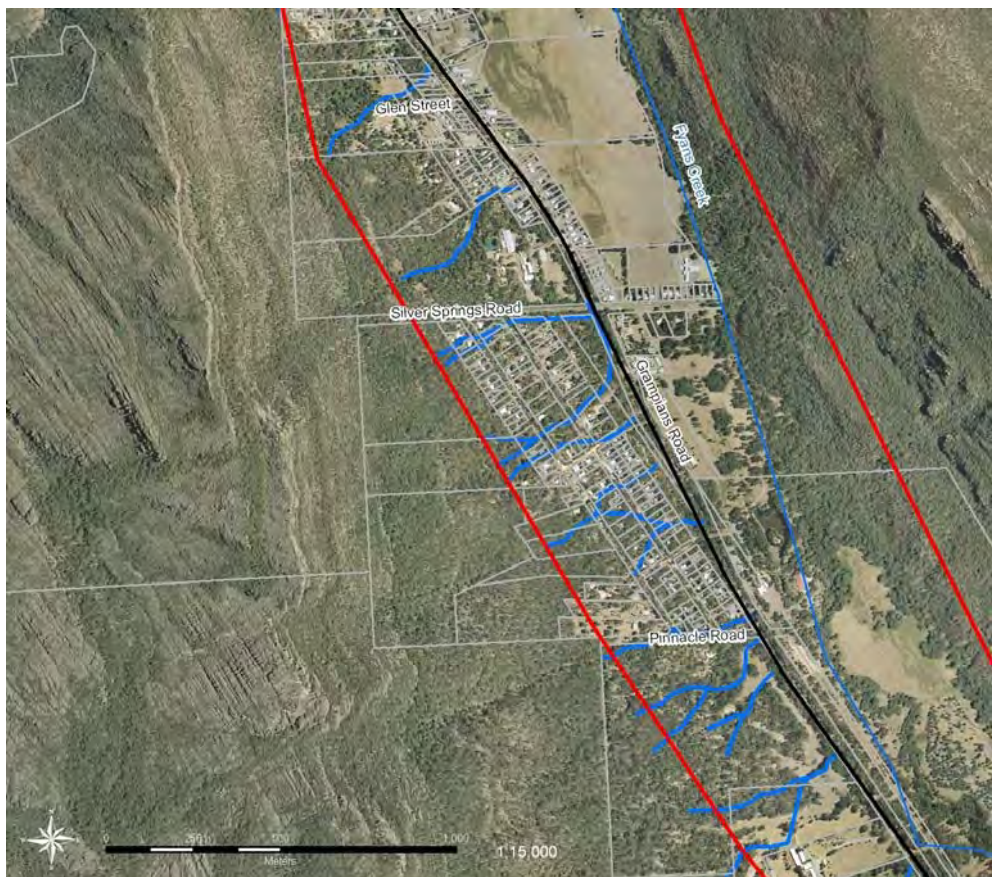


Figure 2-3 Mount Difficult gullies south of Glen Street

This surface runoff generally flows overland as sheet flow before concentrating into gullies. The gullies typically are well vegetated with some large boulders within the waterway. At Grampians Road, these gullies tend to flatten out with some ponding occurring on the western (upstream) side of Grampians Road. The overland flows can carry considerable sediment load, particularly wash off from unsealed roads and ash from the recent (December 2005 – January 2006) bushfires. This sediment can block pipes and culverts. Figure 2-4, Figure 2-5, Figure 2-6 and Figure 2-7 show typical gullies draining the Mount Difficult Range and pondage area adjacent to Grampians Road.



Figure 2-4 Typical gully draining along Mount Difficult Range (High Street south of Koala Road)



Figure 2-5 Gully at Royston Street near Silver Springs Road (note considerable sediment)



Figure 2-6 Pipe culvert under Grampians Road near Young Road. Completely blocked with sediment



Figure 2-7 Ponding area on the western side of Grampians Road near Wattletree Road

This sheet overland flow can give rise to nuisance flooding for properties along the foot of the Mount Difficult Range. As the flow depth is typically shallow, local topographic features (bunds, landscaping, etc.) strongly influence flooding behaviour and flood related damages. Further, the nature of the construction of the properties/buildings contributes to the flooding exposure. A number of existing buildings have been constructed on building pads

formed by cutting into the hill slope or constructed on piles where the front/back of the building is at the upslope ground level. These construction techniques can give rise to overland flows entering the building in the absence of upslope bunding/landscaping to divert overland flow. Figure 2-8 shows a dwelling where the building pad was formed by cutting into slope.



Figure 2-8 Dwelling in High Street

(Note Dwelling floor level lower than upslope ground level)

2.3 Valley floor south of Hemley Court

As outlined, the terrain flattens out adjacent to Grampians Road, the elevated nature of Grampians Road results in some ponding of overland flows on the western side of Grampians Road. The flow to the eastern side of Grampians Road occurs through a number of culverts and by overtopping the road. This shallow overland flow continues to the east and onto the valley floor. The valley floor is relatively flat with a gentle gradient from south to north. The valley floor contains numerous shallow flow paths. These shallow flow paths are likely to be remanent of a chain of ponds morphology. Considerable earthworks have been undertaken on the valley floor with the construction of small dams and/or wetlands. A number of wetlands have been constructed adjacent to the Parks Victoria and Brambuk Cultural Centre buildings. Figure 2-9 shows the flat nature of the valley floor.



**Figure 2-9 Valley floor north of the Lakeside Caravan Park
(Fyans Creek is located on the right edge of the photo)**

Flooding to buildings/dwellings can occur on the eastern side of Grampians Road due to the overland flows across the road. Similar to buildings/dwellings west of Grampians Road, the nature of the building construction can contribute to flooding exposure. Buildings constructed at ground level and/or with a slab on ground technique can be exposed to overland flooding. Figure 2-10 displays a dwelling on eastern side of Grampians Road.



**Figure 2-10 Dwelling on eastern side of Grampians Road
(Note Dwelling floor level at ground level)**

Development on the eastern side of Grampians Road is generally limited to Grampians Road except along Tandara Road, where several residential dwellings have been constructed. A significant overland flow from a gully crosses Grampians Road adjacent to the Tandara Road

intersection. Swale drains have been formed along Tandara Road to accommodate frequent overland flows. Figure 2-11 and Figure 2-12 show the swale drains adjacent to Tandara Road.



Figure 2-11 Swale drain adjacent to Tandara Road



Figure 2-12 Swale drain adjacent to Tandara Road

The overland flow across Grampians Road at Tandara Road joins overland flow along the valley floor from the south. This combined shallow overland flow may threaten dwellings adjacent to Tandara Road where the floor levels are at ground level. From Tandara Road, the overland flow continues along the valley floor to the north. Figure 2-13 shows the inundation across the valley floor.



Figure 2-13 Valley floor inundation (source Margo Sietsma)

2.4 Mount Difficult Range gullies Glen Street to Stony Creek

Similar to the south of Glen Street, several gullies and overland flow paths drain from the Mount Difficult Range between Glen Street and Stony Creek. In this area, the gullies are not as well defined as to the south of Glen Street. Figure 2-14 shows the significant gullies from Glen Street to Stony Creek.

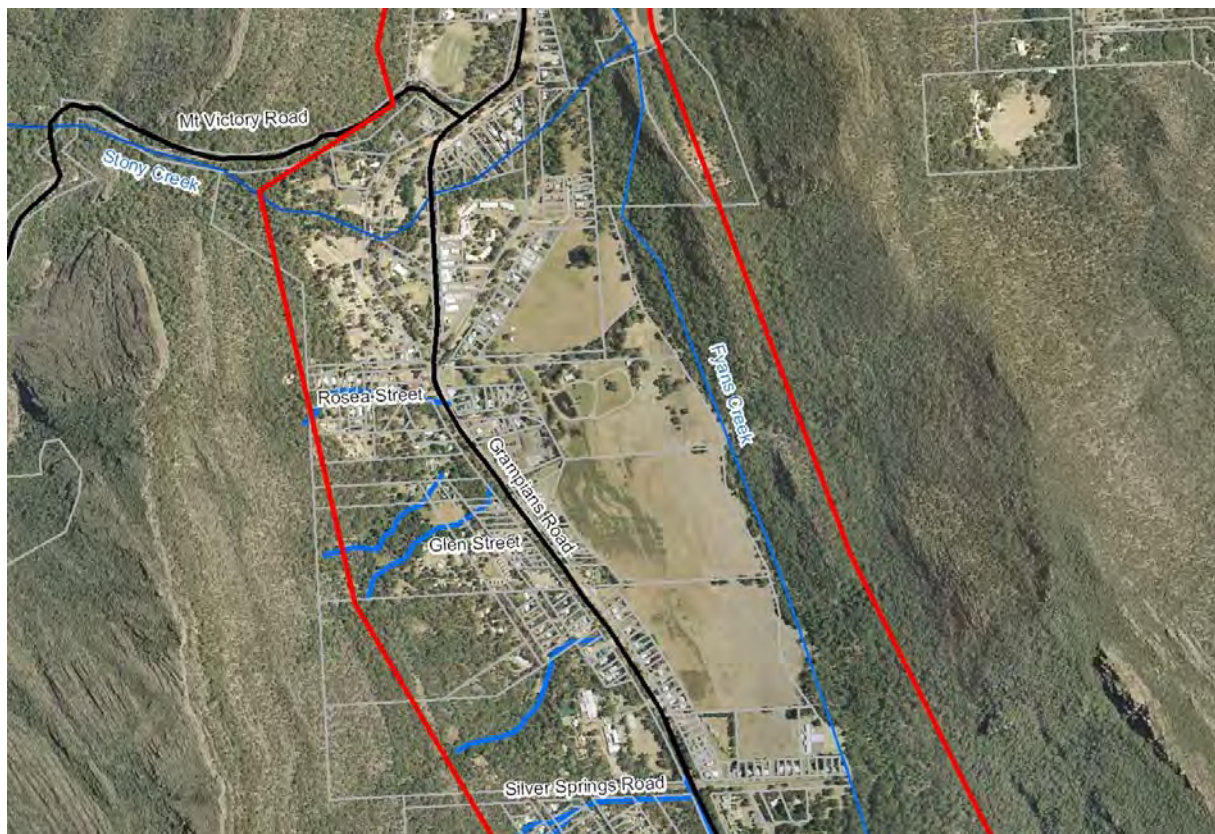


Figure 2-14 Mount Difficult Range gullies Glen Street to Stony Creek

A considerable overland path occurs adjacent to Rosea Street. The course of this flow path has been significantly altered by development. The overland flow path crosses Grampians Road at Rosea Street. A pipe culvert conveys low flows to an open channel on the eastern

side of Grampians Road. During high runoff events, overtopping of Grampians Road occurs with overland flows potentially affecting several buildings. Significant sediment load carried with the overland flow can block pipe culverts, and thus restricting the capacity of the drainage infrastructure. Figure 2-15 and Figure 2-16 show the overland flow path adjacent to Rosea Street.



Figure 2-15 Overland flow path adjacent to Rosea Street (looking upstream)



Figure 2-16 Overland flow path adjacent to Rosea Street (looking downstream across Grampians Road)

A constructed bund is located to the west of the Halls Gap Caravan Park and runs from Mackeys Peak Road to Stony Creek. The bund captures overland flows generated upslope from the caravan park and re-directs these flows to Stony Creek. Thus reduces overland flows across the caravan park and associated flood hazard to campers. Figure 2-17 and Figure 2-18 show the bund along the Halls Gap Caravan Park.



Figure 2-17 Bund along western limit of caravan park



Figure 2-18 Outfall of the Caravan Park bund to Stony Creek

Stony Creek is the largest tributary to Fyans Creek joining within the study area. The waterway is relatively steep and confined with a cobble and boulder lining. Figure 2-19 shows a typical section of Stony Creek upstream from Grampians Road. Stony Creek crosses Grampians Road adjacent to the commercial area. During a flood event in December 1992, Stony Creek threatened a number of commercial buildings to the east of Grampians Road. Figure 2-20 shows the flooding along Stony Creek in the December 1992 flood event.



Figure 2-19 Stony Creek upstream from Grampians Road



Figure 2-20 Stony Creek during December 1992 flood downstream of Grampians Road (Source Wimmera CMA)

Significant ponding has occurred along Grampians Road in front of the commercial and retail buildings. This ponding arises from overland flow generated runoff from the adjacent impervious areas (car park) and from the upslope catchment. Drainage infrastructure (pipes and culverts) convey lower flows from Grampians Road through to Heath Street with higher flows resulting in ponding.



Figure 2-21 Drainage infrastructure adjacent to retail buildings through to Heath Street. Grampians Road in the background

2.5 Mount Difficult Range north of Stony Creek

Discussions with community members suggests, before being diverted along the current course, Stony Creek once turned to the north before Grampians Road and flowed through the current recreation reserve, and continued adjacent to Warren Road to join Fyans Creek downstream of Delley's Bridge, refer to Figure 2-22.



Figure 2-22 Delley's Bridge and Warren Road features

Under current conditions, overland flow from the Mount Difficult Range to the north of Stony Creek, flows along this prior course of Stony Creek. Significant ponding occurs within the Recreation reserve and along Warren Road. The ponding along Warren road arises due to several constrictions in the waterway. Figure 2-23 shows ponding along Warren Road.



Figure 2-23 Ponding along Warren Road

Similar to overland flow within the rest of the study area, overland flow generated to the west of Warren Road could potentially impact on properties along Warren Road due to nature of building construction. Particularly, where buildings are constructed at ground level.

3 AVAILABLE INFORMATION

This section outlines the range of information utilised in this study including previous reports and documents as well as data, both previously available and collected specifically for this study.

3.1 Previous studies

Previous key hydrologic and/or hydraulic studies relevant to the present project and region include:

- **URS** – Lake Bellfield Flood Study: Consulting report for Wimmera Mallee Water (2001)
- **NGSC** – Halls Gap drainage investigations (2006-7)

These resources have been reviewed and drawn upon as necessary to provide background, context and verification of the current study approach and outcomes. A brief summary of the above material follows.

3.1.1 Lake Bellfield Flood Study (URS 2001)

This study analysed large to extreme flood inflows and outflows for Lake Bellfield. The study employed a RORB model to determine flood hydrographs into/out of Lake Bellfield with a hydraulic model (HECRAS) applied to assess downstream flood extents. As noted (URS 2001), the hydraulic model utilised available topographic data and the flood extents are indicative (+/- 1 m).

The RORB model developed by URS (2001) was refined for this flood study, as discussed in Section 5.

3.1.2 Halls Gap drainage investigations (NGSC 2006-7)

NGSC has undertaken extensive drainage investigations for Halls Gap. The focus of these investigations was to address a number of flooding impacts discussed in Section 2. In particular, works have been identified to mitigate flooding impacts.

During the course of this flood study, the study team has liaised extensively with NGSC in an effort to co-ordinate the outcomes from the investigations.

Discussions of the identified mitigation options is provided in Section 8.

3.2 Hydrologic data

Daily rainfall data was obtained from the Bureau of Meteorology for stations at Halls Gap (79020) and Halls Gap post office (79074). Further, daily rainfall stations at Pomonal and Belbellen were also examined. Pluviographic data was obtained for the closest station Wartook Reservoir.

Streamflow data was obtained from Thiess for gauges on Fyans Creek at the outlet of Lake Bellfield (415214) and at Grampians Road Bridge (415217). Table 3-1 outlines the details of the streamflow gauges.

Table 3-1: Details of Streamflow Gauge

Station Number	Station name	Period of record
415214	Fyans Creek at Lake Bellfield Outlet	1965 to date
415217	Fyans Creek at Grampians Road Bridge	1962 to date

Figure 3-1 shows the location of the above rainfall and streamflow gauges. The use of the above data in the hydrologic analysis is outlined in Section 5.

**Figure 3-1 Streamflow and rainfall gauges**

3.3 Topographic data

3.3.1 Overview

There have been three major sources of topographic information gathered during the course of the investigation, these being:

- Aerial Photogrammetry
- Aerial Laser Survey (ALS)
- Field Survey (as part of NGSC drainage investigation)

Following the collection and processing of the topographic information, a detailed digital terrain model was developed as the basis for the establishment of a hydraulic model of the study areas. The sources of the topographic information are discussed in more detail below.

3.3.2 Aerial survey

Aerial Photogrammetry

Aerial photogrammetry was undertaken specifically for the Halls Gap study area. The aerial photogrammetry was undertaken by AAM Hatch Pty Ltd. Figure 3-2 illustrates the extent of the photogrammetry. Price Merrett Consulting undertook the aerial photo control survey.

The nominated accuracy for this survey was a standard error (68% confidence level or 1 sigma) of 0.15m in both the horizontal and vertical planes.

Aerial Laser Survey

Wimmera CMA undertook extensive Aerial Laser Survey (ALS) for the authority's entirety in 2005. The available ALS data for the Halls Gaps region has a nominated accuracy (standard error) of 0.5m in the vertical planes. Figure 3-2 shows the ALS data extent for Halls Gap.

3.3.3 Field survey

Field survey was conducted as part of the NGSC drainage investigation. NGSC supplied pipe, culvert, crest levels along selected roads.

The extent location and extent of the field survey is illustrated in Figure 3-2.

3.3.4 Digital elevation model

Using the topographic survey discussed above, Digital Elevation Models (DEM) of the Halls Gap study areas were constructed. A grid size of 5m was employed.

Further details on the use of the DEM in the hydraulic analysis is provided in Section 6.

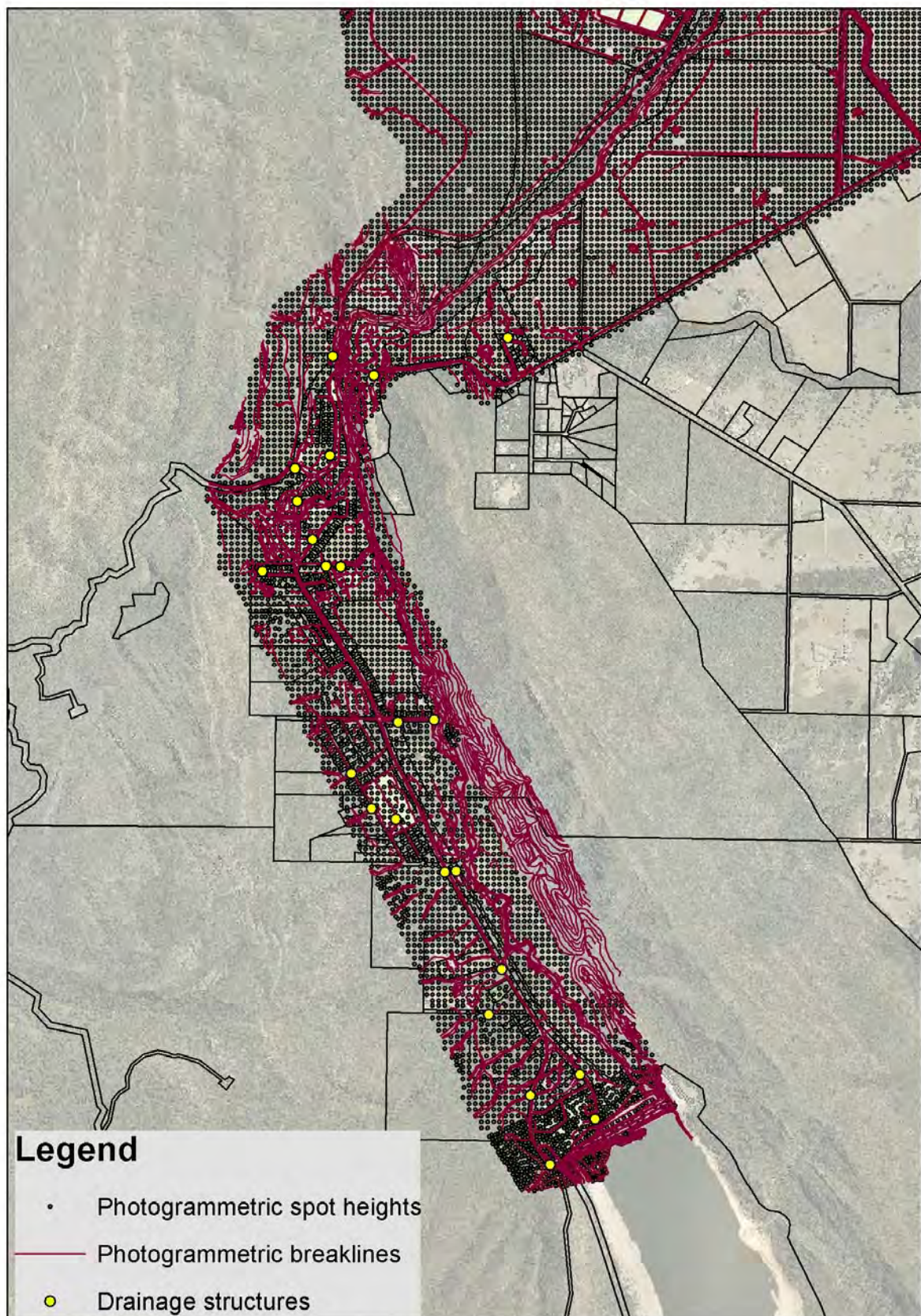


Figure 3-2 Halls Gap study area: Topographic survey elements

4 COMMUNITY CONSULTATION

4.1 Overview

A key ingredient in the development of a widely accepted study outcomes, was the active engagement of the community in the study. The communications strategy adopted by this study was aimed at the community developing a “sense of ownership” of the final study outcomes.

In an effort to engender this “sense of ownership” the consultation process proposed, was based on relationships with landholders within the study area. These relationships were developed over the course of the study through community information sessions and on-going communication of study progress.

To provide regular input to the study from the community, a three stage community process has been undertaken. The aims of the three stages are as follows:

- First stage community consultation:- to raise awareness of the study and identify community concerns.
- Second stage community consultation:- to seek community feedback/input regarding draft flood maps and potential mitigation options.
- Third stage community consultation:- to seek community feedback/input regarding the draft study report, flood warning and response options.

For each of the three community consultations, the study team in conjunction with Wimmera CMA drafted a press release. The press releases were aimed at raising public awareness of the study, and informing the community about the community information sessions. The press releases were supplied to the Stawell Times and was incorporated into articles.

A public notice outlining the study objective and scope, and the location and timing of the community information sessions was placed in the Stawell Times for each of the three community consultation Stages.

Community members who provided their contact details at the Stage 1 and/or 2 community information sessions were posted an invitation to Stage 2 and/or Stage 3 community information sessions.

4.2 Stage 1 community consultation

4.2.1 Aims and elements

The aim of the first stage community consultation is to raise awareness of the study commencement and to begin the development of linkages with key community members.

The first stage community consultation consisted of the following elements:

- Press releases and public notices (as outlined in Section 4.1)
- Community information sessions

4.2.2 Community information sessions

The community information session was in the Halls Gap Community Centre on Thursday 16 November 2006 from 7.00- 8.30pm.

The sessions were conducted in an informal manner with a short introduction presented by Clare Wilson (Wimmera CMA) and a study overview presented by Steve Muncaster (Water Technology).

A number of discussions were conducted with small groups of residents by the study team and Wimmera CMA during the course of the information sessions.

A total of 12-15 residents attended the community information session.

4.2.3 Outcomes of Stage 1 community information session

Community members expressed concern regarding the transport of sediment during flood events. The community sees the potential blockage of drains, pipes and culverts by sediment as a significant flood issue. Further, the maintenance of drainage infrastructure by NGSC is seen as a high priority requiring an improved attention in the future.

The community, while acknowledging the current flooding issues, wish to see any mitigation measures in line with the natural setting. There was a strong sentiment to avoid formal curb and channelling, and significant pipe upgrade where possible. However, there was a strong underlying community desire to see works to address and reduce the flooding problem.

Several community members saw previous planning and development decisions as the cause to their current flooding concerns.

Several site inspections with landholders/residents were undertaken to help obtaining further local information and increase the study teams understanding of flooding in Halls Gap.

4.3 Stage 2 community consultation

4.3.1 Aims and elements

The aim of the second stage consultation was to gain community feedback on the draft flood maps and potential mitigation options. The second stage community consultation consisted of the following elements:

- Press releases and public notices (as outlined in Section 4.1)
- Community information sessions

4.3.2 Community information sessions

The community information session was in the Halls Gap Community Centre on Wednesday 14 March 2007 from 7.00- 8.30pm.

The sessions were conducted in an informal manner with a short introduction presented by Clare Wilson (Wimmera CMA) and study progress presented by Steve Muncaster (Water Technology). A total of 30 -35 community members attended the information session.

A number of discussions were conducted with small groups of residents by the study team and Wimmera CMA during the course of the information sessions.

4.3.3 Outcomes of Stage 2 community information session

Similar to the Stage 1 information session, a strong preference was expressed for any mitigation measures to respect the natural setting. Previous mitigation measures proposed, as part of the early versions of the drainage scheme, involved installation of extensive

stormwater pipe network. The community generally considered such a measure was contrary to the overall amenity.

Several community members expressed concerns that the draft flood maps did not adequately represent the overland flow west of Grampians Road. Wimmera CMA has undertaken several subsequent meetings with community members to discuss their concerns. These concerns were taken into account in the preparation of final flood maps. In particular, the key gully lines, to the west of Grampians Road, were delineated to reflect overland flow path observed by landholders.

4.4 Stage 3 community consultation

4.4.1 Aims and elements

The aim of the third stage consultation was to gain community feedback on the draft flood report, mitigation measures, flood response and warning options. The third stage community consultation consisted of the following elements:

- Press releases and public notices (as outlined in Section 4.1)
- Community information sessions

4.4.2 Community information sessions

The community information session was in the Halls Gap Community Centre on Monday 28 May 2007 from 7.00- 8.30pm.

The sessions were conducted in an informal manner with a short introduction presented by Clare Wilson (Wimmera CMA) and study progress presented by Steve Muncaster (Water Technology). A total of 30 -35 community members attended the information session.

A number of discussions were conducted with small groups of residents by the study team and Wimmera CMA during the course of the information sessions.

4.4.3 Outcomes of Stage 3 community information session

Generally, the community expressed support for the proposed mitigation measures, refer to Section 8.2. The community accepted that the flash nature of flooding in Halls Gap. Further, the community recognised effective flood warning in a flash flooding scenario was limited.

5 HYDROLOGIC ANALYSIS

5.1 Overview

Design flood hydrographs were required for the 1 in 10, 1 in 20, 1 in 50, 1 in 100 and 1 in 200 year floods and the Probable Maximum Flood (PMF) at the following locations:

- Fyans Creek downstream of Lake Bellfield
- Numerous gullies rising on the east and west ridges

As discussed, the Fyans Creek channel downstream of Lake Bellfield has sufficient capacity to convey significant flood events, without inundation of the adjacent land upstream of Delley's Bridge. Downstream of Delley's Bridge, the Fyans Creek channel has a reduced capacity and limited inundation occurs adjacent to the channel.

Significant historical flooding has been reported along the gullies, draining the western ridge (Mount Difficult Range) including Stony Creek. Generally, the flooding is due to overland flow resulting from intense short duration rainfall (thunderstorms).

The catchment hydrologic model, RORB (Laurenson and Mein 1990), was the principal tool employed to estimate design floods at the required locations. The RORB model is an event based conceptual runoff routing model in which rainfall is routed through a network of lumped storages to the catchment outlet. The RORB model applied by this study built on the RORB model employed by URS (2001). Due to limited availability of observed streamflow and pluviographic rainfall data, the RORB model parameters were determined through the application of regional prediction equations.

The following sections detail the input data, methodology and outputs for the hydrologic analysis.

5.2 Historical flood review

As outlined in Section 3.2, no recorded streamflow is available within Halls Gap. In lieu of streamflow data, daily rainfall data provides an indicator of historical flood events within the township. Table 5-1 displays significant daily rainfall events from the combined record for Hall Gap and Halls Gap Post office (079020 & 079074)

Table 5-1 Significant rainfall events

Date	Daily rainfall (mm)
26/11/1906	101.6
25/07/1936	98.8
17/02/1946	107.7
18/02/1946	101.1
6/02/1957	106.9
31/03/1981	101.6
20/12/1992	134.2
29/09/1996	123
21/02/2003	132
14/06/2005	136.2

For the above significant daily rainfall events, robust estimation of corresponding runoff quantity is not possible. However, given the depth of rainfall that fell in these events, significant runoff was likely to have occurred. The magnitude of the resultant peak runoff is highly independent on the intensity of the rainfall. Daily rainfall data does not provide insight to the intensity of the rainfall within the day.

Wimmera CMA collated a number of photographs showing flooding for the December 1992 (20/12/1992) event. These photos reveal considerable flooding, particularly along the Stony Creek.

Comparison of the daily rainfall totals to design rainfall estimates enables a broad assessment of the frequency of an observed rainfall event. A daily rainfall total of 130 mm is considered to have an ARI of 50 – 100 years, with a daily rainfall total of 100 mm having an indicative ARI of 20 to 50 years. The determination of design rainfall estimates is discussed further in Section 5.5.

Using this guidance on rainfall event frequency, the December 1992 event is likely to have an ARI of 50 to 100 years. Further refinement of this indicative ARI is limited by the absence of local pluviographic rainfall and streamflow data.

The installation of a pluviograph in Halls Gap is recommended. The rainfall data collected by this pluviograph will aid in the refinement of future hydrologic assessment.

As discussed in Section 2, overland flow occurs down the hill slope from the Mount Difficult Range. The absence of formal drainage infrastructure leads to nuisance flooding in minor rainfall events (2-5 year ARI events). Based on this minor rainfall event threshold (2 – 5 year), a daily rainfall total of 35 – 40 mm may lead to nuisance flooding. However, rainfall intensity is a major determining factor in runoff quantity.

Rainfall events of 40mm, as was experienced January 2007 and April 2007, caused flooding in houses, the information centre and the shops along Grampians Road

5.3 Fyans Creek RORB model structure

The RORB model, was developed by URS (2001) for use in the Lake Bellfield Flood Study. Several modifications were made to the model structure to reflect the focus on the flood estimation along the gullies. Further, the RORB model was extended to the streamflow gauge on Fyans Creek at the Grampians Road Bridge.

The RORB model sub-catchments were then defined to coincide with watershed boundaries, stream junctions, and the location of gauging stations. In total 82 sub-catchments were delineated. Figure 5-1 shows the RORB model catchment sub-division adopted by this study and the previous RORB model (URS 2001).

5.4 RORB model calibration

The RORB model contains two model parameters, k_c (catchment storage parameter), and m (degree of non-linearity of flood response), that require determination during the model calibration.

The RORB model calibration requires the comparison of the modelled flood hydrographs with observed flood hydrographs at the streamflow gauge on Fyans Creek at the Grampians Road Bridge. For this analysis, an attempt was made calibrate the RORB model to the recorded streamflow.

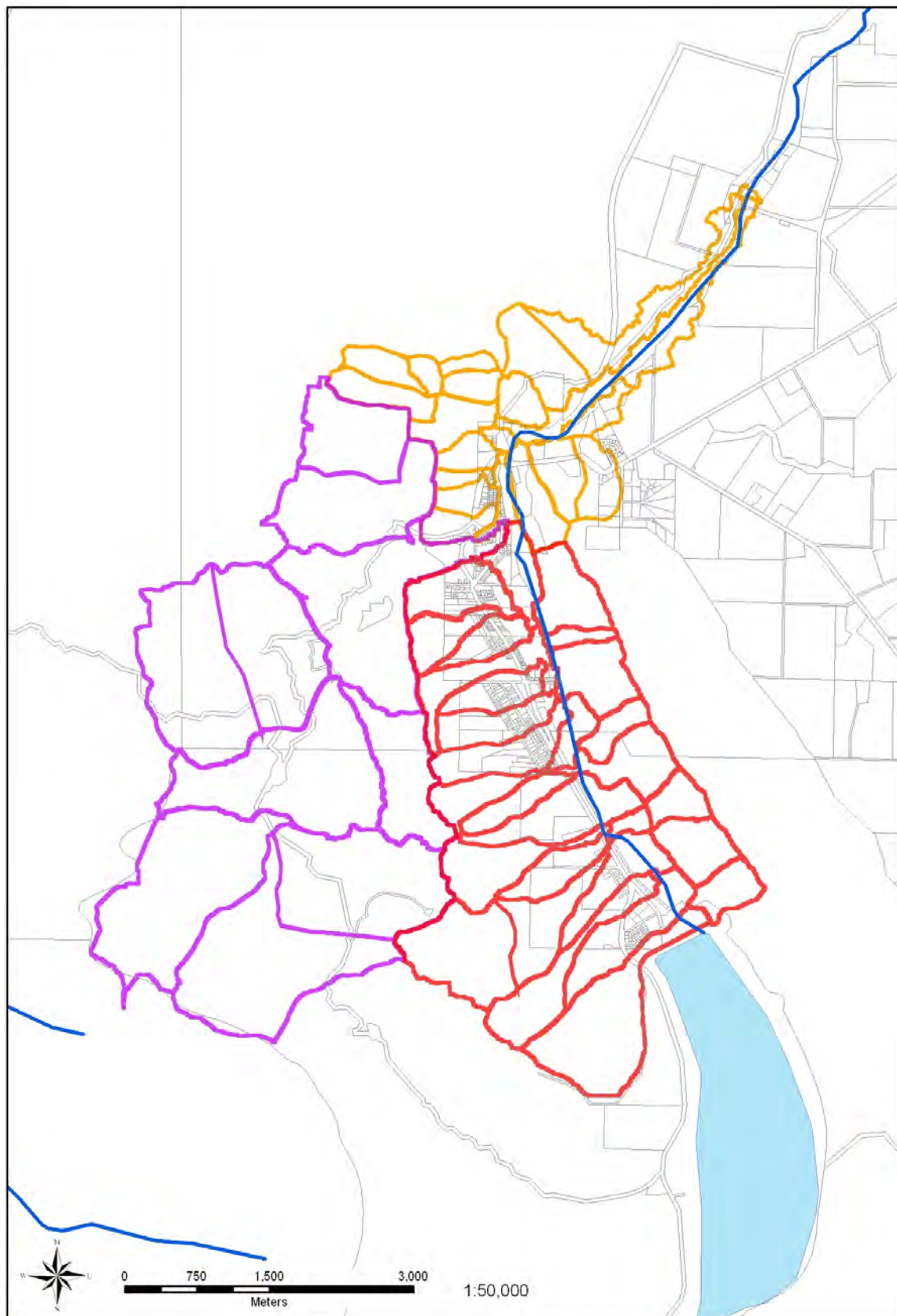


Figure 5-I RORB Model Structure – Catchment Subdivision

The selection of suitable flood events for model calibration was dependent on the availability of concurrent streamflow and pluviographic records. The two flood events selected for calibration: August 1992; and December 1992. These two events were short duration high rainfall (storms) along the adjacent ridges. The details of the selected calibration flood events are given in Table 5-2.

Table 5-2: RORB model calibration event

Event	Event Start & Finish Date	Grampians Road Bridge (415201)
		Recorded Peak flow (m ³ /s)
August 1992	29/08/1992 30/08/1992	9.2
December 1992	17/12/1992 19/12/1992	25.1

As outlined, there are two model parameters (kc & m) requiring calibration. The calibration approach adopted by this study was as follows:

- Set m = 0.8. This value is an acceptable value for the degree of non-linearity of catchment response (IEAust 1999)
- For each calibration event, the initial loss (IL) was determined to result in a reasonable match between the modelled and observed rising limb of the flood hydrograph. The continuing loss (CL) was determined to match the modelled and observed runoff volume.
- For each calibration event, a range of kc values were trialled to achieve reasonable re-production of the peak flow and general hydrograph shape.

The initial loss/uniform continuing loss model was adopted for direct comparison purposes to URS (2001).

For the August 1992 flood event, the inconsistencies between the recorded streamflow at the Lake Bellfield Outlet and Grampians Road Bridge gauges, with recorded peak flows of 9.3 and 10.9 m³/s respectively. A comparison of flood volumes over the event duration at the two gauges reveals total volumes of 3950 ML and 1440 ML at the Lake Bellfield Outlet and Grampians Road Bridge gauges respectively. As the Grampians Road gauge takes in the catchment downstream of Lake Bellfield, it is expected that the flood volumes at the Grampians Road gauge will be higher. Further, the Wartook Reservoir pluviographic rainfall record appears to be unrepresentative of the rainfall pattern affecting the Fyans and Stony Creek catchments.

A comparison of streamflow for the December 1992 flood event, at the two gauges, did not reveal the streamflow inconsistency noted above for the August 1992 flood event. However, as for the August 1992 flood event, the observed pluviographic rainfall data from Wartook Reservoir appears to be unrepresentative of the rainfall pattern in the Fyans and Stony Creek catchments.

The apparent inconsistencies and unrepresentative nature of the streamflow and rainfall observed data have hampered the model calibration. As a result, robust model parameter calibration against historical data is not possible.

5.5 Fyans Creek Catchment RORB model parameter verification

As the model calibration was unsuccessful in the resolution of suitable model parameters, regional parameter prediction relationships were applied. Also, a comparison with the previous RORB model (URS 2001) was undertaken.

Several regional relationships for the RORB model parameter, k_c , have been developed. Generally, these regional relationships estimate k_c from catchment geometry. Table 5-3 displays the regional relations applied and the k_c estimate.

Table 5-3 Fyans Creek RORB model – Regional k_c estimates

SOURCE	REGIONAL RELATIONSHIP	KC
ARR99 Victoria (Mean Annual Rainfall < 800 Mm)	$KC = 0.49 A^{0.65}$	11.9
ARR99 Victoria (Mean Annual Rainfall > 800 Mm)	$KC = 2.57 A^{0.45}$	23.3
Pearse Et Al 2002	$KC = 1.25 DAV$	21.7

The k_c estimates from the regional relationships show considerable uncertainty. URS (2001) adopted a k_c value of 30. This adopted k_c value was based on the Lake Bellfield Spillway Benchmarking for CRC- Forge (CRC-CH 1997).

Given the lack of available calibration data for the RORB model, reliable determination of the k_c value is difficult. The study team has adopted a k_c value of 21.7 as calculated by Pearse et al (2002). This adopted value is similar to the k_c estimates from ARR99 (where MAR < 800 mm) and the URS (2001) study. The study team highlights the considerable uncertainty in the adopted k_c value.

5.6 Fyans Creek Catchment design floods

Design floods were determined for the 1 in 5, 1 in 10, 1 in 20, 50, 100 and 200 year ARI events for Fyans Creek and the gullies downstream of Lake Bellfield using model parameters outlined in Section 5.5. A range of storm durations was trialled to determine the critical storm duration.

Design rainfall depths were calculated for the 1 in 5, 1 in 10, 1 in 20, 50, 100 and 200 year events using the Intensity Frequency Duration analysis (IFD) procedures outlined in Australian Rainfall and Runoff (IEAust 1987). The IFD parameters were provided in Table 5-4.

Table 5-4 Fyans Creek RORB model – IFD parameters

IFD Parameter	Value
1 hour duration 2 year ARI	19.34
12 hour duration 2 year ARI	4.03
72 hour duration 2 year ARI	1.02
1 hour duration 50 year ARI	40
12 hour duration 50 year ARI	7.61
72 hour duration 50 year ARI	2.47
Regional skew G	0.4
Geographic factor F2	4.36
Geographic factor F50	14.79

The design rainfall depth for a range of storm durations and ARI events is provided in Appendix A.

The ARR87 design temporal patterns for Zone 2 were used in the study for all events up to and including the 1 in 200 year event. A uniform spatial rainfall pattern (i.e. same rainfall depths applied to the entire catchment) was adopted for all design events considered by this study. The design rainfall areal reduction factors, developed by Siriwarda and Weinmann (1999) were employed.

A conservative assumption regarding the initial storage volume in Lake Bellfield was made at the direction of Wimmera CMA. Lake Bellfield was assumed to be full at the commencement of the design flood event.

As discussed in Section 5.4, this study adopted k_c of 21.7, and m of 0.8 as the routing parameters for design flood estimation.

The selection of design rainfall losses has a significant impact on the magnitude of the design flood estimates. The underlying assumption of the design flood estimation approach adopted by this study is that the probability (i.e. average recurrence interval) of the design peak flow provided by the RORB model is the same as the probability of the causative design rainfall event. Without observed streamflow for design rainfall losses verification, this study adopted the design losses employed by URS (2001); initial loss: 20 mm, and continuing loss: 2 mm/h.

Table 5-5 displays the RORB model design peak flows for Fyans and Stony Creek.

Table 5-5 Fyans Creek Catchment - RORB model design peak flows

Location	Design peak flow (m^3/s)				
	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	200 Year ARI
Fyans Creek upstream Stony Creek confluence	10.4	16.1	24.2	31.6	39.7
Stony Creek upstream Fyans Creek confluence	12.5	19.3	28.9	37.5	46.7
Fyans Creek at Grampians Road Bridge	20.1	32.2	48.9	64.1	81.8

Appendix A contains the design peak flows for all significant gullies identified in Section 5.3.

5.7 Discussion

The hydrologic analysis for this study was required to estimate design flood hydrographs for Fyans Creek and significant gullies adjacent to Halls Gap. As detailed, the hydrologic analysis employed a RORB model to complete the estimation for the required design floods.

Limited observed streamflow data was available for Fyans Creek downstream of the study area. This observed streamflow data enabled a broad verification of the RORB model parameters for the Fyans Creek catchment. No observed streamflow data suitable for use in RORB model calibration/verification was available for Stony Creek and the significant gullies draining the Mount difficult Range. As a result, the reliability of the flood hydrographs estimated at Halls Gap can not be verified.

The installation of a pluviograph in Halls Gap is recommended. The rainfall data collected by this pluviograph will aid in the refinement of future hydrologic assessment.

The steep terrain may result in significant runoff volumes from relatively minor rainfall events. Further, the steep terrain combined with the absence of formal drainage infrastructure may lead to nuisance flooding in minor rainfall events (2-5 year ARI events). Based on this minor rainfall event threshold (2 – 5 year), a daily rainfall total of 35 – 40 mm may lead to nuisance flooding. However, rainfall intensity is a major determining factor in runoff quantity.

The study team acknowledges considerable uncertainty surrounding the design flood estimates developed by this study. Rigorous calibration and/or validation of the approach is restricted by the absence of streamflow data. The study team considers, while the absolute reliability of design estimates is unknown, the relativity of design estimates is considered reasonable.

6 EXISTING HYDRAULIC ANALYSIS

6.1 Overview

The hydraulic analysis determined flood behaviour for Halls Gap under the existing waterway and floodplain conditions. The flood behaviour was assessed for flood events originating from both Fyans Creek and local catchment rainfall flooding along gullies.

The flood behaviour was assessed for the 10, 20, 50, 100, and 200 year flood events plus an indicative PMF from Lake Bellfield. The design floods for the Fyans Creek catchment, outlined in Section 5.6, were utilised as inflows to the hydraulic analysis.

A numerical hydraulic model was established to assist in assessing flood behaviour for the study. Due to the complex nature of drainage and flooding within Halls Gap, a two-dimensional (2D) model has been developed that includes Fyans Creek downstream of Lake Bellfield and the valley floor (the township of Halls Gap). The two-dimensional hydraulic model, MIKE2I, was the principal tool for the hydraulic analysis.

As discussed in Section 2, the flood behaviour to the west of Grampians Road, is characterised by a number of gullies draining the Mount Difficult Range. These gullies generally have widths less than 5 metres with many less than 3 metres. Further, local small scale features such as landscaping and informal bunds/drains, have significant influences on flood behaviour. Such small scale features are difficult to represent within the hydraulic analysis. In some locations, the shallow overland sheet flow occurs with depths less than 150 mm. Due to the small-scale nature of these gullies and the occurrence of sheet flow, the use of the hydraulic model to determine flood depths and extents, has proven difficult for these gullies. As a result, the study team considers the use of the hydraulic model is unlikely to provide robust flood extents and therefore a formal hydraulic analysis for these areas, using the hydraulic model, has not been undertaken. For these gullies, the study team undertook a field inspection to identify and map significant gullies. The location of the gullies was employed to define land use planning requirements, as discussed in Section 8.3.1.

East of Grampians Road, the flood behaviour is characterised by wider overland flow paths. As such, this flood behaviour is conducive to robust simulation by the hydraulic model. The study team considers the flood extents provided to the east of Grampians Road are suitable for use in the assessment of land use planning requirements.

This section details the input data, methodology and outputs for the existing conditions of the hydraulic analysis.

6.2 Halls Gap hydraulic model structure

6.2.1 Modelling framework

MIKE2I is a comprehensive modelling package for simulating 2D free-surface flows. It is applicable for modelling hydrodynamic and related phenomena in lakes, wetlands and floodplain areas. MIKE2I is a proven and accepted numerical modelling tool for the assessment of complex flood behaviour.

6.2.2 Topographic data

The topographic data employed in this hydraulic analysis was derived from the information provided from the following sources:

- A regular spot elevation grid and linear feature breaklines
- Field survey from the drainage investigations (NGSC 2007).

The model was developed with a grid size of 5 m and the topographic grid is shown in Figure 6-1.

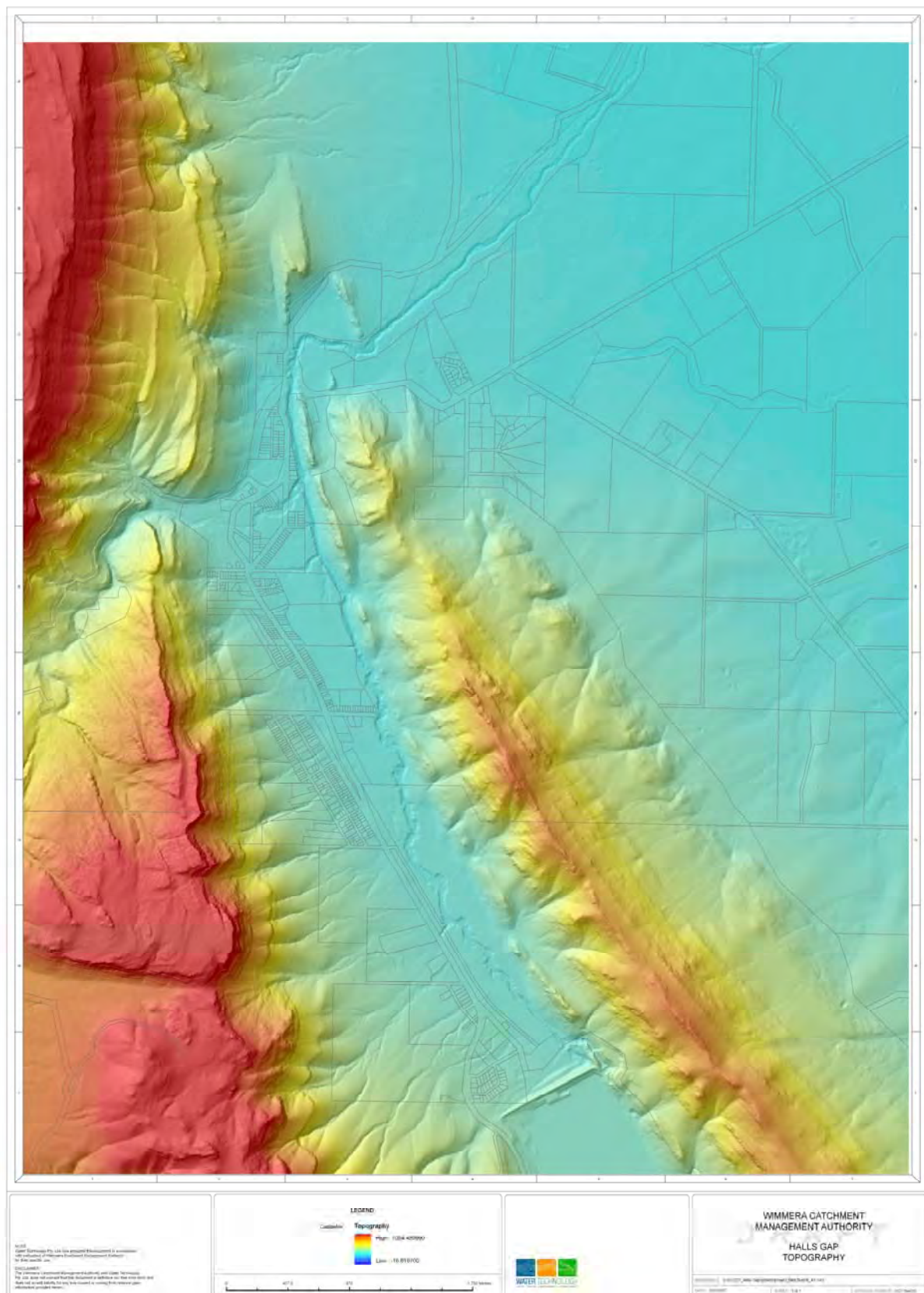


Figure 6-1 Halls Gap hydraulic model topography

6.2.3 Hydraulic roughness

The hydraulic roughness of the study area was estimated using information acquired from aerial photography and site inspections. A detailed hydraulic roughness map for the model was constructed in a GIS system by assigning different Manning's "n" values to different land uses and vegetation types. The adopted Manning's "n" values were in line with typical values employed in previous flood studies. No verification/calibration of Manning's n values was possible due to a lack of concurrent recorded streamflow and flood levels/extents.

6.2.4 Drainage infrastructure

Key drainage infrastructure was incorporated into the hydraulic model. For key drainage elements (culverts & pipes), a grade flow capacity was calculated for the size and slope from the available survey (NGSC 2007). Within the hydraulic model, the calculated flow capacities were entered as a "source and sink" pair. The "source" represented the culvert/pipe outlet and the "sink" represented the culvert/pipe inlet. This treatment enabled the hydraulic model to simulate the flow through these drainage elements.

6.3 Design flood modelling

Given the relative steep nature of the gullies draining the Mount Difficult Range, flood storage plays a minor role in the routing of overland flows, with flow conveyance the primary determinant. The hydraulic model simulation was undertaken using a steady state approach. Design peak flows were entered into the hydraulic model. The use of steady state may lead to conservative flood levels in areas where significant flood storage is available. However, given the uncertainty in both hydrologic and hydraulic analysis, the study team considers a degree of conservatism is appropriate in this application.

As discussed, due to flooding behaviour west of Grampians Road, formal flood mapping is not provided for the area to the west of Grampians Road.

Design flood levels and inundation extents were determined using the MIKE2I model for the 10, 20, 50, 100, 200 year flood events for the area to the east of Grampians Road. As discussed above, a steady state hydraulic analysis was undertaken.

Flood inundation maps for Halls Gap are collated in Appendix B.

6.4 Discussion

Formal calibration of the hydraulic model for Halls Gap is limited by the absence of systematic concurrent streamflow and flood level information. The study team undertook broad validation of the modelled design flood extents through community consultation and a comparison to flood photos. General community agreement with the modelled design flood extents was achieved.

Along the Mount Difficult Range, to the west of Grampians Road, flood behaviour is characterised by shallow overland sheet flow concentrating into numerous gullies. The depth of the overland sheet is influenced by small scale topographic features, such as small depressions, roadside table drains and landscaping. The robust assessment of the sheet overland flow depth is limited by available topographic data and the hydraulic analysis techniques employed. The study team considers the specification of flood depths in these overland flow areas as inappropriate, due to considerable difficulty in estimation. Rather, the study team considers that the Planning Scheme should flag the need to cater for overland flow in the building design. Further details of the proposed Planning Scheme Amendment are provided in Section 8.3.1.

The study team acknowledges considerable uncertainty surrounds the reliability of the flood extents for Halls Gap.

The discussion of flood behaviour is presented for the following seven regions within the study:

- Fyans Creek
- South of Pinnacle Road
- Pinnacle Road to Silversprings/Tandara Road
- Silversprings/Tandara Road to Rosea Street/ Hemley Court
- Stony Creek
- North of Mount Victory Road
- Grampians Road East of Delley's Bridge

6.4.1 Fyans Creek

For the range of flood magnitudes investigated by this study, flood waters are generally confined to the Fyans Creek channel. The channel capacity is sufficient to convey at least the 1 in 200 year ARI flood event. As a result, flooding from Fyans Creek for the events investigated (up to 1 in 200 year), is unlikely to propose a significant threat to properties and infrastructure within Halls Gap.

6.4.2 South of Pinnacle Road

Some nine significant gullies drain the Mount Difficult Range to the south of Pinnacle Road. Along these gullies, there is generally shallow (up to 150 mm) sheet flow down the hill slope. Some ponding occurs along the western side of Grampians Road due to the capacity of the culverts/pipe under the road. Extensive shallow overland flows occur along Sundial Avenue. This overland flow path continues towards Fyans Creek through the caravan park immediately downstream of Lake Bellfield. Such overland flow may give rise to considerable hazard to campers within the caravan park, especially at peak tourist times (Christmas and Easter). To the east of Grampians Road, the overland flow continues across the valley floor into Fyans Creek. Some areas of ponding occur where there are local depressions in the valley floors. This ponding provides flood storage and is likely to attenuate peak flows into Fyans Creek.

6.4.3 Pinnacle Road to Silversprings/Tandara Road

Residential development has occurred between Pinnacle Road and Silversprings Road on the western side of Grampians Road. Several gullies drain through this residential area. Significant overland flow occurs along gullies adjacent to Pinnacle Road, Wattletree Road, Youngs Road and Silversprings Road. The overland flows are generally shallow sheet flow with considerable velocity due to the steep terrain. Within this area, building platforms have been formed by cutting and filling on the steep terrain. This cut and fill construction can lead to flooding by these overland flows.

Overland flows adjacent to Pinnacle Road crossing Grampians Road are directed through the constructed wetlands at the Parks Victoria Centre. The remaining overland paths cross Grampians Road to join any overflow from the Parks Victoria wetland and continue north along the valley floor towards Tandara Road. The valley floor provides flood storage and attenuates peak flows into Fyans Creek.

6.4.4 Silversprings/Tandara Road to Rosea Street/ Hemley Court

Significant overland flow occurs along the Silversprings Road due to the alignment of the road up the hill slope. This overland flow crosses Grampians Road at the corner of Tandara Road. Extensive shallow ponding of floodwaters occurs on the eastern side of Grampians Road at Tandara Road. The overland flow from south of Tandara Road also contributes to this ponding. Several overland paths cross Ellis Street to the north of Hill Street. Similarly overland flow paths have the potential to affect properties where the block is cut and filled. Further to the north of Tandara Road intersection, extensive overland flow occurs across Grampians Road. Shallow inundation occurs across allotments on the eastern side of Grampians Road. Flooding of these properties may occur if a cut and fill building pad is constructed. To the east of Grampians Road, the overland flow continues across the valley floor into Fyans Creek. Some areas of ponding occur where there are local depressions in the valley floors. This ponding provides flood storage and is likely to attenuate peak flows into Fyans Creek.

Extensive shallow overland flow occurs between Hemley Court/Rosea Street and Stony Creek. Overland flows in this area can be affected by residential/recreation development. In particular, overland flow along Rosea Street affects several properties adjacent to Grampians Road. To the north, along Mackeys Peak Road, overland flow leads to ponding along Grampians Road at the commercial/retail properties. This ponding can threaten the existing shops along Grampians Road. Drainage infrastructure enable flows to continue east across Heath Street and onto the valley floor. The existing bund along the western limit of the caravan park directs overland flow north of Mackeys Peak Road to Stony Creek. However, some overland flow occurs to the east of the bund across Mackeys Peak Road. Some shallow flow occurs through the caravan park.

6.4.5 Stony Creek

For Stony creek, some breakout occurs to the upstream of Grampians Road. This breakout results in flooding of the camp ground located between Halls Gap School and Grampians Road. Downstream (to the east) of Grampians Road, Stony Creek is confined to the channel. However, significant flooding occurs at the shops/boardwalk. This flooding may affect the adjacent properties.

6.4.6 North of Mount Victory Road

Overland flow along Mount Victory Road inundates the eastern corner of the recreation reserve with significant ponding along Warren Road. Further overland flow from the hill slope to the west of Warren Road contributes to the ponding. The flow paths continue to the north beyond Bucker Road to enter Fyans Creek. Limited capacity in the underground drainage infrastructure exacerbates the ponding.

6.4.7 Grampians Road East of Delley's Bridge

There are several overland flow paths, from the Mount William Range across Grampians Road to the east of Fyans Creek. These overland flow paths continue across the land to the north of Grampians Road and into Fyans Creek. The overland flow paths may affect the caravan park.

7 FLOOD DAMAGE ASSESSMENT

7.1 Overview

The flood assessment determined the monetary flood damages for design flood hydrographs as determined by the hydrologic and hydraulic models. The Average Annual Damages (AAD) was also determined as part of the flood damage assessment.

As discussed in Section 6.4, flood behaviour to the west of Grampians Road (except in vicinity of Warrens Road) is generally characterised by shallow overland flow concentrating into a number of gullies. Such flow behaviour limits the ability to assess flood depths reliably. To the east of Grampians Road, the flood depth can be robustly assessed.

The flood damage assessment approach adopts different approaches to reflect the changes in flood behaviour from the west and east of Grampians Road. For the west of Grampians Road, a simplified approach, not requiring flood depth, was applied. A refined flood damage assessment approach using flood depth was applied to the east of Grampians Road.

Damages from flooding can be sub-divided into a number of categories. Figure 7-1 shows the various categories commonly used in flood damage assessments.

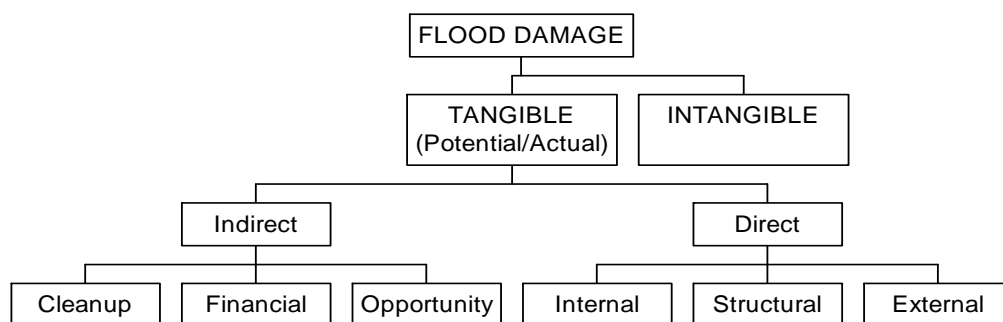


Figure 7-1 Flood Damage Categories

Tangible flood damages are those to which a monetary value can be assigned and include property damages, business losses and recovery costs. Intangible flood damages are those to which a monetary value cannot be assigned and include anxiety, inconvenience and disruption of social activities. Both are a function of flood magnitude. This flood damages assessment focuses on the tangible flood damages. Intangible damages are important but have not been directly accounted for in this flood damage assessment.

Tangible damages can be sub-divided into direct and indirect damages. Direct damages are those financial costs caused by the physical contact of flood waters and include damage to property, roads and infrastructure.

Property damages can be sub-divided into internal and external damages. Internal damages include damage to carpets, furniture and electrical goods. External damages include damages to building structures, vehicles and in rural areas, crops, fencing and machinery.

Tangible direct damages are further defined as either potential or actual damages. Potential damages are the maximum damages that could occur for a given flood event. In determining potential damages, it is assumed that no actions are taken (whether months or hours) prior to or during the flood to reduce damage by, for example, lifting or shifting items to flood free locations, shifting motor vehicles or sandbagging. Actual damages are the expected

damages for a given flood event, allowing for some degree of community flood damage control. The actual damage is calculated as a proportion of the potential damage, based on the community's flood preparedness, a function of community awareness and the lead-time of flood warnings.

Indirect damages are those additional financial costs generally incurred after the flood during clean-up and include the cost of temporary accommodation, loss of wages, loss of production for commercial and industrial establishments and the opportunity loss caused by the closure or limited operation of business and public facilities. Indirect damages are often extremely hard to estimate.

The remainder of this section details the input data required and the methodology adopted for this flood damage assessment.

7.2 Available Information

This section outlines the range of information utilised within the flood risk assessment including property and floor level data, infrastructure data and flood data.

7.2.1 Property and Floor Level Data

The flood extents determined by the hydraulic analysis in combination with visual inspection, were utilised to identify buildings prone to flooding. As discussed, simplified damage assessment methodology was applied for buildings to the west of Grampians Road. For these buildings, the following data was collected:

- Building location:- property address (Street Number and Street Address) and ground coordinates; and
- Building type:- urban and rural residential, commercial, industrial and public.

As discussed, robust assessment of flood depths is constrained by the nature of the terrain in the area west of Grampians Road. Flood prone buildings were identified by visual inspection of the surrounding terrain. Buildings where upslope side was located at the foot of a cut and/or at ground level, were assessed as flood prone. In the area to the west of Grampians Road, a total of 7 buildings were considered flood prone. The 7 buildings consist of 6 residential dwelling and one commercial (motel) building.

The refined damage assessment applied to the east of Grampians Road additionally requires building floor level data. A total of 120 building floor levels were surveyed by Price Merrett.

7.2.2 Infrastructure Data

For this study, as detailed in the report '*Rapid Appraisal Method (RAM) for Floodplain Management*' (DNRE, 2000), total damage to infrastructure was based on the length of road infrastructure inundated. DNRE (2000) considers this assumption reasonable, as much of the service infrastructure follows the paths of road reserves and the quantity of other infrastructure might be expected to be broadly a function of the length of road. Damage to bridges is also incorporated into the DNRE (2000) infrastructure damage cost estimates. Revised damages rates were supplied by Wimmera CMA, as outlined in Section 7.3.1.

Roads were identified using the cadastral information supplied by NGSC and by inspection of aerial photos.

7.2.3 Flood Data

The hydraulic analysis provides a regular grid of flood elevations and flood depths for the study area to the east of Grampians Road and in the vicinity of Warrens Road. By overlaying the flood elevations and depths onto the property data, a flood level can be

assigned to each flood affected building, similarly lengths of road inundated can easily be calculated. The 10, 20, 50, 100 and 200 year ARI design floods were assessed in this study, with a 5 year ARI flood event assumed to result in no significant flood damage cost.

7.3 Approach

The flood damage assessment was based on the RAM (DNRE, 2000) and current best practice. The Bureau of Transport Economics report '*Economic Costs of Natural Disasters in Australia*' (BTE, 2001), provides an excellent source of information regarding methodology and cost estimates for flood damage assessments. Wimmera CMA supplied additional infrastructure damage costs.

The flood damage assessment first estimated costs associated with direct flood damage (e.g. structural building, contents, external property, and infrastructure damage), then considered the costs associated with indirect flood impacts (e.g. emergency services, clean-up costs, alternative accommodation costs).

As outlined, simplified and refined damage assessment approaches were applied.

7.3.1 Direct Flood Damage

Property Damage – simplified approach

The simplified approach employed in this study, applied unit damage costs for each of the 7 buildings identified to the west of Grampians Road. Table 7-1 provides the adopted unit damages.

Table 7-1 Simplified approach – Direct property unit damages

Building type	Unit damage (September 2007 dollars)
Residential	\$29,250
Non residential- large	\$142,700

The above unit damages were based values provided in RAM (DNRE 2000), with adjustments based on the Consumer Price Index (CPI) ratio to September 2007.

Property Damage – Refined approach

For each property to the east of Grampians Road and adjacent to Warrens Road, was assessed for inundation above floor level or below floor level by querying the design flood depths and the floor level from the property survey. Adjusted ANUFLOOD (Smith & Greenway, 1992) stage-damage curves were then applied to each property for above floor flooding and an adjusted stage-damage curve from report '*Floodplain Management in Australia*' (DPIE, 1992), was used for properties with below floor flooding.

The ANUFLOOD stage-damage curves were factored up by 60% to bring them up to a 1999 flood damage cost level as recommended by the RAM (DNRE, 2000). The ANUFLOOD stage-damage curves were further adjusted by the CPI ratio to September 2007, to bring them all up to a September 2007 flood damage cost level.

In this study, properties that contain buildings have been designated either residential medium value or commercial medium value. Essentially, all non-residential properties are designated as commercial, irrespective of their use, so that shops, Council premises and light industry etc. are assigned the same flood-depth to damage curve. The medium value residential damage curves have been adopted for residential properties and the medium

value class two commercial damage curves have been adopted for commercial properties. The survey team used to collect this data were experienced in these types of surveys and categorised the majority of the buildings as medium quality. It is recognised that this approach is an approximation, but is considered appropriate given the lack of individual and detailed building size, age, use, value and quality information.

The DPIE stage-damage curve for external damages was factored up by the CPI ratio to September 2007, to bring them all up to a September 2007 flood damage cost level. Note that there is no distinction between residential and commercial external damages. It was found that many of the properties inundated below floor level were only partly inundated. The flood damage cost was reduced by the ratio of the flooded area and the property area.

The stage-damage curves used in this study are displayed in Figure 7-2.

The stage-damage curves were applied to each inundated property and the costs summed to calculate the total direct potential flood damage cost.

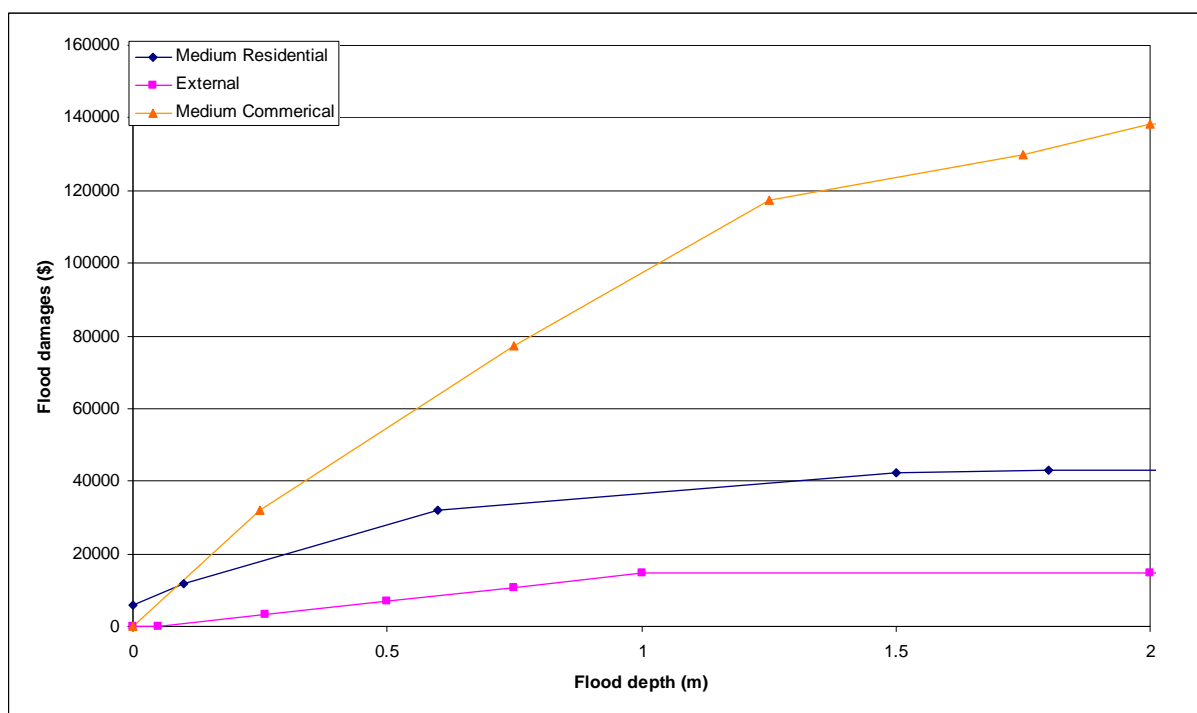


Figure 7-2 Adopted Stage-Damage Curves for Residential, Commercial and External Flooding

Actual to Potential Damage

The total direct potential flood damage cost is the cost that would be incurred if no mitigation measures are taken prior to or during a flood. In reality communities generally have some degree of warning, and particularly if a community has had previous flood experience, it may reduce the effect of the flood significantly. Measures such as evacuation, doorstep sandbagging or the removal of valuable items to a safe level above flood waters have the potential to reduce the flood damage cost. The flash flooding nature of events in Halls Gap limits the response time of residents and landholders. To reflect this limited warning and response time, a potential to actual direct flood damage reduction factor from RAM (DNRE, 2000) of 0.9 was adopted. This conservatively assumes that the community has no flood experience and have less than 2 hours warning time, as shown in Figure 7-3.

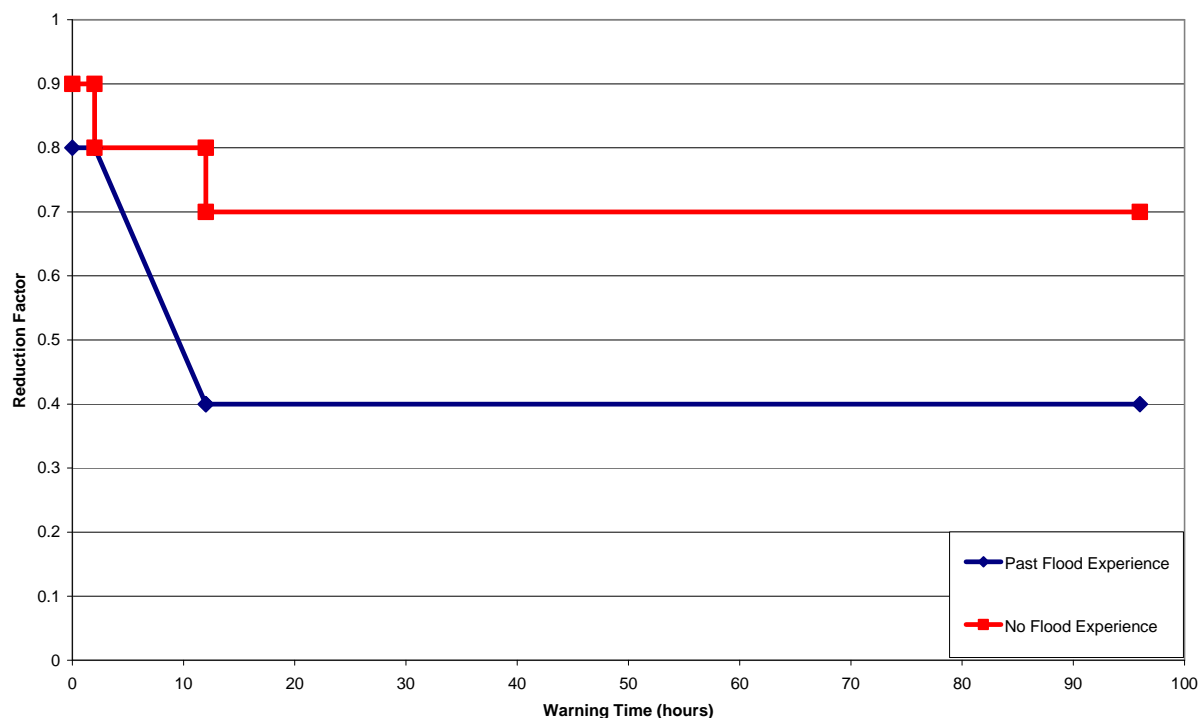


Figure 7-3 Reduction Factor Curves for Potential to Actual Direct Damage Ratio

Infrastructure Damage

Damage to infrastructure includes street and road repairs (including restoration of weakened subgrades), bridge repairs, telephone and telecommunications facilities, electrical connections, water supply and sewerage infrastructure and resulting higher maintenance costs.

For this study, as detailed in the RAM (DNRE, 2000), total damage to infrastructure was based on the length of road infrastructure inundated. DNRE (2000) considers this assumption reasonable, as much of the service infrastructure follows the paths of road reserves and the quantity of other infrastructure might be expected to be broadly a function of the length of road.

While it is appreciated that using the length of road inundated as the primary measure of total damage to infrastructure is a coarse approximation, it is considered reasonable, as it is the best estimate that we have due to lack of data and as it is only a small portion of the total damage cost.

Roads are subdivided into three categories in DNRE (2000) – highway, sealed road and unsealed road. Roads inundated were identified as sealed roads from cadastral information supplied by NGSC and by inspection of aerial photos.

The length of road inundated for the design flood events was calculated. The RAM (DNRE, 2000) estimates of \$10,000 per km for initial road repairs, \$5,000 per km for road accelerated deterioration and \$3,500 per km of road for bridge repairs were adjusted by a CPI ratio for 1999 to September 2007, to bring them all up to a September 2007 flood damage cost level. The adopted flood damage rates for infrastructure are shown in Table

7-2. The length of inundated road for each design flood event was then multiplied by the adopted flood damage rates.

Table 7-2 Adopted Infrastructure Flood Damage Rates

INFRASTRUCTURE	FLOOD DAMAGE RATES (PER KM OF ROAD INUNDATED)
INITIAL ROAD REPAIRS	\$12,842
ACCELERATED ROAD DETERIORATION	\$6,421
BRIDGE REPAIRS AND MAINTENANCE	\$4,495
TOTAL	\$22,471

Estimates adopted from BTE (2001) and adjusted to a September 2007 cost level by a ratio of CPI.

7.3.2 Indirect Flood Damage

Indirect flood damages are damages incurred as a consequence of a flood but are not due to the direct impact of the flood itself (e.g. emergency services, clean-up costs, alternative accommodation, lost business opportunity, etc.). Indirect damages are extremely hard to estimate and are often calculated by assuming they equal 30% of the total actual direct flood damage cost (including damage to properties and infrastructure), as in the RAM (DNRE, 2000), however it is recommended that this be revised to best suit population density. BTE (2001) suggests adopting a more rigorous approach, and provide estimates on the cost of post flood clean-up, relocation and emergency response actions. BTE (2001) suggest that post flood residential clean-up may cost approximately \$424 (adjusted by September 2007 CPI) for materials and approximately 160 hours in labour (an average weekly wage of \$1,294 for June 2007 was adopted from the Bureau of Statistics website). The total commercial clean-up was estimated as \$3,080 (adjusted by September 2007 CPI - \$2,400) for inundated properties (BTE, 2001). It was assumed that for external damages (below floor flooding) that the indirect damage cost was equal to one weeks labour. BTE (2001) estimates the cost of residential relocation per property as \$68 (adjusted by September 2007 CPI - \$53) per house for relocation of household goods. Wimmera CMA suggested \$100 per person per night for alternative accommodation (assuming an average of 2.6 people per household from Bureau of Statistics, and a requirement of seven nights accommodation). BTE (2001) also suggest that volunteer emergency response costs be considered and that estimates of volunteer hours be made. It has been assumed for this study that for the 100, 50 and 20 year ARI design flood events that 50, 40 and 30 volunteers respectively worked for fifteen hours (assuming average weekly wage above). The BTE (2001) cost estimates were based on figures from 1999, they were adjusted by a ratio of CPI for 1999 to September 2007.

To put all these figures into perspective, when applying the above indirect flood damage estimates to each design event it works out that the total indirect flood damage cost is approximately 43% of the total actual direct flood damage cost for the 100 year ARI event and approximately 37% for the 20 year ARI event. This is perhaps higher than the recommended 30% as suggested in the RAM (DNRE, 2000). The above indirect flood damage rates are deemed to provide a good estimate of indirect flood damage costs. The BTE (2001) estimates are adopted in this study.

Table 7-3 Adopted Indirect Flood Damage Rates

Indirect Flood Damage Item	Flood Damage Rates
<i>Residential Clean-up Costs</i>	
- Materials	\$424 per household (1)
- Labour	\$5,175 per household (1,2)
<i>Commercial Clean-up Costs</i>	
- Total	\$3,080 per building (1)
<i>Below Floor Flooding Clean-up Costs</i>	
- Total	\$1,294 per property (3)
<i>Residential Relocation Costs</i>	
- Relocation of household items	\$68 per household (1)
- Alternative accommodation	\$700 per household (1,4)
<i>Emergency Response Costs</i>	
- 100 year ARI	\$24,259 (5)
- 50 year ARI	\$19,407 (5)
- 20 year ARI	\$14,555 (5)

1 Estimate adopted from BTE (2001) and adjusted to a September 2007 cost level by a ratio of CPI.

2 Residential labour cost based on 160 hours of labour and an average weekly wage of \$1,294.

3 Below floor flooding cost based on one weeks labour and an average weekly wage of \$1,294.

4 Alternative accommodation cost assumes an average of 2.6 people per household at \$100 per night for 7 nights.

5. Emergency response costs assume that for the 100, 50 and 20 year ARI event that 50, 40 and 30 volunteers respectively worked for 15 hours each at an average weekly wage of \$1,294.

7.3.3 Total Flood Damage

The total flood damage cost was calculated as the sum of the direct actual property flood damage cost the direct infrastructure flood damage cost and the indirect flood damage cost.

The Average Annual Damage (AAD) was also calculated. The AAD is a measure of the flood damage per year averaged over an extended period. It is calculated by the area under the flood frequency and total flood damage curve. It assumes that no flood damage is incurred at the 5 year ARI flood event, and considers floods up to the 200 year ARI event. The flood damage assessment was conducted for the 10, 20, 50, 100, and 200 year ARI flood events.

7.4 Summary

Table 7-4 and Figure 7-4 provide a summary of the flood damage assessment.

Table 7-4 Flood damage summary

ARI (years) AEP	200 0.005	100 0.01	50 0.02	20 0.05	10 0.1
<i>Simplistic assessment</i>					
Properties Flooded Above Floor - Residential	6	6	4	3	2
Properties Flooded Above Floor - Commercial	1	1	1	1	1
Direct potential damage	\$300,659	\$300,659	\$248,006	\$221,680	\$195,353
<i>Refined assessment</i>					
Properties Flooded Above Floor	10	9	9	8	8
Properties Flooded Below Floor	65	62	50	43	38
Total Properties Flooded	75	71	59	51	46
Direct Potential External Damage Cost	\$3,415	\$3,182	\$2,693	\$2,189	\$1,863
Direct Potential Residential Damage Cost	\$5,061	\$4,835	\$4,564	\$4,316	\$4,136
Direct Potential Commercial Damage Cost	\$308,241	\$301,897	\$298,932	\$270,924	\$269,096
Total Direct Potential Damage Cost	\$617,376	\$610,574	\$554,195	\$499,109	\$470,448
Total Actual Damage Cost (0.9*Potential)	\$555,639	\$549,516	\$498,776	\$449,198	\$423,403
Infrastructure Damage Cost	\$64,147	\$61,735	\$58,098	\$52,352	\$50,128
Indirect Clean Up Cost	\$41,889	\$39,505	\$39,120	\$35,251	\$34,930
Indirect Residential Relocation Cost	\$676	\$676	\$676	\$676	\$676
Indirect Emergency Response Cost	\$24,804	\$20,670	\$16,536	\$12,402	\$8,268
Total Indirect Cost	\$67,369	\$60,851	\$56,332	\$48,329	\$43,874
Total Cost	\$687,154	\$672,102	\$613,207	\$549,879	\$517,405

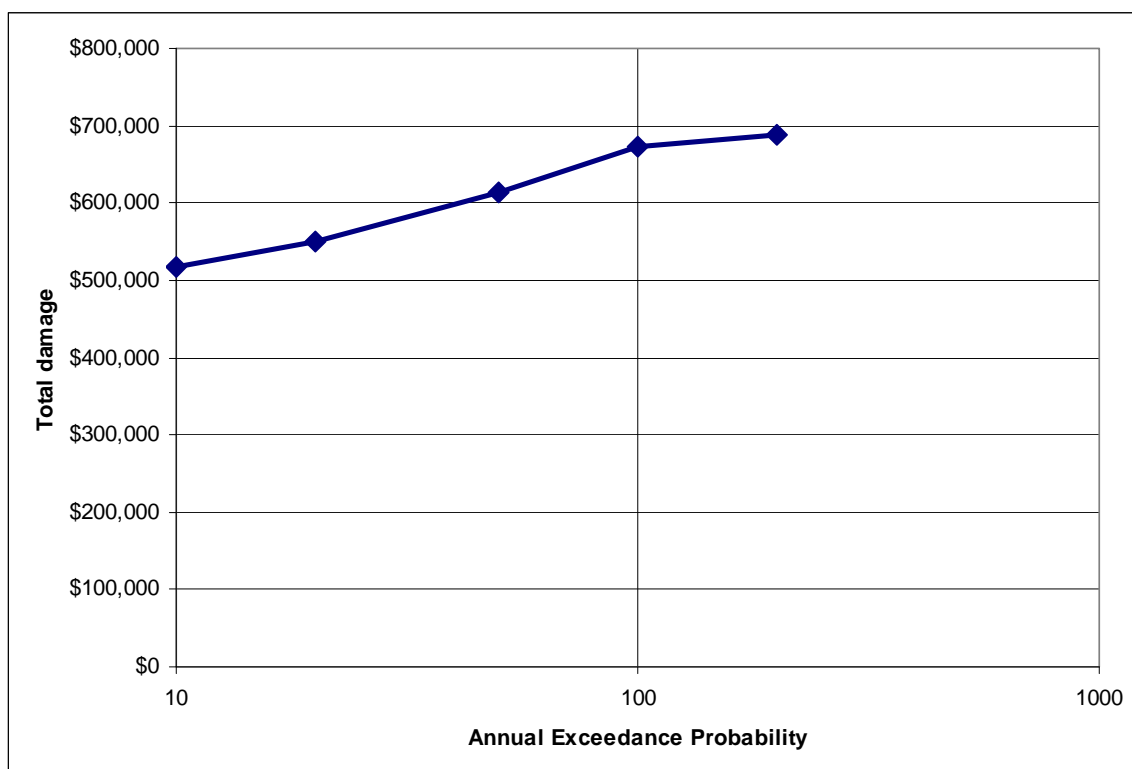


Figure 7-4 Flood damage summary

The average annual damages were estimated at \$54,000.

As seen in Figure 7-4, the flood damages displays a relatively small increase with flood magnitude. This reflects the relatively small increases in flood depths and extent with increasing flood magnitude.

Appendix C contains of the properties affected above floor level.

8 PRELIMINARY MITIGATION ASSESSMENT

8.1 Overview

Mitigation measures provide a means to reduce the existing flood risk. Mitigation measures can reduce existing flood risk by lowering the likelihood of flooding and/or lowering the flood damages (consequences) for a given flood depth. Mitigation measures can be broken into:

- Structural – Physical barriers or works designed to prevent flooding up to a specific design flood standard. Structural measures aim to reduce existing flood risk flood by lowering flood likelihood at given locations. Structural works include levees, floodways drainage and waterway works, retarding basins, and improvements to hydraulic structures.
- Non-structural- Management and planning arrangements between relevant authorities designed to reduce related flood damages. Non-structural measures aim to reduce existing flood risk flood by lowering flood damage. Non-structural measures include land use planning, flood warning and flood response.

This section provides a preliminary assessment of the potential mitigation options identified during the course of this study. This preliminary assessment is aimed at providing a broad assessment of the feasibility for a range of mitigation measures.

This preliminary assessment of mitigation measures options does not equate to an endorsement of these measures but rather provides a basis from which a future comprehensive floodplain management study could be undertaken considering a greater range of mitigation options available.

8.2 Structural mitigation measures

8.2.1 Range of potential measures

Structural mitigation measures generally consist of works to enhance flood storage and/or improve flow conveyance. During community consultations, a strong support was given to “measures that slow the runoff from the hill slope”, i.e. enhance flood storage. With this support in mind, the initial assessment was made of the following mitigation measures:

- Small scale retarding basins
- Overland flow diversion banks and bunds
- Culvert and/or pipe augmentation

The NGSC drainage investigations have proposed a number of waterway and pipe upgrades. In the design of these upgrades, careful consideration must be given to the pipe blockage due to sediment wash off.

Sections 8.2.2 to 8.2.6 provide initial comments on the feasibility of the above structural mitigation measures and the proposed NGSC works.

8.2.2 South of Pinnacle Road

As discussed, significant overland flow occurs through the caravan park. This overland flow proposes considerable flood hazard to campers. This overland flow path could be diverted around the caravan park via diversion bund located around the caravan park. Preliminary assessment indicates no adverse flooding impacts would occur on the adjacent properties. Figure 8-1 displays the potential diversion bund adjacent to the Lakeside Caravan Park. The

typical bund height, including a 300 mm freeboard, is about 500 mm. This bund would prevent entrance of overland flow to the caravan park.

The study team recommends NGSC assess the feasibility of a small diversion bund along the indicative alignment shown in Figure 8-1 . This assessment should consider any adverse flooding on adjacent properties due to flow re-direction.



Figure 8-1 Potential mitigation measure – Lakeside Caravan Park

8.2.3 Pinnacle Road to Silversprings/Tandara Road

Extensive sheet overland flow occurs in this area with considerable impacts on dwellings and buildings. To attenuate the runoff from the hill slope, small scale retarding basins could be sited on significant gullies to the west of High Road. However, due to the steep terrain limited additional flood storage could be utilised by any retarding basin. Preliminary assessment indicates limited scope exists for retarding basins with sufficient capacity to provide adequate runoff attenuation.

However, the study team recommends the retainment of existing vegetation and waterway form to safeguard against loss of existing flood storage.

Four buildings were identified as prone to flooding from overland flow due to the nature of construction. Small diversion banks/landscaping on the uphill side of these dwellings/buildings provides the re-direction of overland flow around the dwellings/buildings.

The study team recommends NGSC assess the feasibility of small diversion bunds. This assessment should consider any adverse flooding on adjacent properties due to flow re-direction.

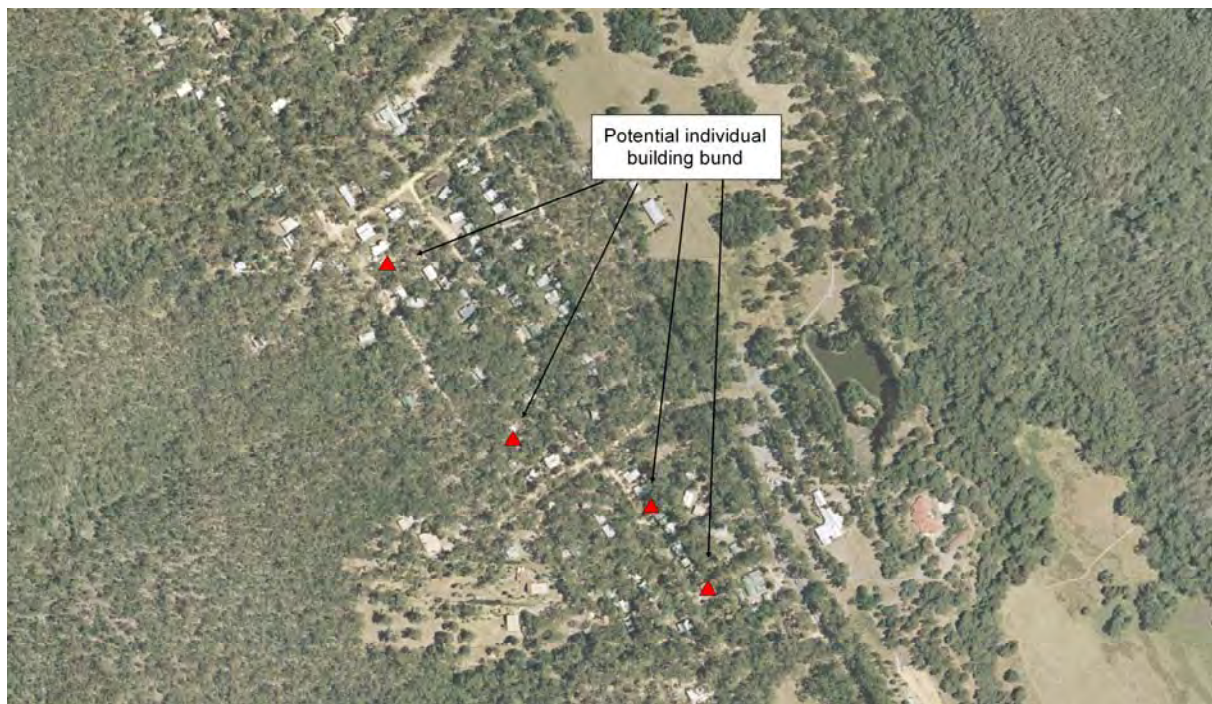


Figure 8-2 Potential mitigation measure – Pinnacle Road to Silversprings Road – Individual building bunds

The NGSC's proposed Halls Gap drainage scheme provides for the construction of several small diameter main drains in this area. These proposed drains would reduce overland flow in frequent flood events (~ less than 10 year ARI). Due to their size, limited reduction in overland flow would occur in large flood events.

The study team supports the drainage augmentation as proposed by NGSC.

8.2.4 Silversprings/Tandara Road to Rosea Street/ Hemley Court

Extensive sheet overland flow occurs in this area with considerable impacts on dwellings and buildings. To attenuate the runoff from the hill slope, small scale retarding basins could be sited on significant gullies to the west of Ellis Street. However, due to the steep terrain limited additional flood storage could be utilised by any retarding basin. Preliminary assessment indicates limited scope for effective attention exists.

Similar to Section 8.2.3, ***the study team recommends the retainment of existing vegetation and waterway form to safeguard against loss of existing flood storage.***

Diversion banks and/or landscaping on the uphill side of dwellings/buildings with a cut and fill construction may aid to re-direct overland flow around the dwellings/buildings. Also, there are buildings where the floor level is at the ground level with potential for overland flows to inundate. A total of 11 buildings were identified as at risk of above floor inundation. In particular, such bunds would reduce flooding damage to properties adjacent to the corner of Rosea Street and Grampians Road. Figure 8-3 displays the location of potential individual buildings bunds. Typically, these bunds would be in the order of 300 mm high, and would prevent overland flows entering the buildings.

The study team recommends NGSC assess the feasibility of small diversion. This assessment should consider any adverse flooding on adjacent properties due to flow re-direction.



Figure 8-3 Potential mitigation measure – Silversprings Road to Rosea Street – Individual building bunds

Further reduction in flooding adjacent to Rosea Street and Grampians Road is achieved by the proposed drainage augmentation in this area suggested by the NSGC drainage scheme.

The study team supports the drainage augmentation under Grampians Road adjacent to Rosea Street as proposed by NGSC.

Extension of the existing bund behind the caravan park further to the south would intercept some overland flows adjacent to Rosea Street. However, the effect of this bund on overland flow is limited as considerable runoff generated on downslope (eastern) side of the bund. This overland flow results in ponding and flooding to the retail buildings along Grampians Road. The NGSC drainage scheme proposes pipe augmentation through to Heath Street to reduce the ponding along Grampians Road.

The study team supports the drainage augmentation as proposed by NGSC. To limit increases in runoff generated adjacent to the Halls Gap Caravan Park, the study team recommends the use of pervious pavements in any car parking areas.

8.2.5 Stony Creek

Flooding along Stony Creek is generally confined to the waterway. Downstream of Grampians Road, Stony Creek threatens several retail buildings in a large flood event. As this threat is limited to large events, the study team considers no works are required.

However, the study team recommends no further development at lower elevation in this area should be approved by NSGC.

8.2.6 North of Mount Victory Road

Drainage from this area creates ponding adjacent to the Recreation Reserve and along Warren Road. Additional culverts/pipes from Warren Road to Grampians Road, and through to Fyans Creek would reduce flooding. Also improving the conveyance of the open drain along Warren Road with some local waterway works may alleviate the ponding. The NGSC drainage scheme proposes the removal of obstructions and constrictions in the open drain along Warren Road. The current obstructions consist of driveways with limited culvert capacity underneath. A preliminary assessment shows these proposed works would reduce ponding along Warren Road. Figure 8-4 displays the location of potential waterway works.

The study team supports the drainage augmentation as proposed by NGSC.



Figure 8-4 Potential mitigation measure – Warren Road – Waterway works

A diversion bund and/or landscaping of the western boundary of properties on Warren Road could intercept overland flows from the upslope.

The study team recommends NGSC assess the feasibility of a small diversion bund. This assessment should consider any adverse flooding on adjacent properties due to flow re-direction.

8.3 Non structural mitigation measures

8.3.1 Revised flood related planning provisions and overlays delineation

The current Northern Grampians Planning Scheme applies no flood related zones and/or overlays in Halls Gap. However, a Design and Development Overlay (DDO) applies to private land within the study area. This DDO has the capability to apply conditions on the

building form. Such conditions could be employed to reduce the potential of above floor flooding due to overland flows.

As discussed, the robust determination of overland flood depths to the west of Grampians Road was not possible. The study team considers the application of appropriate objectives to address overland flow in the DDO is warranted. The draft revisions to the DDO reflects this position. To preserve the overland flow capacity of significant gullies to the west of Grampians Road, significant gullies were identified and mapped. Figure 8-5 shows locations of significant gullies to the west of Grampians Road. This figure is proposed for inclusion in the planning scheme.

Planning and Environmental Design prepared a draft Planning Scheme Amendment to enable the application of the DDO and the identification of significant gullies.

To the east of Grampians Road and adjacent to Warren Road, the existing conditions hydraulic analysis, discussed in Section 6, provides a basis for the delineation of the flood related planning overlays.

The Land Subject to Inundation Overlay (LSIO) identifies land prone to flooding during a 100 year flood event. A draft LSIO delineation, based on the 1 in 100 year ARI flood extent obtained from the hydraulic analysis, is shown in Figure 8-6.

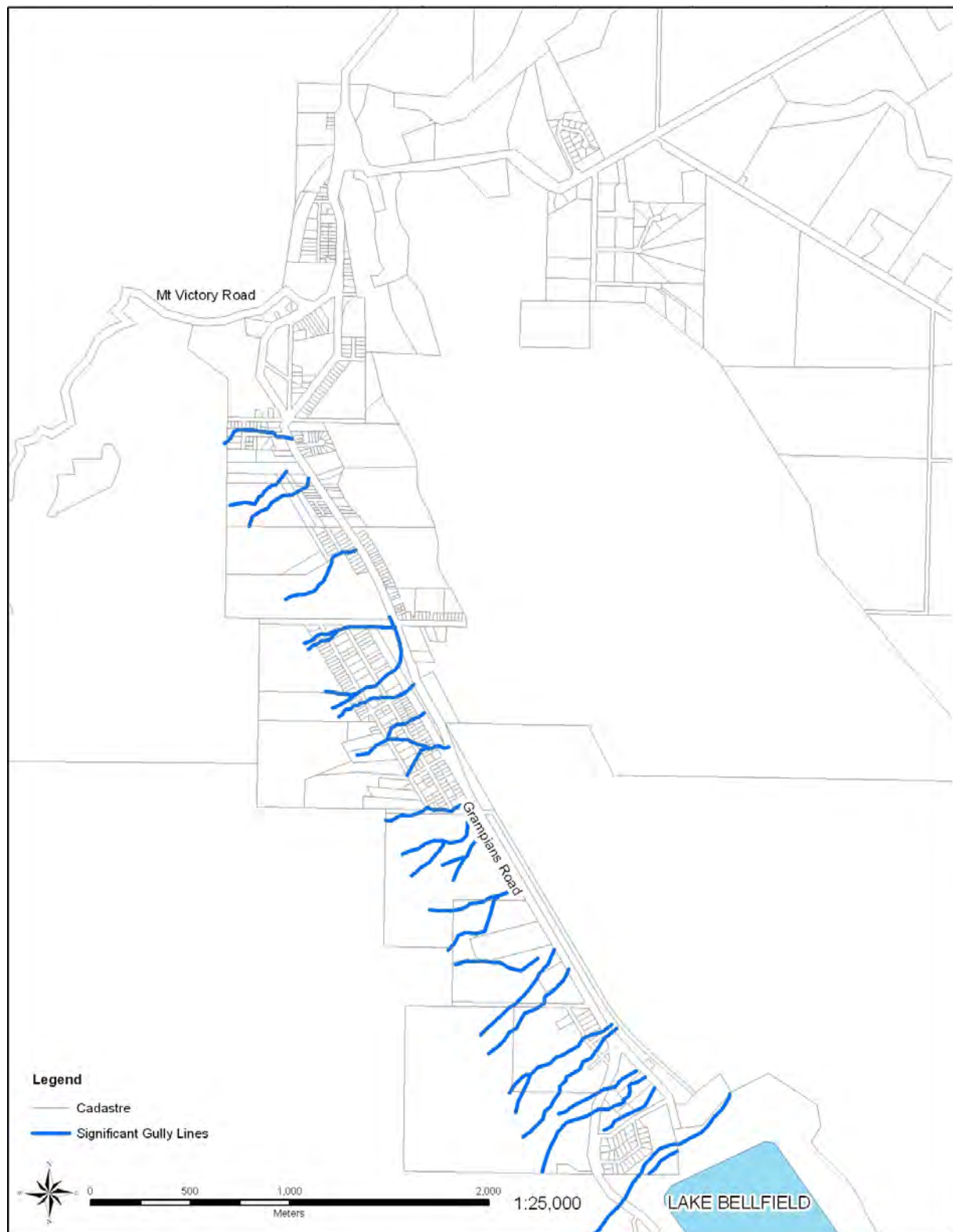


Figure 8-5 Significant gullies to the west of Grampians Road

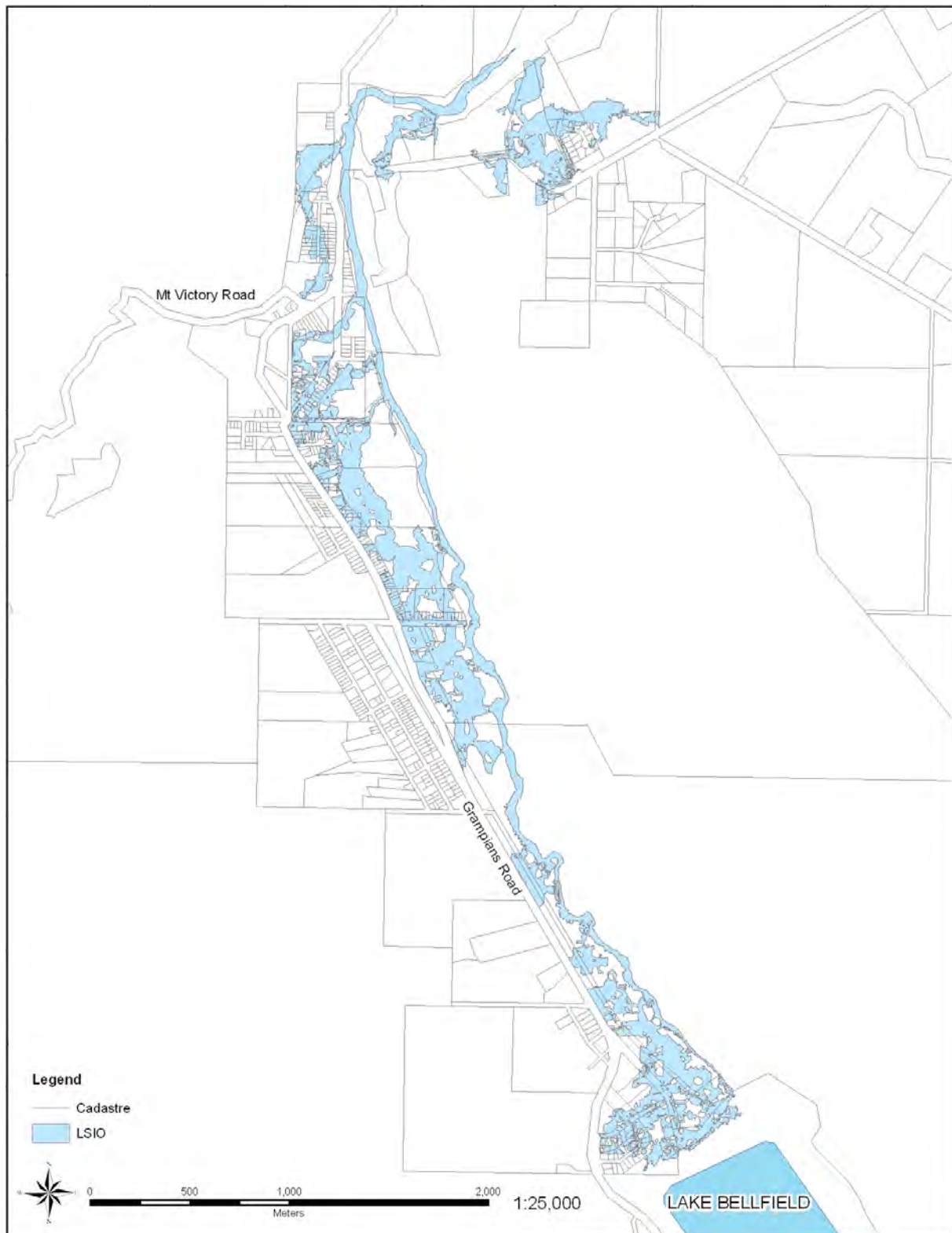


Figure 8-6 Draft LSIO delineation

In addition to LSIO, the Victorian Planning Provisions (VPP), enable the delineation of the Floodway Overlay (FO). The FO is intended to delineate land subject to higher flood risk. The study team utilised guidelines provided by DNRE (1998b) to investigate possible delineation of FO. The guidelines provide three approaches to the delineation of FO as follows:

- Flood frequency
- Flood hazard
- Flood depth

For **flood frequency**, Appendix A1 of the advisory notes (DNRE 1998b), suggest areas which flood frequently and for which the consequences of flooding are moderate or high, should generally be regarded as floodway.

Flood hazard combines the flood depth and flow speed for a given design flood event. The advisory notes (DNRE 1998b) for delineating the floodway based on flood hazard. The flood hazard for the 1 in 100 year ARI event was considered for this study. Figure 8-7 displays the flood hazard criteria for floodway delineation.

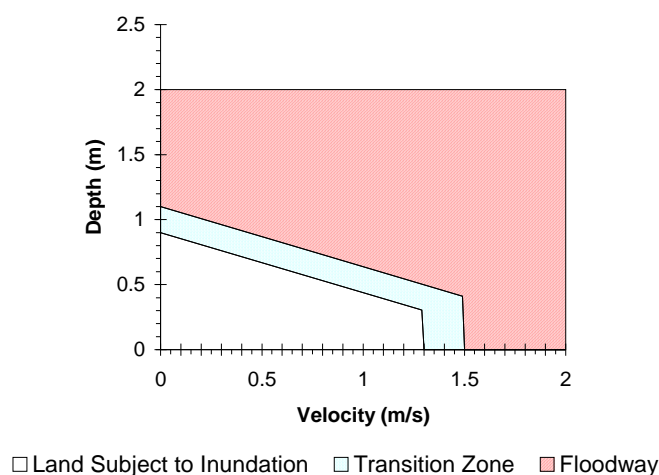


Figure 8-7 Floodway overlay flood hazard criteria

For **flood depth**, regions with a flood depth in the 1 in 100 year ARI event greater than 0.5m were considered as FO based on the flood depth delineation option.

Figure 8-8 shows the draft FO delineation for consideration by NGSC and Wimmera CMA.



Figure 8-8 Draft FO delineation

As part of this flood study, Planning and Environmental Design prepared a draft Planning Scheme Amendment.

The study team recommends that the NGSC adopt the delineation of flood related overlays and appropriate conditions within the DDO. Further, the study team recommends that Wimmera CMA provide the appropriate assistance to NGSC to enable the timely adoption of the draft Planning Scheme Amendment.

8.3.2 Flood forecasting and warning

VFWCC (2005) identified flood warning system development priorities throughout Victoria and ranked the Wimmera River catchment second on a list of ten priority catchments.

The study team understands Wimmera CMA, in conjunction with local authorities in the Wimmera River catchment, including NGSC is undertaking a project to address a number of the concerns raised in VFWCC (2005) for the Wimmera catchment.

However, due to flash nature of flooding in Halls Gap there is limited lead time for effective flood forecasting and warning dissemination. As a result, the study team believe there is limited benefit to Halls Gaps arising from the current flood warning upgrade.

8.3.3 Flood response and awareness

With significant residential development occurring along the base of the Mount Difficult Range and within the Halls Gap Valley floor region (many at ground level), a major flood event is likely to cause significant damages. Many owners of such properties are likely to be unaware of the flooding risks as most have been built post the last significant flood event and many owners live permanently outside of Halls Gap. In addition to raising flood awareness amongst property owners, there is a need to inform the significant number of tourists that are exposed to flooding, particularly campers who are more highly exposed to this risk.

Flood response for Halls Gap is outlined in the Northern Grampians Shire Municipal Emergency Management Plan (MEMP) and the accompanying Flood Sub-plan.

A revised NGSC Flood Sub-plan has been prepared by Michael Cawood and Associates, and includes relevant information on local flood behaviour and intelligence from the existing conditions hydraulic analysis.

The study team recommends that the NGSC adopt all aspects of the revised Flood Sub-plan as an integral part of the MEMP. This includes measures aimed at 'keeping the Plan alive' and relevant to the community.

The study team recommends the preparation of community flood awareness material to communicate the understanding of flood risk developed by this study. Such material would provide residents and business owners an overview of flood risk at their property, and outline preparedness measures aimed at reducing flood damages.

9 STUDY CONCLUSIONS AND RECOMMENDATIONS

This section summarises the conclusions and recommendations arising from this study.

Hydrologic analysis

The study team acknowledges considerable uncertainty surrounding the design flood estimates developed by this study. Rigorous calibration and/or validation of the approach is restricted by the absence of streamflow data. The study team considers, while the absolute reliability of design estimates is unknown, the relativity of design estimates is considered reasonable.

Comparison of the daily rainfall totals to design rainfall estimates enables a broad assessment of the frequency of an observed rainfall event. A daily rainfall total of 130 mm is considered to have an ARI of 50 – 100 years, with a daily rainfall total of 100 mm having an indicative ARI of 20 to 50 years. The determination of design rainfall estimates is discussed further in Section 5.5.

Using this guidance on rainfall event frequency, the December 1992 event is likely to have an ARI of 50 to 100 years. Further refinement of this indicative ARI is limited by the absence of local pluviographic rainfall and streamflow data.

The installation of a pluviograph in Halls Gap is recommended. The rainfall data collected by this pluviograph will aid in the refinement of future hydrologic assessment.

As discussed in Section 2, overland flow occurs down the hill slope from the Mount Difficult Range. The absence of formal drainage infrastructure leads to nuisance flooding in minor rainfall events (2-5 year ARI events). Based on this minor rainfall event threshold (2 – 5 year), a daily rainfall total of 35 – 40 mm may lead to nuisance flooding. However, rainfall intensity is a major determining factor in runoff quantity.

Hydraulic analysis

Detailed hydraulic analysis of the significant gullies to the west of Grampians Road was restricted by the steep terrain and ill defined waterways. The flood mapping was limited to the east of Grampians Road except along Stony Creek.

Formal calibration of the hydraulic model has been limited, given the lack of reliable concurrent streamflow and flood level information. The study team undertook broad validation of the modelled design flood extents through community consultation and a comparison to flood photos.

The study team acknowledges considerable uncertainty surrounds the reliability of the flood extents for Halls Gap.

Flood damages

The flood damages displays a relatively small increase with flood magnitude from \$517,000 (10 year flood event) to \$687,000 (200 year flood event). This reflects the relatively small increases in flood depths and extent with increasing flood magnitude. The average annual damages were estimated at \$54,000.

Structural mitigation measures

The study team supports the proposed NGSC drainage scheme. The construction of small bunds/landscaping may prevent flooding from overland flows and should be further considered by NGSC.

Land use planning

The study team recommends that the draft flood related planning overlays forms the basis of a draft Planning Scheme Amendment. The Design Development Overlay provides a means to control building construction to reduce overland flooding potential, for the area west of Grampians Road. The application of Floodway and Land Subject to Inundation overlays is proposed as the planning instrument to the east of Grampians Road and adjacent to Warren Road.

Flood Awareness

The study team recommends the preparation of community flood awareness material to communicate the understanding of flood risk developed by this study. Such material would provide residents/ business owners over an overview of flood risk at their property, and outline preparedness measures aimed at reducing flood damages.

Flood Response

The study team recommends that the outcomes of this study form the basis of a revised Flood Sub-plan as an integral part of the NGSC MEMP. This revised Flood Sub-plan has been prepared as part of this study.

10 REFERENCES

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APPENDIX A HYDROLOGIC ANALYSIS

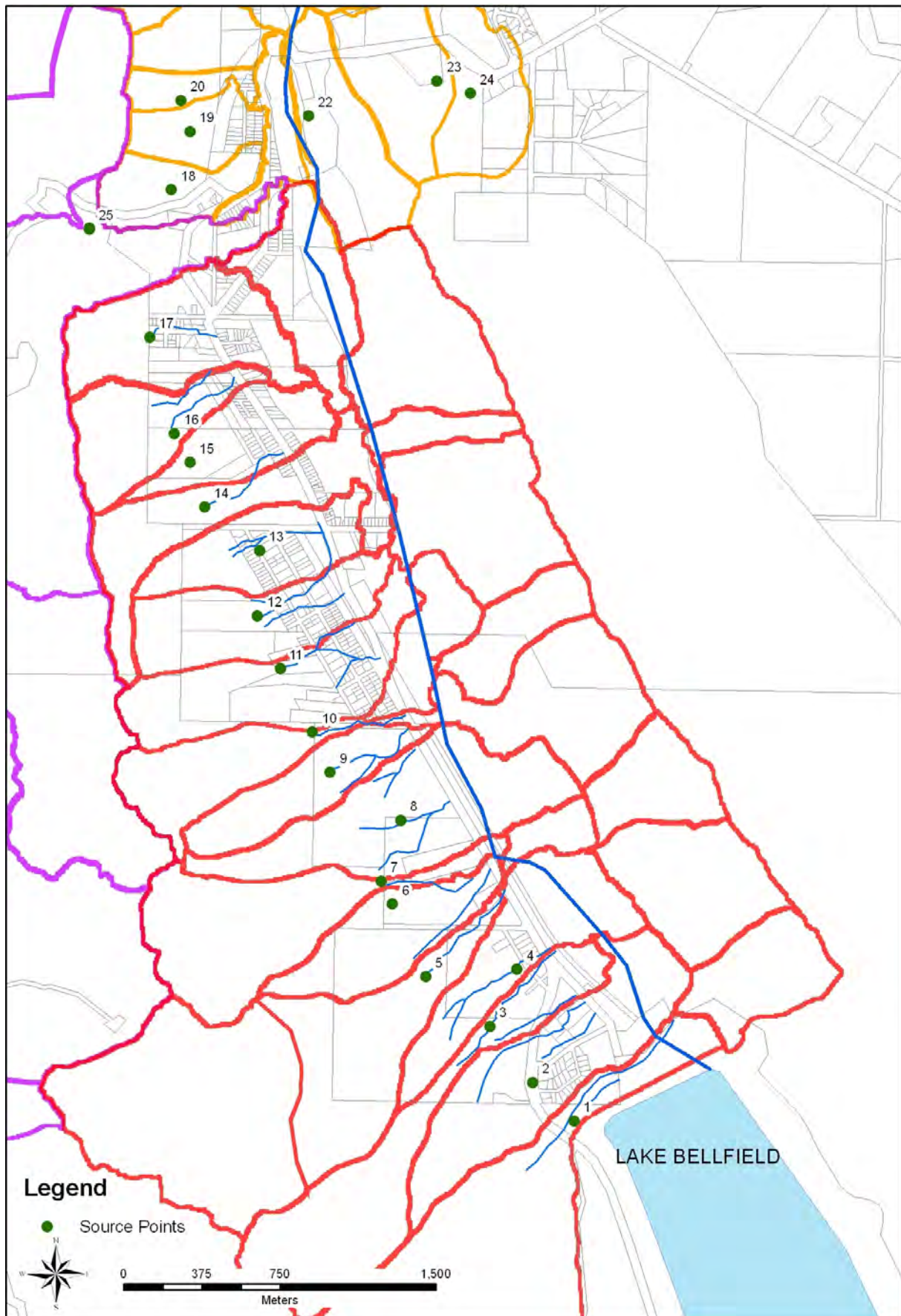
Design rainfall depths for Halls Gap

Duration		1 Year ARI	2 Year ARI	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI
(mins)	hours	mm	mm	mm	mm	mm	mm	mm
15	0.25	7.7	10.2	13.8	16.3	19.5	24.3	28.3
30	0.50	10.7	14.2	19.1	22.4	27.0	33.5	38.5
45	0.75	12.7	16.8	22.5	26.4	31.7	39.0	45.8
60	1.00	14.2	18.8	25.2	29.5	35.3	43.6	50.0
90	1.50	16.7	22.1	29.3	34.2	40.8	50.1	57.9
120	2.00	18.6	24.6	32.4	37.8	45.0	55.2	63.6
180	3.00	21.7	28.4	37.5	43.5	51.6	63.0	72.3
270	4.50	25.2	32.9	43.1	50.0	59.0	71.6	82.4
360	6.00	28.0	36.6	47.6	54.8	64.8	78.6	90.0
540	9.00	32.6	42.5	54.9	63.0	74.2	89.8	102.6
720	12.00	36.2	47.2	60.7	69.6	81.6	98.6	112.4
1080	18.00	40.1	52.7	69.5	80.6	95.6	117.0	134.6
1440	24.00	43.2	56.9	76.3	89.3	106.8	132.0	152.9
1800	30.00	45.3	60.3	81.6	96.3	116.1	144.3	168.0
2160	36.00	47.2	63.0	86.0	102.2	123.8	155.2	181.4
2880	48.00	49.9	66.7	93.1	111.8	136.3	172.8	203.0
3600	60.00	51.6	69.6	98.4	118.8	145.8	186.0	220.2
4320	72.00	52.6	71.3	101.5	123.8	153.4	197.3	234.7

Design peak flows

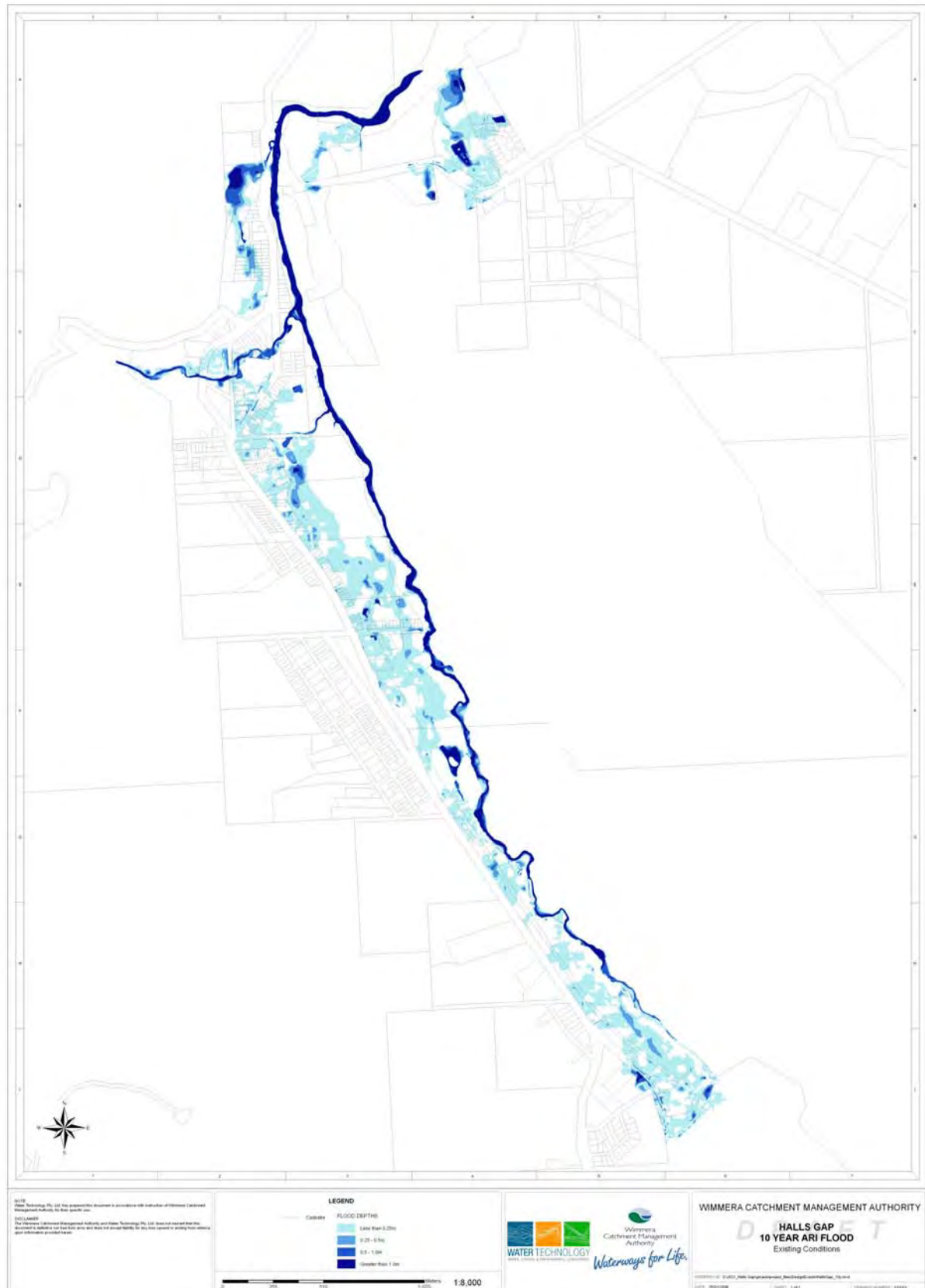
Inflow point	Peak flow (m ³ /s)				
	10 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI	200 yr ARI
1	2.1	2.9	4.3	5.6	7.1
2	1.6	2.3	3.7	5.1	6.4
3	1.0	1.4	2.1	2.8	3.5
4	1.5	2.2	3.8	5.2	6.5
5	2.2	3.1	4.7	6.1	7.5
6	0.7	1.0	1.6	2.1	2.7
7	1.0	1.4	2.1	2.7	3.4
8	2.1	3.1	5.2	7.2	8.9
9	0.6	0.8	1.3	1.7	2.2
10	0.6	0.9	1.3	1.8	2.3
11	1.1	1.5	2.3	3.1	3.9
12	0.9	1.3	2.0	2.7	3.4
13	0.7	1.0	1.5	2.1	2.6
14	1.0	1.4	2.1	2.9	3.7
15	0.8	1.1	1.8	2.5	3.2
16	0.6	0.8	1.2	1.6	2.0
17	1.1	1.7	2.6	3.6	4.6
18	0.5	0.7	1.0	1.4	1.8
19	0.6	0.9	1.5	2.0	2.5
20	0.3	0.4	0.6	0.9	1.1
21	0.6	1.0	1.7	2.3	2.9
22	0.7	1.0	1.5	1.9	2.5
23	1.0	1.5	2.6	3.5	4.4
24	0.7	1.0	1.6	2.2	2.8
25 (Stony Creek)	19.8	27.9	41.0	52.6	65.5

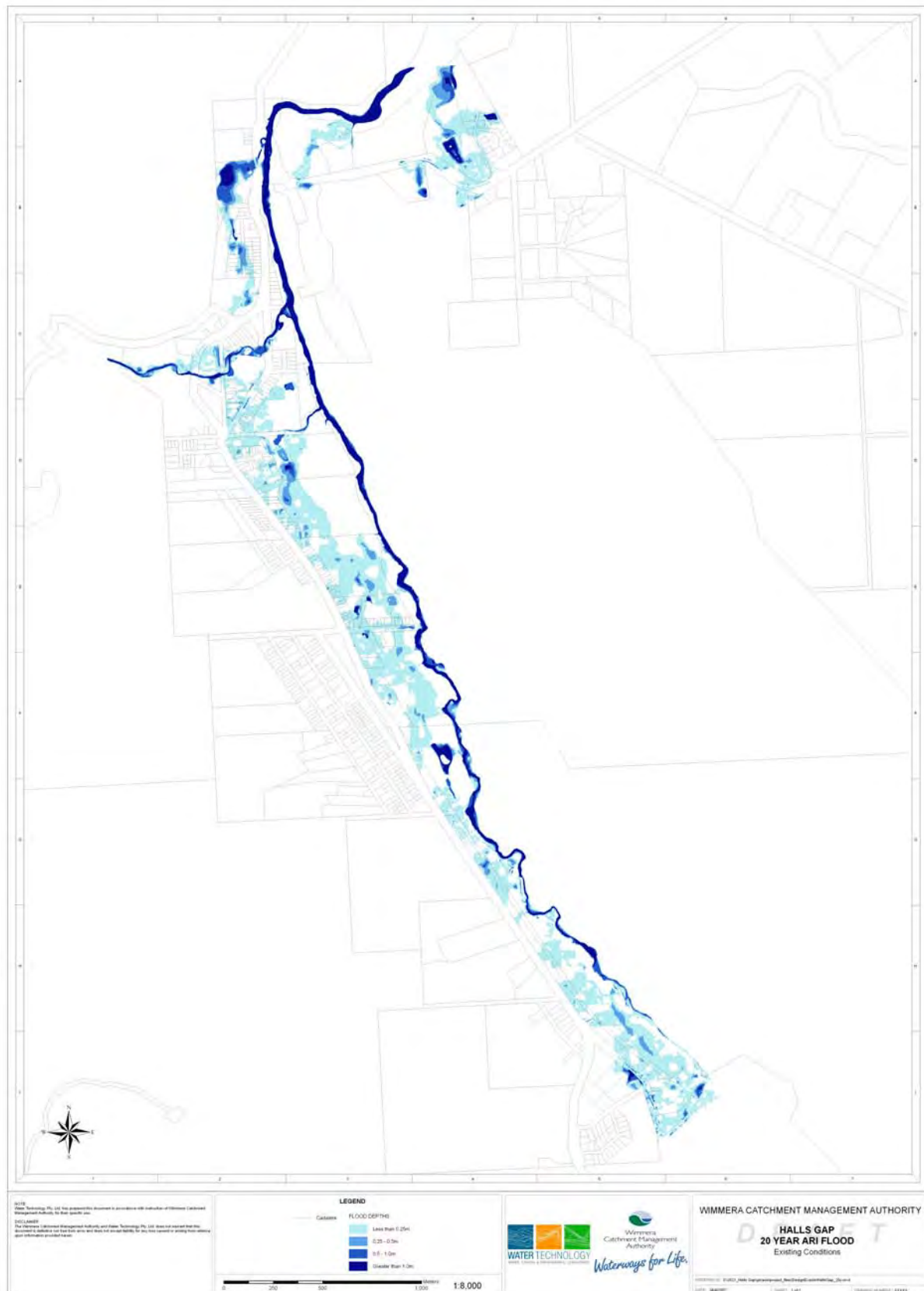
Inflow point locations are shown on the following figure

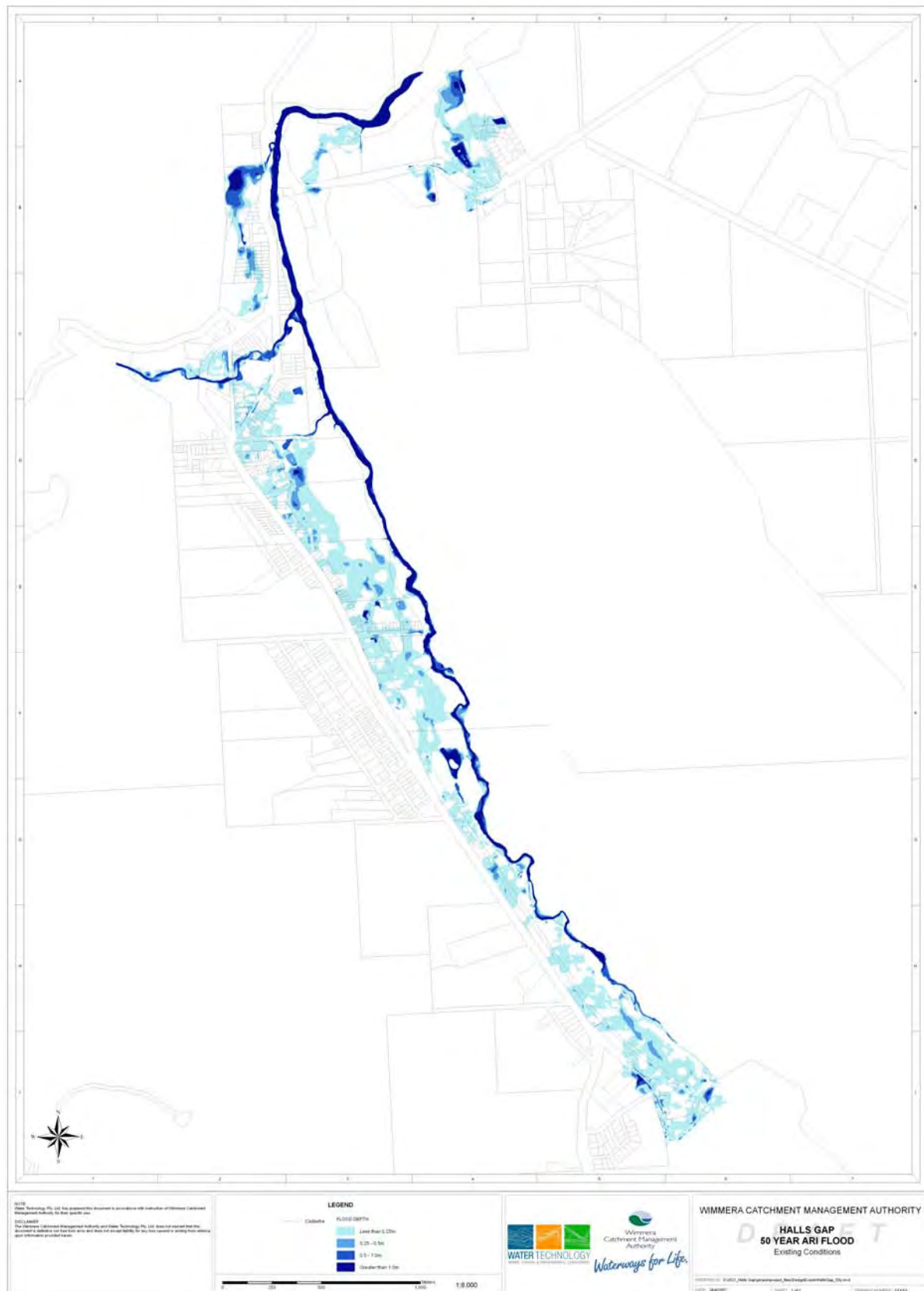


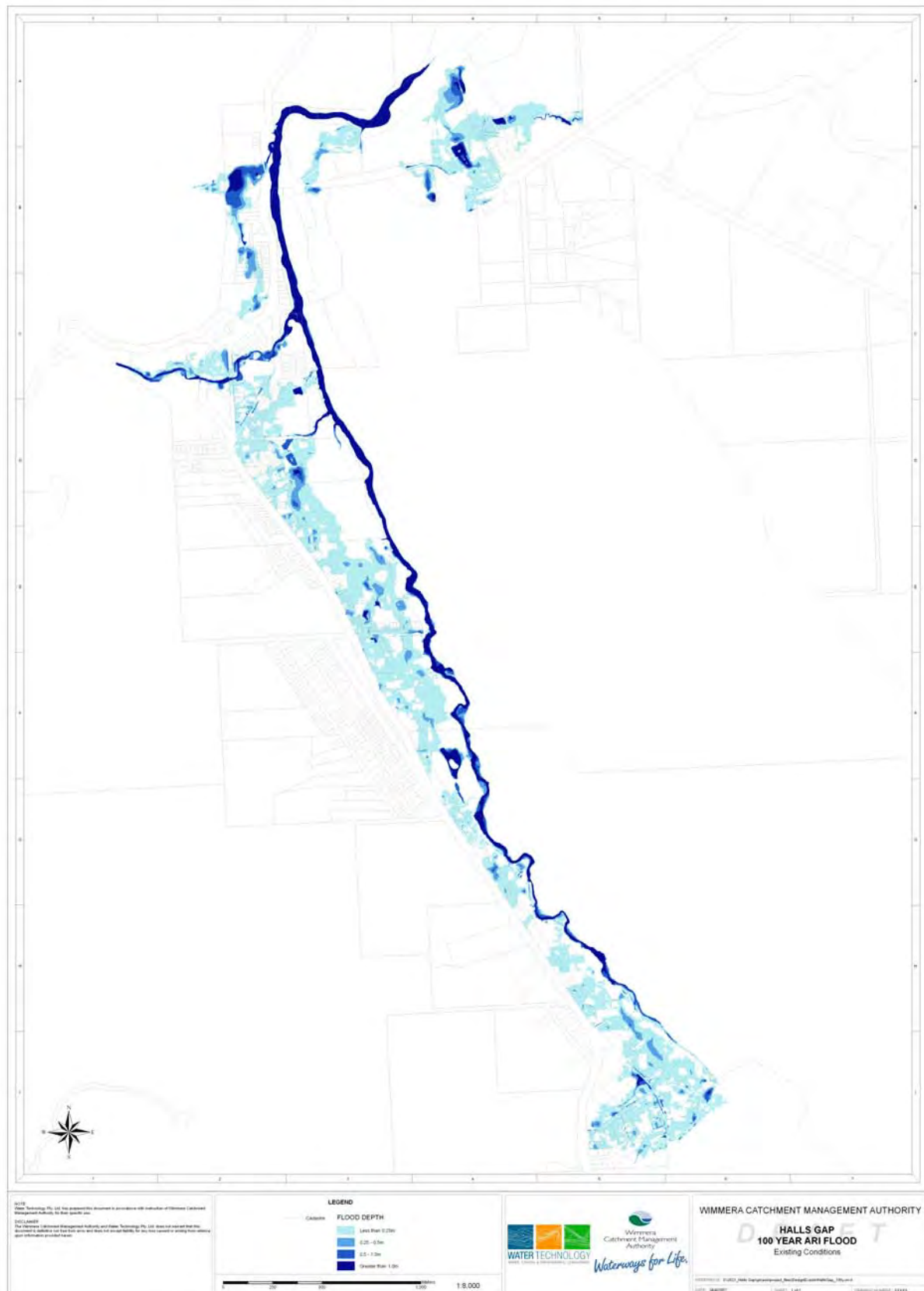
Inflow point locations in Halls Gap

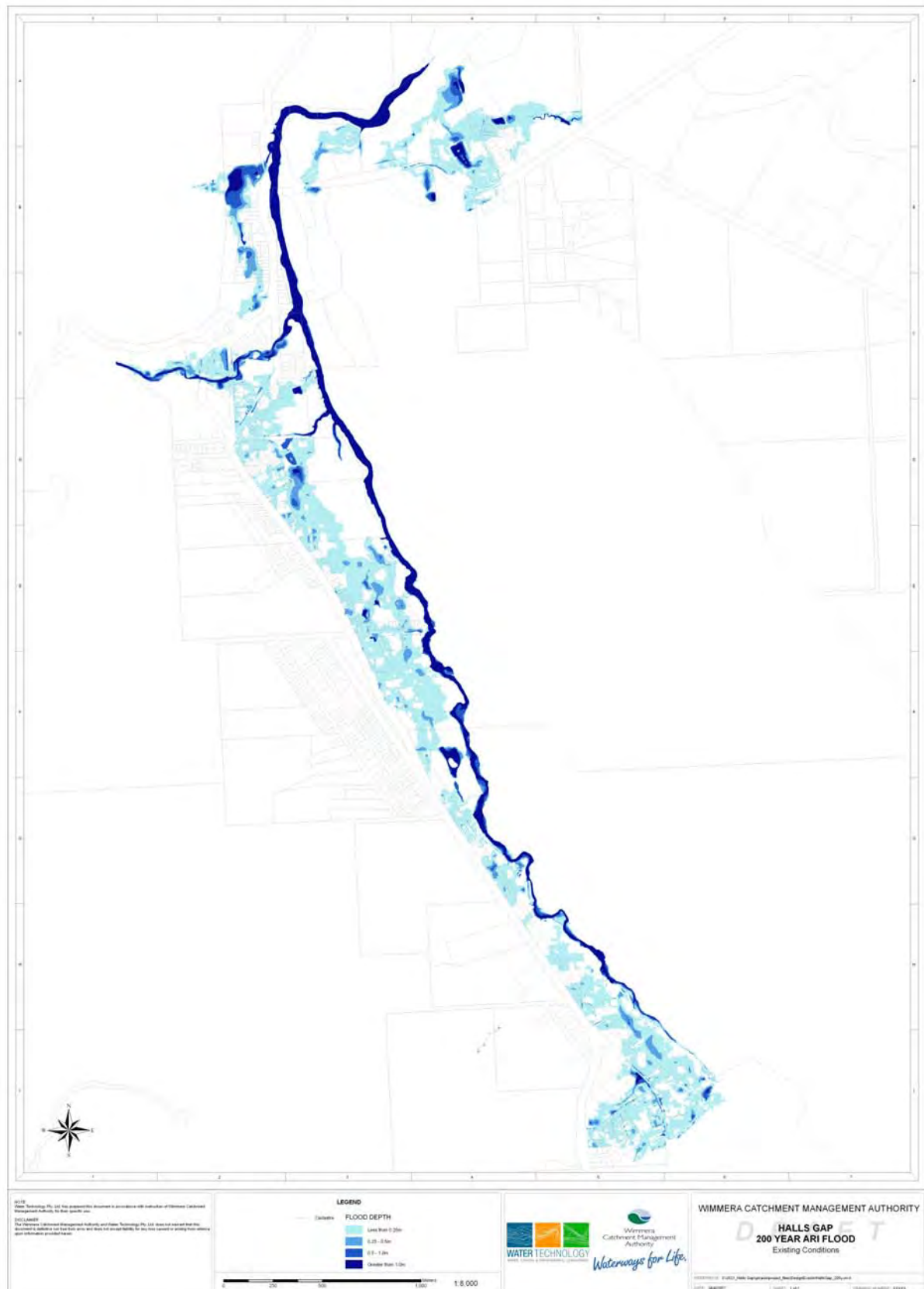
APPENDIX B DESIGN FLOOD MAPS

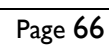












APPENDIX C FLOOD DAMAGE ASSESSMENT

Property Type and Address	Floor Level	Flood level (m AHD)					Water Depth Above Floor				
		10yr	20yr	50yr	100yr	200yr	10yr	20yr	50yr	100yr	200yr
Motel Unit: 245 Grampians Road	227.71	227.78	227.79	227.80	227.82	227.83	0.08	0.09	0.10	0.11	0.12
Motel Unit: 245 Grampians Road	228.03	228.14	228.15	228.16	228.17	228.18	0.11	0.12	0.13	0.14	0.14
Motel Unit: 245 Grampians Road	228.51	228.68	228.69	228.70	228.70	228.71	0.17	0.18	0.19	0.20	0.20
Motel Unit: 245 Grampians Road	227.61	228.16	228.16	228.17	228.17	228.17	0.55	0.55	0.56	0.56	0.56
Shed/Office: 215 Grampians Road	227.28	227.43	227.43	227.44	227.43	227.43	0.16	0.16	0.16	0.16	0.16
Motel: 153 Grampians Road	228.09	228.84	228.84	228.85	228.85	228.85	0.75	0.75	0.75	0.75	0.75
Motel: 141 Grampians Road	226.75	228.26	228.26	228.27	228.27	228.27	1.51	1.51	1.52	1.52	1.52
Shed: 10 Heaths Road	225.02	225.13	225.14	225.15	225.16	225.17	0.11	0.12	0.13	0.14	0.15
Toilet: 117 Grampians Road	226.87					226.92					0.05
Shop: 97 Grampians Road	227.85			228.22	228.25	228.25			0.37	0.40	0.41