MINNEGANG CREEK FLOODPLAIN RISK MANAGEMENT STUDY

Final Report

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Foreword

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

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

The policy provides for technical and financial support by the State Government through five sequential stages. These stages are:

- **Data collection:** determines the availability of data and defines data requirements.
- **Flood Study:** determines the nature and extent of flooding.
- **Floodplain Risk Management Study:** evaluates management options for the floodplain in respect of both existing and proposed developments.
- **Floodplain Risk Management Plan:** involves formal adoption by Council of a plan of management for the floodplain.
- **Implementation of the Plan:** includes undertaking property modification and flood mitigation works to protect existing development, implementing appropriate flood response procedures, increasing community awareness and the use of policy documents such as Local Environmental Plans to ensure development and land use is compatible with the flood hazard.

This Floodplain Risk Management Study constitutes the third stage of the management process for the Minnegang Creek catchment.

The next stage of the floodplain risk management process will involve the development of a draft Floodplain Risk Management Plan based on the recommendations of this study.

Executive Summary

INTRODUCTION

Wollongong City Council commissioned Kellogg Brown & Root Pty Ltd (KBR), formerly Kinhill Pty Ltd, to undertake a Floodplain Risk Management Study for the Minnegang Creek catchment, which is located approximately nine kilometres south of Wollongong.

Minnegang Creek flows through the suburb of Lake Heights, extending from the northern shore of Lake Illawarra to the intersection of Lake Heights Road and Flagstaff Road. It has two main tributaries as well as several minor branches. These are shown in Figure 2-2.

AIMS OF THE CURRENT STUDY

This study aims to evaluate management options, which can be implemented within the catchment to mitigate the effects of flooding. The recommendations from this study will form the basis of a Floodplain Risk Management Plan for the Minnegang Creek catchment.

The Floodplain Risk Management Study aims to:

- Provide a description of the flooding problems within the catchment including an assessment of flood damages.
- Identify potential floodplain management measures to reduce flooding.
- Assess management measures by considering hydraulic, economic, social and environmental factors.
- Involve the community affected by flooding in the assessment and decision-making process.
- Review planning and development controls and develop a Planning and Development Controls Matrix for the Minnegang Creek catchment to form part of Council's *Draft Development Control Plan 54 "Managing Our Flood Risks"* (Wollongong Council 2003).
- Develop a recommended scheme of management options to be used to formulate the Floodplain Risk Management Plan.

THE FLOOD PROBLEM

There have been five significant flood events in the Minnegang Creek catchment within the last twenty years. However, limited information is available regarding the nature of these flood events in the catchment. A significant number of flood levels were recorded for December 1985 and October 1987 events, in the areas immediately upstream and downstream of Barina Park detention basin. However, for the other three events, only limited flood levels were recorded within the catchment.

The steepness of the catchment leads to relatively contained flood flows within the creek, and therefore there is not a large floodplain adjacent to the creek. Over much of the catchment there is little difference between the flood extents for events of different annual exceedance probability (AEP), including the Probable Maximum Flood (PMF) event.

For the purposes of this study, the catchment was divided into nine zones to define the existing flooding problems. Zones were defined where the flooding mechanism and potential management options are similar for an area. The zones are listed below and their locations are shown on Figure 4-1.

- Zone 1 - Upstream of Lake Heights Road
- Zone 2 - Upstream of Barina Avenue
- Zone 3 - Melinda Grove Tributary
- Zone 4 - Barina Park Detention Basin
- Zone 5 - Downstream of Barina Park
- Zone 6 - Minnegang Creek
- Zone 7 - Upstream of Lake Illawarra
- Zone 8 - Ranchby Avenue Tributaries
- Zone 9 - Lower Catchment Tributaries

DESIGN FLOWS AND FLOOD LEVELS

Design flows and flood levels were established for the catchment in the *Minnegang Creek Flood Study* (KBR 2002). These were determined using a RAFTS hydrological model and MIKE 11 hydraulic model of the catchment.

The flood levels determined as part of the Flood Study were based on 100% blockage of all structures (with diameter less than 6 m) for all events, which is consistent with Council's *Conduit Blockage Policy* (Wollongong City Council 2002). However, the modelling and assessment of flood mitigation options is based on a more practical application of the Policy, as outlined in Section 3.3.6. The difference between the adopted blockage policy and the strict interpretation of the Policy is essentially the level of blockage assumed for the 20% AEP event. To allow for a valid comparison between the existing catchment conditions and the proposed management options, the 20% AEP event design flood levels for existing conditions have therefore been recalculated according to the more practical application of the Policy for use in the Floodplain Risk Management Study. It should be noted that the Flood Study has not been revised to incorporate the new design flood levels for the 20% AEP event.

IMPACTS AND COSTS OF FLOODING

Only a small proportion of residents in the catchment are directly affected by flooding. This is because of the relatively contained flows throughout the catchment.

The number of affected properties and the damages caused by flooding are shown in Table 1. The highest concentration of affected properties lies directly downstream of Barina Park.

Table 1 Impacts and costs of flooding

Flood Event	Number of flood-affected properties		Flood damage
	Above-floor flooding	Property flooding	
20% AEP	5	35	$108,000
5% AEP	13	43	$396,000
2% AEP	17	44	$475,000
1% AEP	17	48	$560,000
PMF	20	59	$1,080,000
		Average Annual Damage	$63,600
		Present Worth of Damages (50yrs @ 7% pa)	$880,000

FLOODPLAIN RISK MANAGEMENT OPTIONS EXAMINED

Potential mitigation options for the Minnegang Creek catchment have been developed from commonly accepted floodplain risk management measures. The *Floodplain Management Manual* (NSW Government 2001) divides floodplain risk management measures into three categories, namely:

- Property modification measures
- Response modification measures

- Flood modification measures.

A range of measures from each of the above categories was considered. The options considered for the Minnegang Creek catchment are shown in Table 2. Each option was assessed individually and effective options were then recommended for inclusion in a mitigation scheme for the catchment. Table 2 also shows the options that were recommended for inclusion in potential mitigation schemes for the catchment.

Table 2 Mitigation options considered

Option Number	Description	Recommended
Z1-1	Flood warning signs at Lake Heights Road	No
Z2-1	Voluntary purchase of 68 Barina Avenue, grassed floodway through 68 Barina Avenue, culvert installation under Barina Avenue	No
Z2-2	Voluntary purchase of 68 Barina Avenue, rock lined channel from Lake Heights Road to Barina Avenue, culvert installation under Barina Avenue	No
Z2-3	Voluntary purchase of 68 Barina Avenue	No
Z2-4	House raising at 68 Barina Avenue	Yes
Z3-1	Create easement through 7 Gilgandra Street, construct concrete v-drain between Gilgandra Street and Barina Park	No
Z4-1	Excavation in Barina Park to increase basin capacity, provision of a spillway and installation of warning signs	In part
Z4-2	Raising level of basin embankment to increase basin capacity, provision of a spillway and installation of warning signs	In part
Z4-3	Excavation and increased level of basin embankment within Barina Park, provision of a spillway and installation of warning signs	In part
Z5-1	Voluntary purchase of 42, 63 and 65 Mirrabooka Road, voluntary purchase of 96, 98 and 99 Weringa Avenue, grassed floodway from Barina Park to downstream of Weringa Avenue, culvert installation under Mirrabooka Road and Weringa Avenue	No
Z5-2	Voluntary purchase of 42, 63 and 65 Mirrabooka Road, voluntary purchase of 96, 98 and 99 Weringa Avenue, rock lined channel from Barina Park to downstream of Weringa Avenue, culvert installation under Mirrabooka Road and Weringa Avenue	Yes
Z5-3	Voluntary purchase of 42, 63 and 65 Mirrabooka Road, voluntary purchase of 96, 98 and 99 Weringa Avenue	No
Z5-4	House raising at 40, 63, 65, 67 and 69 Mirrabooka Road, house raising at 97, 98,99, 100 and 101 Weringa Avenue	No
Z5-5	Voluntary purchase of 42, 63 and 65 Mirrabooka Road, voluntary purchase of 96, 98 and 99 Weringa Avenue, rock lined channel from Barina Park to downstream of Weringa Avenue, road closures at Mirrabooka Road and Weringa Avenue	No
Z5-6	Voluntary purchase of 42, 63 and 65 Mirrabooka Road, voluntary purchase of 96, 98 and 99 Weringa Avenue, rock lined channel from Barina Park to downstream of Weringa Avenue, existing pipes to be used as culverts under roads	Yes
Z6-1	Vegetation clearing within Minnegang Creek	No
Z7-1	Removal of the Illawarra Yacht Club carpark culvert	No
Z7-2	Install third 1.65 m culvert at the Illawarra Yacht club culverts	No
Z7-3	Diversion of high flows through the yacht club culvert by excavation adjacent to Minnegang Creek	No

Option Number	Description	Recommended
Z8-1	Create easement through 1 and 2 Ranchby Avenue, construct concrete v-drain between vacant land and Minnegang Creek	No
Z8-2	Create easement through 16 Ranchby Avenue, construct concrete v-drain between vacant land and Minnegang Creek	No
Z8-3	Create easement through 21 and 30 Ranchby Avenue, construct small concrete trapezoidal channel between vacant land and Minnegang Creek	No
Z8-4	Create easement through 29 Ranchby Avenue, construct concrete v-drain between Ranchby Avenue and Minnegang Creek	No
Z8-5	Create easement through 53 Ranchby Avenue, construct concrete v-drain between Ranchby Avenue and Minnegang Creek	No
Z8-6	Create easement, construct concrete v-drain between Gordon Crescent and Ranchby Avenue	No
Z8-7	Create easement through 16 Ranchby Avenue, construct grass swale between vacant land and Minnegang Creek	No
Z9-1	Align Canberra branch with vacant block between 75 and 77 Denise Street	No
Z9-2	Construct grass swale in Denise2 branch (at 30 Trevor Avenue)	No
Overall	Catchment wide community education program	Yes
Overall	Maintenance of catchment flow paths	Yes
Overall	Emergency management	Yes

Most of the options listed above are independent, and their implementation would not affect other parts of the catchment. The primary exception to this independence occurs for Zones 4 and 5, where flooding problems are interrelated and management strategies for each zone must therefore be considered in conjunction with the other zone. The recommended voluntary purchases and channel construction for Zone 5 provides the optimum outcome in terms of flood protection, reduction in the current threat to personal safety and the long-term management of flood prone land in the catchment. Augmentation of the existing detention basin within Barina Park is not recommended since there could be no further improvement in flooding when undertaken in conjunction with the Zone 5 works. However, two components of each Zone 4 option (the provision of a spillway for the existing basin embankment and installation of flood warning signs) are recommended in conjunction with the proposed Zone 5 works.

MITIGATION SCHEMES

From the range of options listed in Table 2, two mitigation schemes for the catchment were developed. These are listed in Table 3. The only difference between the two schemes is the culvert configurations to be provided at Mirrabooka Road and Weringa Avenue.

Each scheme leads to similar flood levels and flows to existing conditions in the upper parts of Minnegang Creek downstream to Barina Park. The spillway and proposed channel ensure that the flows over the weir of the detention basin are conveyed effectively to Minnegang Creek. Flood levels downstream of Barina Park are substantially reduced over existing conditions due to the lowering of the invert levels along the channel compared to the existing configuration. Levels along the lower part of Minnegang Creek are not changed significantly from existing conditions.

Table 3 Mitigation schemes

Zone	Scheme 1	Scheme 2
1	n/a	n/a
2	House raising - 68 Barina Avenue	House raising at 68 Barina Avenue
3	n/a	n/a
4	Spillway for detention basin and flood warning signs	Spillway for detention basin and flood warning signs
5	Voluntary purchase of six properties and rock lined channel from Barina Park to Minnegang Creek with new culverts under Mirrabooka Road and Weringa Avenue	Voluntary purchase of six properties and rock lined channel from Barina Park to Minnegang Creek with existing pipes used as culverts under roads
6	n/a	n/a
7	n/a	n/a
8	n/a	n/a
9	n/a	n/a
Catchment-wide	Community education program	Community education program
Catchment-wide	Maintenance of catchment flow paths	Maintenance of catchment flow paths
Catchment-wide	Emergency management	Emergency management

The only difference between the schemes is the existing 1.35 m pipes retained as culverts in Scheme 2 do not have sufficient capacity to convey the 20% AEP event under Mirrabooka Road and Weringa Avenue. The 1.5 m diameter culverts proposed for Scheme 1 ensure that no flows pass over these roads in the 20% AEP event.

Implementation of either mitigation scheme would lead to a substantial reduction in the effects of flooding within the Minnegang Creek catchment. The number of properties affected by flooding for each event is shown in Table 4, for both mitigation schemes. The two schemes provide flood protection to the same properties within the catchment.

Table 4 Flood-affected properties

Option Name	Properties affected by above-floor flooding					Properties affected by below-floor flooding				
	PMF	1%	2%	5%	20%	PMF	1%	2%	5%	20%
Existing Conditions	20	17	17	13	5	59	48	44	43	35
Scheme 1	6	4	4	4	3	48	38	35	33	28
Scheme 2	6	4	4	4	3	48	38	35	33	28

The economic assessment of the mitigation schemes shows, that despite the substantial reduction in flood damages, the benefit-cost ratio for implementation of either scheme is significantly less than one. The results of the economic assessment are shown in Table 5.

Table 5 Economic evaluation of mitigation schemes

Option Name	Scheme 1	Scheme 2
Existing Average Annual Damage	$63,600	$63,600
Average Annual Damage with works in place	$23,000	$23,000
Net present worth of benefit	$560,000	$560,000
Estimated cost	$2,147,000	$2,093,000
Benefit-cost ratio	0.26	0.27

With a benefit-cost ratio of less than one, neither of the schemes can be justified purely from an economic viewpoint. However, the intangible benefits which cannot be quantified (and are therefore not taken into account in the economic evaluation) are considered to be highly significant. As a result, overall assessment of the proposed mitigation works, taking into account the existing flood situation, risk to life and property and long-term management of flood prone land in the catchment, is deemed to justify the need for the proposed works. Therefore, with the lowest overall cost, Scheme 2 is recommended for implementation.

THE NEXT STEPS

The next steps in the floodplain management process are:

- Preparation of the *Draft Minnegang Creek Floodplain Risk Management Plan* including a program of works, priorities for implementation and identification of potential funding sources.

- Adoption of the *Minnegang Creek Floodplain Risk Management Plan* by Council and implementation as funds become available.

CONTENTS

CONTENTS

TABLES

CONTENTS

FIGURES

ABBREVIATIONS AND ACRONYMS

AAD	Average Annual Damage
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ANCOLD	Australian National Committee on Large Dams
AR&R	Australian Rainfall and Runoff
CPI	Consumer Price Index
DCP 54	Draft Development Control Plan 54 "Managing Our Flood Risks"
DIPNR	Department of Infrastructure, Planning and Natural Resources
DISPLAN	Wollongong Local Disaster Plan
DLWC	Department of Land and Water Conservation (now incorporated into DIPNR)
FMM	Floodplain Management Manual
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
FRP	Flood Risk Precinct
LGA	Local Government Area
MIKE 11	The hydraulic model used in this study
NSW	New South Wales
OSD	On-site Stormwater Detention
PMF	Probable Maximum Flood
RAFTS	Runoff Analysis and Flow Training Simulation (the hydrologic model used in this study)
RL	Reduced Level
SES	State Emergency Service

1 Introduction

Minnegang Creek is situated approximately 8.5 km south of Wollongong, and significant flooding has previously occurred within parts of the Minnegang Creek catchment. Kellogg Brown & Root Pty Ltd (KBR), formerly Kinhill Pty Ltd, was engaged by Wollongong City Council (Council) to undertake the preparation of a draft Floodplain Risk Management Plan (FRMP) for the Minnegang Creek catchment.

The FRMP is being developed in three stages; a Flood Study, a Floodplain Risk Management Study (FRMS) and a FRMP. This is consistent with the approach recommended in the NSW Government's *Floodplain Management Manual: the management of flood liable land* (FMM) (2001).

A final draft of the *Minnegang Creek Flood Study* was completed in June 2002. It defined the existing flood behaviour in the Minnegang Creek catchment for the 20%, 5%, 2% and 1% Annual Exceedance Probability (AEP) events. Flood events were defined through design flows, flood surface profiles, flow velocities and flood contours. The Probable Maximum Flood (PMF) for the catchment was also estimated as part of the Flood Study.

This FRMS, as the second stage of the above process, aims to develop and assess possible floodplain management options to minimise the impacts from flooding, investigate flood hazards and define flood damages. The FRMS is needed to identify and assess issues for input into the decision making process, which will result in the FRMP.

The final stage involves the development of a cost-effective FRMP, recommending a program of measures for implementation within the study area, and Council's formal adoption of the FRMP.

The background to the current study is described in Section 2, including previous studies in the area and the parties involved in this current study. Section 3 details the methodology that has been adopted to quantify the damages in the catchment resulting from flooding. Section 4 describes the nature of flooding in the Minnegang Creek floodplain based on the findings of the Flood Study. A discussion of possible mitigation options is presented in Section 5 and the results and implications of each of the mitigation options are given in Section 6. Several combinations of these mitigation options were examined as the preferred schemes in Section 7. Planning and development controls are considered in Section 8. Finally, conclusions and recommendations to be used to formulate the FRMP are made in Section 9.

2 Background

This section details the background to the FRMS. Further details are provided in the *Minnegang Creek Flood Study* (KBR 2002).

2.1 CATCHMENT DESCRIPTION

The Minnegang Creek catchment is located approximately 8.5 km south of Wollongong, in the suburb of Lake Heights. The catchment rises from the northern shore of Lake Illawarra to the intersection of Lake Heights Road and Flagstaff Road. The catchment location is shown in Figure 2-1.

Approximately 80% of the catchment is developed, mostly with low density residential housing. The remaining 20% is either recreational area or cleared open space.

Most areas in the catchment could be considered fully developed within their respective land zone entitlements as they currently exist. The large cleared area in the north west of the catchment between Flagstaff Road, Hilltop Avenue, Ranchby Avenue and Noble Parade, currently within Zone 2(a) Low Density Residential, presents the most significant opportunity for future development. Furthermore, it is likely that such development will take place in the near future following Council approval of a development application for a low density, 38-lot subdivision.

The creek system consists of a combination of natural open watercourses and piped drains. Minnegang Creek flows from the north-west of the catchment to the south-east where it discharges into Lake Illawarra. Minnegang Creek has two main tributaries. The first flows from the north of the catchment, follows Melinda Grove and then passes under Gilgandra Street, confluencing with Minnegang Creek upstream of Mirrabooka Road. The second tributary commences in the south-west, from Gordon Crescent and flows under Ranchby Avenue, confluencing with Minnegang Creek upstream of Lake Heights Road. Figure 2-2 shows the location of Minnegang Creek and these main tributaries within the catchment boundaries. There are also minor branches of Minnegang Creek draining the area between Hilltop Avenue and 30 Ranchby Avenue, the area between Claremont Avenue and 46 Ranchby Avenue and the area between 7 Canberra Road and Minnegang Creek.

Figure 2-2 also illustrates the extent of the hydraulic model and shows the branch names used in the model, which are referred to throughout this report.

2.2 DATA COLLECTION

The first stage in the preparation of the flood study was data collection. Data was primarily collected from the following sources:

- Council;
- Bureau of Meteorology;
- detailed surveys of the piped drainage system and open channel systems within the catchment;
- a floor and yard level survey of flood-affected properties within the catchment;
- site inspections; and
- on-site meetings and discussions with local residents.

The data compiled from each of these sources is detailed in the *Minnegang Creek Flood Study*.

2.3 PREVIOUS STUDIES

The only flood study that has been carried out specifically for the Minnegang Creek catchment was completed as the first stage of this floodplain risk management process. Prior to this, Lawson & Treloar Pty Ltd (2000) carried out a flood study of Lake Illawarra, covering a catchment area of approximately 235 km^2. The *Lake Illawarra Flood Study* investigated flooding of Lake Illawarra to evaluate current peak flood levels for a range of design rainfall events under existing catchment and lake conditions. The results for flooding within Lake Illawarra at Griffin Bay were used to derive the tailwater levels for the Minnegang Creek catchment.

2.4 PARTIES INVOLVED

The following parties have been involved in the preparation of this FRMS:

- Wollongong City Council - councillors and engineers;
- Department of Infrastructure, Planning and Natural Resources (DIPNR), incorporating the former Department of Land and Water Conservation (DLWC);
- State Emergency Service (SES), Wollongong branch;
- KBR; and
- the local community.

Representatives from each of the above stakeholders form the Minnegang Creek Floodplain Risk Management Committee (FRMC). The FRMC acts as a focus and a forum for the discussion of technical, social, economic, ecological and cultural issues related to flooding within the catchment.

The floodplain risk management process for the Minnegang Creek catchment, including this FRMS is subject to a funding arrangement under the State Government's Floodplain Management Program (administered by the Department of Infrastructure, Planning and Natural Resources) on a 2:1 (State/Federal Government:Council) basis.

HYDRAULIC MODEL BRANCH NAMES

MINNEGAN
LAKEHTS2
RANCHBY1
RANCHBY2
RANCHBY3
RANCHBY4
BARINA
MELINDA
KARRABAH
GILGAND
DENISE1
DENISE2
DENISE3
GILGAND

N

1:6000 @ A3

Figure 2-2

WATERCOURSE LAYOUT AND HYDRAULIC MODEL BRANCH NAMES

Minnegang Creek Floodplain Risk Management Study

3 Damage Assessment

3.1 INTRODUCTION

To quantify the impact of floods within the Minnegang Creek catchment, flood damages have been estimated. This is an important process in the FRMS, which allows the impacts of the proposed mitigation options to be compared quantitatively to the effects of flooding under existing conditions within the catchment. Proposed mitigation options should lead to a reduction of flooding impacts within the catchment, as measured by the flood damage assessment.

The following section describes the types of flood damages that were considered in the FRMS and the methodology that was used to estimate flood damages.

3.2 DAMAGE CATEGORIES

It is usual to divide flood damages into two categories, tangible and intangible damages. The former may be further divided into direct and indirect damage components. Each of these damage categories is discussed below.

3.2.1 Direct damages

Direct damages result from the action of floodwaters. Direct damages measure the costs incurred to replace or repair goods, structures, facilities and possessions damaged by floodwaters. They can be further divided into:

- damage to building contents;
- structural damage to buildings; and
- external damage including the structure and contents of sheds, vehicles and infrastructure.

The level of direct damages varies according to the severity of the flood. Damages include the costs of cleaning, repairs to or replacement of damaged items. Costs of infrastructure damage are generally borne by councils, utility providers and public authorities. Due to the difficulties in quantifying these infrastructure damage costs, they are often specified as a percentage of the direct damages.

3.2.2 Indirect damages

Indirect damages are the costs to businesses and individuals caused by a flood additional to the direct damages. Examples of indirect damages are additional costs (above normal costs) for food and accommodation, loss of wages by employees, loss of sales for commercial and industrial properties and opportunity cost to the public caused by the closure of public facilities.

3.2.3 Intangible damages

Intangible damages attempt to reflect the non-monetary effects of flooding. There are two primary areas where intangible damages are important:

- social impacts
- environmental consequences.

Social effects of flooding may include increased levels of emotional stress and mental and physical illness caused by flooding. As the damages vary according to the flood preparedness of the community, they are therefore difficult to quantify. However, as social damages include a consideration of the likely loss of life, they play a major role in policy decisions (Taylor et al 1987).

Environmental and ecological costs of flooding are also difficult to quantify. The extent of damage depends on the size of the catchment and the characteristics of flooding within the area.

Due to the difficulties in quantifying the level of damage, intangible damages have not been included in the damage assessment for the Minnegang Creek catchment. However, the social and environmental impacts of each of the mitigation options have been assessed qualitatively in conjunction with the hydraulic performance and damage assessment.

3.3 METHODOLOGY

The following methodology was implemented to estimate the damages resulting from flooding within the Minnegang Creek catchment, for both existing conditions and in the comparison of different mitigation options.

3.3.1 Properties at risk

Properties at risk of flooding were identified using the flood extents for the PMF event for existing conditions from the MIKE 11 modelling of the catchment. All buildings identified to be at risk were then surveyed to obtain the following information:

- property number and street name
- property type (commercial, industrial, residential, public, vacant)
- building construction type (floor and walls) and condition of the building
- size of building and number of storeys
- spot level at the lowest point in the property
- floor level of the lowest habitable part of the building
- a description, floor level and location of any other structures on the property.

3.3.2 Properties database

A spreadsheet database of the information collected in the survey was created, which was used for the damages calculations. It is relevant to note that several of the surveyed properties were excluded from the damages calculations as it was considered that these properties would be protected from flooding by solid fences adjacent to the flow path. Due to the small depth of flow (less than 500 mm) in these locations, failure of the fence and subsequent property damage is unlikely during flooding.

3.3.3 Stage-damage curves

Stage-damage curves were developed to provide an estimate of the potential damage that could be incurred for different levels of inundation. One curve was used for above-floor flooding for all residential properties within the catchment. The use of a single stage-damage curve for all residential properties involves a large degree of generalisation. However, studies that have been carried out show that the differences in flood damages to properties constructed of brick and weatherboard are very small (Smith and Greenaway 1983) and it was therefore considered reasonable to adopt one curve for all houses in the catchment.

The above-floor stage-damage curve was developed from the standard curve for residential damages from ANUFLOOD (Smith and Greenaway 1983). On advice from the former DLWC, the ANUFLOOD stage-damage curve was adjusted based on the Consumer Price Index (CPI) from 1983 dollars to 2002 dollars (ABS 2002) and then doubled. This accounts for the current insurance practice of 'new for old' replacement of contents, rather than residual value as was the case when the ANUFLOOD curve was originally derived, as well as a number of other relevant factors.

There are three commercial properties within the Minnegang Creek catchment. Only one of these properties, the Illawarra Health Service Early Childhood Centre was assessed to be at risk from flooding. Due to the small size of the building and nature of the commercial activities, this property was assigned the residential stage-damage curve adopted for the other properties in the catchment.

Separate stage-damage curves were used to determine the damages external to the residential buildings. These curves included damage to cars, sheds or other structures on the property. Three curves were adopted for external damages to model the following combination of property features:

- properties with no storage facilities;
- properties with storage facilities (eg. garage, shed or underfloor storage); and
- properties with storage facilities and other structure(s) (eg. chicken sheds, entertainment area, greenhouse etc).

For each of the above categories, it was assumed that there is one car at every house. This is considered a reasonable assumption based on Australian Bureau of Statistics (ABS) data which shows that only 15% of households in the Lake Heights area do not own a registered vehicle and that some households have multiple cars (ABS 1998). It was also assumed that the average value of a car is $10,000. Vacant residential blocks were assumed to incur no damages.

The stage-damage curves adopted for the above-floor and external property damages are presented in Appendix C.

3.3.4 Direct damages calculations

Direct damages were calculated at each property by comparing the flood level at the property to the level of the floor or ground to determine the depth of inundation. This was then used to calculate the damage based on the stage-damage curves.

The flood level was determined by assigning each property a weighting between two adjacent MIKE 11 cross sections. For some properties, different weightings were adopted for the above-floor flooding damage assessment and the property flooding damage assessment. The different weightings were determined from the location of the surveyed spot levels within the property.

An in-house computer program was used to read the output from MIKE 11 and to calculate the flood level, depth of inundation and the resulting damage from the assigned stage-damage curve for each property.

3.3.5 Other damages

Other damage categories were calculated as a fixed percentage of the direct damages calculated from the stage-damage curves. These were:

- Indirect damage - 30% of direct damages
- Infrastructure damage - 50% of direct damages

These ratios were adopted based on values used in previous studies of a similar nature (including the Fairy Creek Floodplain Management Study, Kinhill 1996) and those recommended in ANUFLOOD (Taylor et al 1987).

3.3.6 Blockage policy

A worst case blockage scenario was adopted for the hydraulic modelling presented in the *Minnegang Creek Flood Study* (KBR 2002). This assumed 100% blockage of all structures within the catchment. This was consistent with the *Conduit Blockage Policy* (Wollongong City Council 2002), which specifically addresses the installation of new structures across watercourses and the analysis of existing structures.

However, the *Conduit Blockage Policy* in its existing form does not specifically address the upgrading of existing structures. Therefore, if the current policy was strictly applied to the assessment of a proposed culvert upgrading, no benefit would be derived from the upgrading. Consequently, the upgrading of existing structures would never appear to be warranted. This situation has clear ramifications in the context of floodplain management and in the development and assessment of options for flood mitigation.

Following discussions between Council, DLWC and various consultants working on flood studies throughout the Wollongong local government area (LGA), it was decided that an assumption of zero blockage would apply for the purpose of economic appraisal of flood mitigation options for flood events of smaller magnitude than the 5% AEP flood.

Accordingly, the methodology adopted for the damage assessments and flood risk mapping undertaken for the current study is consistent with the following guidelines:

- For the 20% AEP event (and more frequent events) the blockage factor for all structures is 0% (ie. clear).
- For the 5%, 2% and 1% AEP events and the PMF event the blockage factor is 100% for structures with a diagonal opening of less than 6.0 m and 25% for structures with a diagonal opening of greater than 6.0 m.

While the *Conduit Blockage Policy* does not specifically cover debris control structures, the following approaches have been formulated through discussions between Council, DIPNR and Lawson & Treloar, and have been adopted for the purposes of this study:

- The impact of a debris control structure is limited to the first downstream culvert.
- For a debris control structure to be assumed to be effective, a high level bypass channel should be included as part of the design. Upstream creek rehabilitation may also be necessary.
- A debris control structure has no impact on blockage of structures for the 20% AEP event (already assumed to be 0%).
- For the 5%, 2% and 1% AEP events and the PMF event, a debris control structure reduces the blockage factor from 100% to 25% for culverts with a diagonal opening greater than 1.5 m and less than 6.0 m.
- A debris control structure has no impact on the blockage factor to be applied for culverts with a diagonal opening of less than 1.5 m or greater than 6.0 m.

3.3.7 Actual flood damages

Flood damages may be classified as either potential or actual damages. Potential damages are the maximum damages that could eventuate should a flood occur. It is assumed in estimating the potential damages that no mitigative actions are taken to prevent the damages. Actual damages are the damages that occur in a real flood, allowing for the impacts of mitigative measures that may be taken by residents.

The difference between actual and potential damages depends on the flood warning period and the flood preparedness of the flooded community. In the Minnegang Creek catchment, the flood warning period is very short due to the short response time of the catchment. For options and schemes where community education is not implemented, it has been assumed that the actual damages would be equal to the potential damages, as residents would have little time to act to avoid or reduce the damages.

3.3.8 Average annual damages

The average annual damage (AAD) is equal to the total damage caused by all floods over a period of time, divided by the number of years in that period. It is assumed in calculating the AAD that the degree of development is constant over this period. The AAD for the catchment, for both existing conditions and with mitigation options implemented, was calculated from the area under the damage versus exceedance probability curves.

4 Existing Flood Behaviour

4.1 INTRODUCTION

Existing flood behaviour within the Minnegang Creek catchment was examined in the *Minnegang Creek Flood Study* (KBR 2002). The details of the hydrologic and hydraulic modelling undertaken for the Flood Study and this study are provided in Appendices E, F and G. This section provides an analysis of the findings of the Flood Study and the effects of these findings on the development of flood mitigation options.

4.2 EXISTING FLOODING BEHAVIOUR

4.2.1 Flood history

There have been several large flood events in the Minnegang Creek catchment within the last twenty years. The most significant of these occurred on the following dates:

- 14 December 1985
- 23 October 1987
- December 1990
- 17 August 1998
- 24 October 1999.

Limited information is available regarding the nature of these flood events in the catchment. A significant number of flood levels were recorded for December 1985 and October 1987 events, in the areas immediately upstream and downstream of Barina Park detention basin. However, for the other three events, only limited flood levels were recorded within the catchment.

Residents involved in the community consultation for this study remembered these events causing significant flooding. No information is available on the recurrence interval of the above events, with the exception of the August 1998 storm event, which had a recurrence interval of approximately two years in the vicinity of the Minnegang Creek catchment. Other events causing more limited flooding have occurred regularly within the catchment.

4.2.2 Flow characteristics

The topography of the catchment plays an important role in determining the flooding behaviour of Minnegang Creek. The steepness of the catchment leads to relatively contained flood flows within the creek, and therefore there is not a large floodplain adjacent to the creek. Over much of the catchment there is little difference between the flood extents for events of different exceedance probabilities, including the PMF event.

In some locations within the catchment, the creek has been piped under properties and roads. When the capacity of the system is exceeded or Council's *Conduit Blockage Policy* (Wollongong City Council 2002) is applied, flows in these locations are wide due to the lack of defined overland flow paths.

Flow depths are reasonably shallow over most of the catchment. This can be attributed to the small flow volumes within the tributaries and minor branches of Minnegang Creek. Within Minnegang Creek itself, flood flows have significant depths in the lower parts of the catchment. There are also two locations in the upper part of the catchment, upstream of the Lake Heights Road culvert and upstream of the start of piped drainage system, where significant depths of water occur due to ponding.

In all events, there are significant water depths in Barina Park due to the detention of water by the embankment. Modelling indicates that water may reach depths of up to 3 m directly upstream of the embankment.

4.2.3 Critical duration

The critical duration storm for the Minnegang Creek catchment was found to be the two hour storm event. This is considered a reasonably long critical duration given the size of the Minnegang Creek catchment. However this can be attributed to the design rainfall temporal patterns in *Australian Rainfall and Runoff* (IEAust 1987), which often lead to a critical duration of two hours regardless of the catchment size (KBR 2002).

The peak flows and flood levels along Minnegang Creek occur after approximately 40 minutes in the upper parts of the catchment. In smaller events, such as the 20% AEP event, the peak flows downstream of the Barina Park detention basin occur approximately one hour following the start of the storm event. The degree of attenuation provided by the detention basin decreases as the magnitude of the storm event increases. Along the tributaries and minor branches of Minnegang Creek the time to peak flow is approximately 20 to 30 minutes.

4.2.4 Effects of structures

There are five major structures within the catchment; the Barina Park detention basin, the Jane Avenue pedestrian bridge and three major culvert structures under Lake Heights Road, Northcliffe Drive and the Illawarra Yacht Club carpark. Blockage of these structures, in accordance with Council's *Conduit Blockage Policy* (Wollongong City Council 2002), leads to the worst case scenario for flood levels within the catchment. However, no diversions of flood flows to adjacent areas occur when any of these structures are blocked.

4.3 ZONE DEFINITIONS AND FLOODING BEHAVIOUR

The catchment has been considered in terms of localised areas, which suffer from similar flooding mechanisms and support similar land uses. Each of these areas has been termed a 'zone'. Figure 4-1 shows the identified zones within the catchment.

1:6000

ZONE NUMBERS AND NAMES

Zone	Name
1	Upstream of Lake Heights Road
2	Upstream of Barina Ave
3	Melinda Grove tributary
4	Barina Park detention basin
5	Downstream of Barina Park
6	Minnegang Creek
7	Upstream of Lake Illawarra
8	Ranchby Avenue tributaries
9	Lower catchment tributaries

Figure 4-1

ZONE BOUNDARIES

Minnegang Creek Floodplain Risk Management Study

The zones have been defined in such a way that similar mitigation options are suited to the zone as a whole.

Summaries of the existing flooding problems in each zone are presented in the following sections. Figure 4-2 provides an overview of existing flood behaviour, including the 1% AEP flood extent and contours, design peak discharges at various locations within the catchment, and peak depths of inundation at major road crossings. More detailed information, including plots of flood extents and contours for various design events, and discussion of existing flood behaviour is contained in the *Minnegang Creek Flood Study.*

4.3.1 Zone 1: Upstream of Lake Heights Road

The culvert at Lake Heights Road restricts flow and leads to increased flood levels upstream of the road. This is not considered a significant problem as the area immediately upstream of Lake Heights Road is currently undeveloped and the floodwaters do not impact on residential properties. The attenuation provided by the culvert also helps to reduce the flood flows downstream of Lake Heights Road, where significant flooding problems currently exist.

The main problems associated with the ponding of flows behind the Lake Heights Road culvert are:

- the depth of ponded water immediately upstream of the culvert, ranging between 2.9 - 3.3 m for the 20% AEP and PMF events respectively; and
- the frequency of road overtopping, which occurs for events greater than or equal to the 20% AEP event.

Flood flows over Lake Heights Road are not considered a significant problem as the road is not a major thoroughfare and a number of alternative access routes are available within the catchment. Flood flows are concentrated around the low point of the road and do not divert into adjacent areas.

However, safety in this area is an issue due to the depths of water, both across the road and upstream of the culvert. Due to the size of the culvert (1.2 m diameter), the possibility of a person being washed into the culvert is also an issue.

4.3.2 Zone 2: Upstream of Barina Avenue

Downstream of Lake Heights Road, the capacity of the channel and piped drainage system is inadequate and the flood waters pass through several properties. Flooding within this zone is a major problem due to the lack of a defined overland flow path through the properties fronting Barina Avenue. Two properties are affected by above-floor flooding; one in the 20% AEP event and one in the PMF event. Other flooding problems occur at the headwall at the start of the piped drainage system. Significant ponding, in the order of 2.6 - 3.2 m for all design events considered, occurs at this location due to the configuration of the headwall with respect to the surface levels of the surrounding area.

4.3.3 Zone 3: Melinda Grove tributary

For most of this zone, flood flows are confined to existing roadways. However, this is not considered a significant problem since the roads are small residential streets and the flows are reasonably shallow. For the properties on Karrabah Crescent and Mirrabooka Road, the flow path generally follows property boundaries since no formal overland flow path exists. The damages from these flows are low, as no above-floor flooding occurs in these locations.

Flooding at 5, 7 and 9 Gilgandra Street is more significant as the houses lie within the flow path. No above-floor flooding would occur for these properties, but flooding affects garages and similar structures within the properties.

4.3.4 Zone 4: Barina Park detention basin

Assuming no blockage of the low level outlet structure, the Barina Park detention basin currently has sufficient capacity to prevent spilling in a flood event slightly smaller than the 20% AEP event. Larger events will result in overtopping of the basin embankment. The flood extents determined for the basin show that the full area of the Barina Park playing fields is not utilised in detaining flood flows. If the basin outlet is assumed blocked, then overflow from the basin will occur for events greater than approximately the 50% AEP event.

Community consultation has also indicated that the community holds concerns about the time required for the basin to drain and the playing fields to open after a flood event. Concerns were also raised regarding the build up of rubbish and grass clippings within the basin, and the effects that this may have on the performance of the basin.

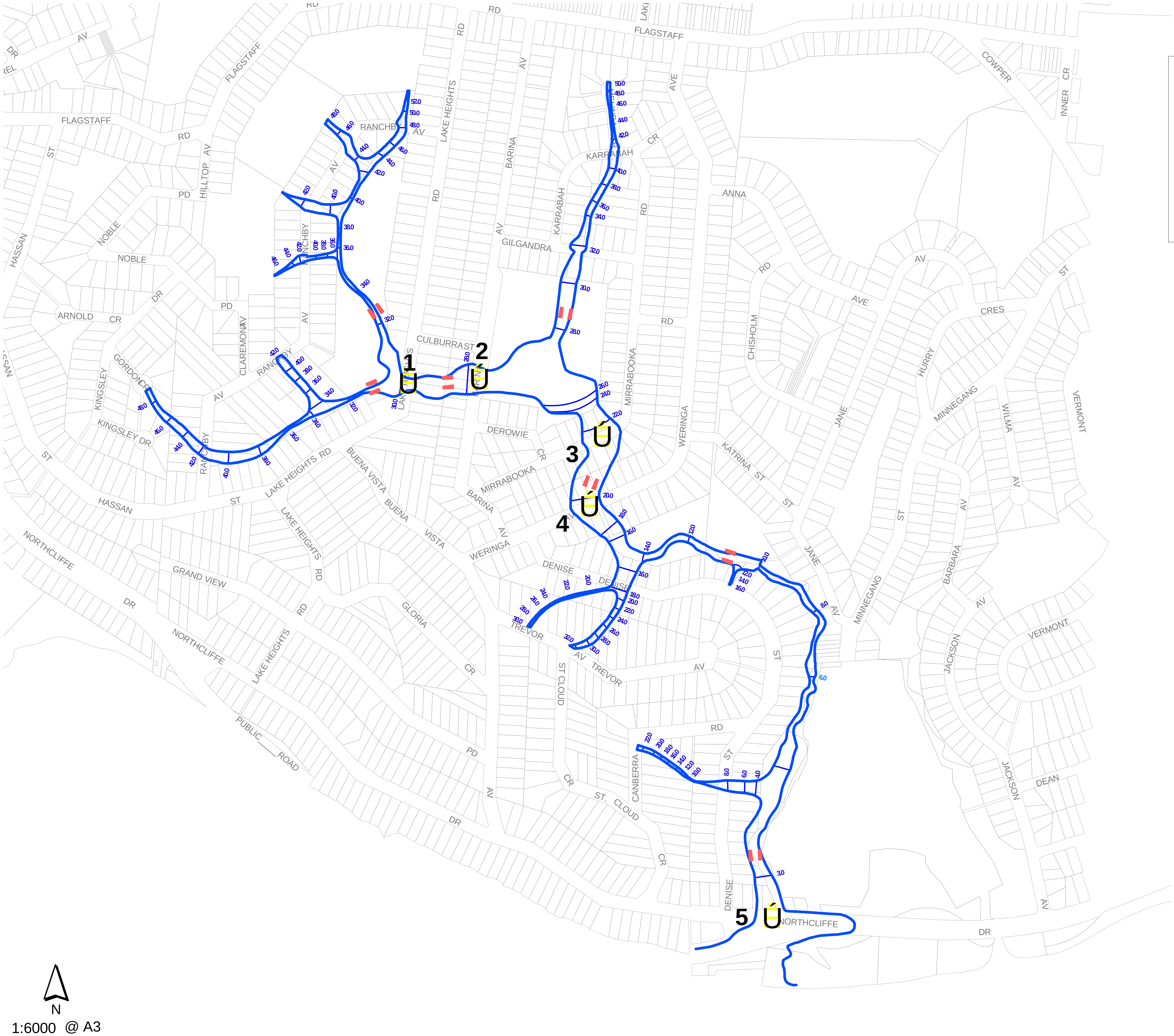
4.3.5 Zone 5: Downstream of Barina Park

The properties downstream of Barina Park, located on Weringa Avenue and Mirrabooka Road, have a high risk of flooding and the majority of properties affected by above-floor flooding within the catchment lie within this zone. Significant flows overtop the basin in Barina Park in all design events considered, ranging from 7.2 - 23.5 m^3/s for the 20% AEP and 1% AEP events respectively. These flows then travel overland through this zone. There is no defined overland flow path, and as a result the floodwaters travel through properties and houses. Flood flows in this zone have significant depths (ranging between 0.5 - 0.8 m for the 20% AEP and 1% AEP events respectively) and reasonably high velocities (in the order of 1.0 m/s).

4.3.6 Zone 6: Minnegang Creek

The impacts of flooding within this area of the catchment are small. Due to the steep slope of the properties on Denise Street, no above-floor flooding occurs within the zone. Along Minnegang Creek, the depth of flooding over the properties is significant and flow velocities are reasonably high.

Previously proposed works for this area include gabion walls along the eastern bank adjacent to the housing commission estate and a low flow pipeline following the alignment of the creek. It is understood that these channel works were not approved and thus have not been implemented to date. The works are unlikely to be considered again or undertaken in the future.



LEGEND

- Flow location (peak flows shown on figure)
- Road crossings (peak flood depth shown in table below)
- 1% AEP flood contours
- 1% AEP flood extent

Figure 4-2

OVERVIEW OF EXISTING FLOOD BEHAVIOUR

Minnegang Creek Floodplain Risk Management Study

4.3.7 Zone 7: Upstream of Lake Illawarra

There are significant flooding problems in this area of the catchment. In all events, the modelling indicates that flows from Minnegang Creek overtop Northcliffe Drive (refer to Figure 4-2 for depths of flooding).

This was confirmed by the community consultation, which indicates that Northcliffe Drive is flooded two to three times per year. This leads to closure of the road, which is an issue given the importance of the Northcliffe Drive for access to the suburbs around Lake Illawarra.

The *Lake Illawarra Flood Study* (Lawson & Treloar 2000) indicates that if Lake Illawarra is flooded, then Minnegang Creek will be flooded by Lake Illawarra for several hundred metres upstream of the confluence of the lake and the creek. Therefore, in storm events over the whole of the Illawarra region, when Lake Illawarra floods, mitigation options in Minnegang Creek will be ineffective at preventing flooding within this zone as backwater flooding from Lake Illawarra is the predominant cause of inundation. It is relevant to note that although Northcliffe Drive is the major thoroughfare through this area, alternative access routes on higher ground are available in the event that it were to become impassable due to flooding. Therefore, this situation does not present a critical emergency management issue.

4.3.8 Zone 8: Ranchby Avenue tributaries

Flows in this part of the catchment are small and shallow. However, no overland flow paths have been provided to convey the flows. The flows therefore lead to property flooding, although two houses on Ranchby Avenue are affected by minor above-floor flooding in a 20% AEP event.

4.3.9 Zone 9: Lower catchment tributaries

The characteristics of floodwaters in Zone 9 are similar to those in Zone 8, discussed in the previous section. Despite the small and shallow flows, external property damage from floodwaters is a problem due to the absence of defined overland flow paths. One house on Trevor Avenue is affected by minor above-floor flooding.

4.4 POPULATION AFFECTED BY FLOODING

Due to the contained nature of the flood flows within the catchment, only a relatively small number of properties within the catchment are affected by flooding.

Table 4-1 shows the number of properties affected by flooding for each different design flood event. It should be noted that the third column includes properties affected by above-floor flooding.

Most properties along the overland flow paths (whether formally defined or not) are affected by yard flooding. However, the number of properties where a significant level of damage would occur due to yard flooding has been assessed to be much less and these are the properties shown in Table 4-1. The number of properties where above-floor flooding occurs is minimal and the majority of these (14 out of 20) are located directly downstream of the Barina Park detention basin.

Table 4-1 Number of properties affected by flooding

Event	Above-floor flooding	Property flooding (incl. above-floor flooded properties)
20% AEP	5	35
5% AEP	13	43
2% AEP	17	44
1% AEP	17	48
PMF	20	59

Many properties that back onto Minnegang Creek in the lower part of the catchment are subject to yard flooding but, with houses generally built on the street front and the land falling away towards the creek, are not affected by above-floor flooding. Other flood-affected properties lie within informal overland flow paths, above sections of the piped drainage system. The ground is generally much flatter in these locations, floor levels are lower and therefore the properties are at risk of above-floor flooding once the piped system capacity is exceeded and floodwaters divert overland. In these locations the consequences of flooding are more serious.

Other residents of the catchment, though not directly affected by floodwaters inundating their properties, are impacted indirectly through the effects of flooding on infrastructure and other facilities. In larger flood events significant flows pass over some roads within the catchment, particularly Lake Heights Road, Barina Avenue, Mirrabooka Road, Weringa Avenue and Northcliffe Drive (refer Figure 4-2). These flows would lead to short road closures. It should be noted, however, that alternative routes are available to access all parts of the catchment and adjoining areas, therefore road closures are not considered to create a significant emergency management problem.

4.5 COMMUNITY AND CULTURAL ISSUES

The community of the Minnegang Creek catchment has experienced several significant floods over the last few decades as well as minor flooding events. Flooding and its effects within the catchment raise several important issues in relation to the community, which are discussed below.

4.5.1 Hazards to human life

As discussed in Section 3.2.3, intangible damages play a very important role in policy decisions and the development of management options. One of the most important components of intangible damages is the consideration of the likely loss of life and/or injuries resulting from flooding.

Within the Minnegang Creek catchment, significant hazards exist during flood events. These include the:

- depth of flows across roads within the catchment;
- ease of access to all culverts;
- significant depth of ponded water within the Barina Park detention basin; and

- lack of signage in and around Barina Park detention basin warning of the dangers of flash flooding within the basin.

4.5.2 Flood preparedness

Consultation indicated that long-term residents have a higher degree of flood preparedness than residents who are new to the area. Individuals who have resided in the catchment for some time generally have strategies in place to reduce the damages caused by flooding. For example, some residents move their cars from trapped low points when rain falls within the catchment for a certain duration. The community consultation indicated that some new residents are unaware of the flooding problems within the catchment, and are sceptical that floods could affect their properties.

4.5.3 Social profile and socio-economic effects of flooding

The social profile of the Minnegang Creek catchment has been developed from ABS data from the 1996 census (ABS 2000).

Approximately half of the population of the Minnegang Creek catchment was born in Australia. Of those born outside of Australia, only a small number are from the main English-speaking countries (ie. Canada, Ireland, New Zealand, South Africa, UK and USA). This leads to a high proportion of residents who speak a language other than English (approximately 50%). Most of the residents in the catchment are long term residents, with 80% of the population having lived at the same address for at least 5 years prior to the 1996 census.

The unemployment rate for residents of the catchment was 14% in 1996. This rate is higher than the average unemployment rate of 12.3% for the Wollongong LGA and 9.5% for NSW (Wollongong City Council 2001).

The socio-economic level of the community is important in determining its ability to cope with and to recover after a flood event. Some members of the Lake Heights community are in a poor position to withstand the financial consequences of flooding. However, in many cases residents may not be able to afford to move to a flood-free area. This creates an undesirable situation for residents who must periodically suffer from flooding, and yet cannot afford the consequences. Of particular concern in the Minnegang Creek catchment is the location of parts of Bundaleer Estate, which is a Department of Housing medium-density residential estate. Bundaleer Estate is located within Zone 6 adjacent to the lowest reach of Minnegang Creek, to the north of Northcliffe Drive.

Under current conditions, houses in the estate are considered to be reasonably well protected from flooding by fences adjacent to Minnegang Creek. However, if these fences were damaged then above-floor flooding is likely to occur at two properties in a 1% AEP event.

4.5.4 Community consultation

Community consultation has been undertaken as part of the floodplain risk management process with the aim of collecting data, both recorded and anecdotal, about flooding within the catchment. It has also aimed to disseminate information regarding flooding within the catchment and the actions being taken by Council to reduce the effects of flooding.

To date, community consultation and participation in the floodplain risk management process has included:

- requests for community representatives to be members of the FRMC for the catchment in early 2001;
- community newsletter sent to residents in the catchment in September 2001;
- display of the draft flood extent maps on Level 6 of the Council Administration Building in October 2001;
- residents' meeting to confirm the results of the draft Flood Study and to collect extra information about flooding in the catchment in November 2001;
- second community newsletter to inform residents of draft floodplain management options being considered for the catchment, distributed in August 2003;
- display of flood extent map, flood risk precinct map and preliminary floodplain management options at Wollongong City Library, Warrawong District Library and Wollongong Council Administration Building throughout September 2003; and
- a public information session at Illawarra Yacht Club on Saturday 13 September 2003.

Participation levels by the community in these programs have been low. This has been partially attributed to external factors. Many of the community members work full time, especially in shift work, which would reduce their availability to attend community meetings. Other considerations for the level of participation of the residents of the area may be lack of English skills. Community newsletters produced during the Flood Study were multilingual. Other information produced during the floodplain risk management process has been printed in English. This may act as a barrier to participation in community consultation programs.

Many of the residents of the catchment have lived in the area for a number of years and have experienced a number of flood events. Some residents have attempted to address the flooding problems at their properties by the erection of walls, fences and/or other structures to modify flood flows. Many of these structures have not been subject to Council approval and as such represent ad-hoc solutions to flooding within the catchment, with the potential to exacerbate flooding in other areas.

Other results of the community consultation indicate that the community would support improvements to the environmental and aesthetic features of Minnegang Creek, if this can contribute to a reduction in flooding.

The Barina Park detention basin is unfavourably perceived by the community members who participated in the community workshop. Residents are primarily concerned about the dangers of the basin embankment collapsing, although there is currently no known reason to question the stability of the embankment. Concerns were also raised about the length of time taken for the basin to drain after rainfall.

Community feedback on the floodplain management options recommended by this study is further discussed in Section 7.4.

4.5.5 Heritage

A search of the NSW State Heritage Register and NSW State Heritage Inventory found no listed heritage items within the suburb of Lake Heights.

Due to the disturbed nature of the catchment, it is unlikely that any items of indigenous heritage would be affected by flooding in the catchment or by the construction of proposed mitigation options. This should be further investigated prior to implementation of any scheme of mitigation options.

4.6 CURRENT FLOOD WARNING AND EVACUATION PROCEDURES

Flood emergency management measures for the Wollongong LGA are documented in the *Wollongong City Local Flood Plan* (SES 2003) (Local Flood Plan), currently in draft form, which is a sub-plan of the *Wollongong Local Disaster Plan* (DISPLAN).

Due to the short response time for the Minnegang Creek catchment, a characteristic that is common to all catchments in the Wollongong area, the possibilities for flood warning are extremely limited. Currently, no catchment-specific warnings are issued. When severe weather warnings are issued for the whole of the Wollongong area, then public safety messages are issued through the media for the entire region.

The response of the SES is generally limited to residences that suffer above-floor flooding or are isolated by floodwaters. This is due to the scale of flooding within the Wollongong area. Therefore, the SES does not generally respond to calls for help where flooding is limited to the property and does not cause above-floor flooding.

Community awareness of flood-related issues is addressed through information brochures about flooding sent to ratepayers. However, there are a significant number of properties within the Minnegang Creek catchment where the ratepayers are not the occupiers of the property, for example rented or housing commission properties. The occupiers of these properties would therefore not necessarily receive flood information and consequently may have a lower degree of flood preparedness.

4.7 ANNUAL AVERAGE DAMAGE

In summary, the total AAD for the Minnegang Creek catchment under existing conditions was determined to be $63,600. The damage assessment summary is provided in Appendix I.

5 Mitigation Measures

5.1 INTRODUCTION

This section discusses possible mitigation measures to be implemented within the Minnegang Creek catchment to alleviate the existing flooding problems. It has been structured to present details of mitigation options with respect to floodplain management in general. This section also presents specific details about the application of the measures to the Minnegang Creek catchment.

5.2 FLOODPLAIN RISK MANAGEMENT MEASURES

Potential mitigation options for the Minnegang Creek catchment have been developed from commonly accepted floodplain risk management measures. The FMM divides floodplain risk management measures into three categories. Each of these categories is discussed below.

5.2.1 Flood modification measures

The purpose of flood modification measures is to change the behaviour of the flood itself, by reducing flood levels, velocities and/or extents of inundation. These measures have been previously known as "structural" measures. They aim to reduce the threat to existing properties exposed to floodwaters.

As flood modification measures involve structural works to modify the floodwater behaviour, they tend to be costly to implement and can have significant impacts on the environment. They are therefore generally only used to address existing flooding problems, rather than prevent flooding for new developments.

Flood modification measures described in the FMM are:

- flood mitigation dams
- retarding basins
- levees
- bypass floodways
- channel modifications
- floodgates.

The only measures that can be practically implemented in the Minnegang Creek catchment involve retarding basins and channel modifications. Due to the small size, steep topography and highly developed nature of the catchment, there is very limited scope for implementing any of the other flood modification measures.

5.2.2 Property modification measures

Property modification measures aim to impose development controls and modify existing properties in the floodplain to reduce the damages caused by flooding. These measures were previously referred to as "non-structural" measures in the *Floodplain Development Manual* (NSW Government 1986). Property modification measures can be effective in ensuring that there is no future growth in flood damages. This is achieved by preventing inappropriate development of the floodplain and by limiting potential damages to reasonable levels. Property modification measures referred to the FMM include:

- land zoning
- voluntary purchase
- house raising
- flood proofing
- flood access
- development controls.

Council has advised KBR that for voluntary purchase to be considered feasible, the property must suffer from above-floor flooding in a 5% AEP event. In addition, the depth of above-floor flooding must be greater than 1 m in the 1% AEP event.

Aside from these guidelines for voluntary purchase, each of the above measures is feasible to implement within the Minnegang Creek catchment.

5.2.3 Response modification measures

These measures aim to change the reaction of the community to flooding within a particular catchment. The risk of flooding will not be completely eliminated by flood modification measures or property modification measures unless they are developed for the PMF. It is therefore important that the continuing flood risk is recognised by the community and that measures are implemented to reduce the personal danger and property damage associated with this risk (NSW Government 2001).

Typical response modification measures are:

- flood education
- flood prediction and warning
- local flood plans
- recovery planning.

Community education and recovery planning have been further examined in Section 6.11.

5.2.4 Mitigation measures applicable in the Minnegang Creek catchment

Table 5-1 presents a summary of the mitigation measures that have been considered for the Minnegang Creek catchment, and provides a qualitative assessment of their applicability.

5.3 METHODOLOGY FOR OPTIONS ASSESSMENT

Overall, the primary objectives of the floodplain management options should be that:

- they reduce the impact of flooding and flood liability on land owners and occupiers;
- they do not cause flood conditions elsewhere in the catchment to worsen over existing conditions, and
- the growth in flood damages is contained by ensuring that new development takes into account the susceptibility of land to flooding.

The effects of the proposed mitigation options on flooding within the catchment have been assessed under a number of criteria. These criteria are described below.

5.3.1 Hydraulic performance

The hydraulic performance of the option, or combination of options, is important in determining the effectiveness of the option in reducing flooding within the catchment. Hydraulic performance has been determined through consideration of peak flood levels, flows and velocities as indicated by the MIKE 11 modelling.

For the schemes of mitigation options, hydraulic performance has been categorised by considering the impacts of the schemes on:

- flood levels, by using peak height profiles for the 1% AEP event; and
- the amount of flood affected land, by using plan views showing the extents of inundation.

5.3.2 Economic assessment

As described in Section 3, AAD has been adopted to quantify the damages resulting from flooding within the Minnegang Creek catchment. This is a measure of the cost of flood damages that could be expected, as a long term average, each year.

A flood mitigation proposal may be considered to be economically feasible if the benefit-cost ratio is greater than one. This is achieved when the present value of benefits (in terms of flood damages avoided) exceeds the present value of costs of implementing the proposal (both capital costs and ongoing costs). However, this does not account for social impact and safety issues, which may warrant a lower benefit-cost ratio.

The present value of the benefits has been calculated using an expected life of 50 years for the mitigation options and a discount rate of 7%. Calculations have also been carried out for the discount rates of 4% and 10% to assess the sensitivity of the calculated present value to the adopted discount rate.

Table 5-1 Mitigation measures considered for Minnegang Creek catchment

Option	Zones considered	Improvement in flood levels / flows / velocities	Potential reduction in flood damages	Cost	Environmental / Social issues	Practical to implement
Flood modification measures						
Augmentation works to Barina Park detention basin	4	Good if land is available for significant volume increase	Good if peak basin discharge is reduced	High	Improvement in water quality depending on detention times Disruption to playing fields during construction	Yes
Channel widening	6	Good	Good	High	Opportunities for aesthetic and ecological improvement, channel disturbance	May require voluntary purchase for sufficient land
Channel regrading	6	Will reduce flood levels if flow is currently reduced by invert levels	Good	High	Sediment transport changes Channel disturbance	Yes
Channel lining	2,4,5,6	Reduction in flood levels Increase in velocities and downstream flows	Good	High	Habitat loss Reduction in aesthetic amenity Safety issues due to higher velocities	Yes
Channelisation of existing piped system	2, 4, 5	Flood extents reduced as flow contained in channel	Good	High	Opportunities for environmental improvements Safety issues due to open channel	May require voluntary purchase for sufficient land
Clearing channel vegetation	1, 6, 7, 8	Reduction in flood levels Increase in flow velocities	Good	Low	Habitat loss Increased erosion	Possibly but would require regular creek maintenance
Road lowering	5,9	Reduction in flood extents over road	None, unless part of a larger scale floodway/ overland flow route	High	Increased likelihood of road being closed in floods Increased damage to road during floods	Depending on services under road and levels of adjacent properties
Culvert modifications	1,2,7	Good in smaller events but poor in larger events Potential blockage is an issue	Poor, as damages are more significant for larger events	High	Increased scour downstream of culvert	Depending on required size and scope of work
Piped network amplification	2,3,5,8,9	Negligible for large events	Poor as damages are more significant for larger events	High	May disrupt private property during construction	Yes

Option	Zones considered	Improvement in flood levels / flows / velocities	Potential reduction in flood damages	Cost	Environmental / Social issues	Practical to implement
Property modification measures						
Development controls - filling	All zones	Filling to reduce flood levels at individual properties	Good if channel works prevent increases in flooding due to loss of storage	Low	May make land development unattractive due to increased works required for development Filling within floodway s may exacerbate flooding	Limited due to degree of existing development in catchment
Development controls - floor levels, building materials	All zones	None	Good	Low	May make house construction more expensive Risk to personal safety remains	Limited due to degree of existing development in catchment
Development controls - fencing	All zones	Reduction in flood levels, reduction in flow diversions	Poor as more effective in small events	Low	Loss of privacy Loss of current level of protection at individual properties	Yes
Development controls - flowpaths (easements)	All zones	None, but restricts future blockage	None	Medium	Need to purchase defined flowpaths	Depends upon required geometry
Voluntary purchase	2,5	Facilitates implementation of other structural and non-structural measures	Good	High	Long term residents may not want to sell Improved open space Opportunity for ecological benefits (eg. vegetated buffer zone) Risk to personal safety eliminated	Yes however may require a long time frame Also need to consider Council's criteria for VP and potential to gain funding
House raising	2,5	None	Good for building damage, poor for property damage	High	Short term disruption to residents Makes housing impractical for elderly/disabled residents Risk to personal safety remains	Depends on house type
Flood proofing	All zones	None	Good for building damage, poor for property damage	Medium	None Risk to personal safety remains	Depends on house type
On-site stormwater detention (OSD)	All zones	No improvement from existing flooding or in larger flood events	Negligible	Costs to developers	Need to ensure existing or future property owners aware of and committed to OSD maintenance	Limited due to degree of existing development in catchment
Zoning	All zones	None	Good	None	Good if land is zoned for public recreation	Limited due to degree of existing development in catchment

Option	Zones considered	Improvement in flood levels / flows / velocities	Potential reduction in flood damages	Cost	Environmental / Social issues	Practical to implement
Response modification me asures						
Community education	All zones	None	Good if residents are aware of likely flow paths	Low	Possible modifications to community behaviour may lead to increased environmental and flood awareness	Yes
Emergency management planning	All zones	None	None	Low	Improved flood response from both community and emergency services due to better knowledge and understanding of local flooding issues	Yes

To determine the capital cost of the proposed mitigation options, unit construction rates have been adopted. These unit rates are based on typical industry values for the greater Sydney area (Rawlinsons 2002) as well as unit rates recommended by Council. The adopted unit rates have been listed in Appendix D.

5.3.3 Qualitative assessment

Each floodplain management option was also assessed qualitatively to determine its advantages, disadvantages and feasibility. Criteria that were considered in this assessment included:

- social impact, public safety and general community acceptance
- impact on the general health of Minnegang Creek
- visual impacts
- other environmental impacts (erosion, siltation, flora and fauna, heritage and noise)
- engineering feasibility or difficulties
- impact on emergency response management.

The potential for acid sulfate soils to exist within the Minnegang Creek catchment has been previously identified. This factor should be considered in the final design of any mitigation options recommended in this report. Where possible, the design of flood mitigation works should avoid the disturbance of any potential acid sulfate soil sites, as well as avoiding changes to the natural water table levels throughout the catchment. This last point is most relevant in relation to any proposed lowering of existing creek bed levels.

6 Modelling, Results and Discussion of Investigations

6.1 INTRODUCTION

This section presents the options for flood mitigation within the Minnegang Creek catchment that have been investigated in detail.

Each option and its rationale have been described. Specific issues related to individual mitigation options have been highlighted in the relevant sections below. The results of the hydraulic modelling of each option as well as the economic and qualitative assessment have been presented for each zone. Finally, recommendations for the most effective mitigation measures for each zone have been made.

Appendix E presents details of changes made to the MIKE 11 model to represent each of the mitigation options. Appendix E also contains the full details of the number of flood affected properties for each option.

Hydrologic modelling of the catchment is unchanged from the *Minnegang Creek Flood Study* (KBR 2002). Therefore a brief summary of the RAFTS hydrologic model which was set up for the Flood Study has been provided in Appendix F. Full details of the hydrologic modelling were presented in the Flood Study report (KBR 2002).

Hydraulic modelling was undertaken using the MIKE 11 model that was set up as part of the Flood Study. The only modifications to the MIKE 11 model for the current study involve the more practical application of Council's *Conduit Blockage Policy* (Wollongong City Council 2002) as discussed in Section 3.3.6. A summary of the MIKE 11 model set up for the Flood Study is given in Appendix G. Full details of the MIKE 11 modelling were provided in the Flood Study.

It is important to note that the hydraulic modelling undertaken for this study is at a level of detail for concept design and the costs for each option are indicative. Detailed design of options adopted as part of the Floodplain Risk Management Plan would be required. In general, detailed design would have to consider issues such as:

- detailed survey in the vicinity of the works
- the location of services
- transitions to natural surface levels
- regrading of roads to ensure that low points are aligned with works
- quantities and costing.

6.2 ZONE 1: UPSTREAM OF LAKE HEIGHTS ROAD

6.2.1 Rationale

The attenuation provided by the Lake Heights Road culvert helps to reduce the flood flows downstream of Lake Heights Road. Despite the advantages provided by the culvert in terms of flow attenuation, it is not considered reasonable to increase the storage available at this location as the area upstream of the culvert is too small to justify the works.

The main problems associated with the ponding of flows behind the Lake Heights Road culvert are the depth of ponded water and the frequency of road overtopping. Safety in this area is an issue due to the depths of water, both across the road and upstream of the culvert.

One option is to install flood depth indicators and signs. Community education programs could also be implemented to increase community awareness of the flooding risks in the area.

Due to the size of the culvert (1.2 m diameter), the possibility of a person being washed into the culvert must also be considered. To prevent this, the existing handrail over the culvert could be extended to reduce access to the area upstream of the culvert. There are some distinct disadvantages associated with this alternative. Handrails above structures can become blocked in a flood event. If the handrail were extended, this would decrease the effective flow area above the culvert in the case of blockage, leading to an increase in flood levels upstream of the culvert and exacerbating the current flooding. This is an undesirable situation. The second disadvantage associated with increased fencing at this location would be the increased difficulty for emergency services to access the area upstream of the culvert, should a person need to be rescued from the area. Thus increased fencing at this location is not recommended.

6.2.2 Modelling methodology and hydraulic performance

The options proposed for Zone 1 were not modelled in MIKE 11.

6.2.3 Economic evaluation

The costs associated with installing signs at this location would be minimal and no ongoing costs would be incurred.

Due the small size of the catchment, a single community education program would be relevant to the whole catchment. Identification of the flooding problems in Zone 1 would comprise only one part of any program. Therefore the costs for community education would not be attributed to this zone individually.

6.2.4 Qualitative assessment

Installation of signs and flood depth indicators is a slightly controversial issue within residential areas. Signage would have benefits in increasing the awareness of flooding within the catchment. It would also be effective in increasing safety during flood events, as residents and visitors to the area would have an indication of the depth of flow over Lake Heights Road.

Limited previous examples of warning signs and depth indicators being used within urban residential areas were found during research for this study. One project in New Zealand found that the installation of flood danger signs led to complaints by residents that the signs were "too obvious" (Kingsbury 2000). This feedback was primarily from residents trying to sell their properties. Vandalism of the signs would also be a risk.

6.2.5 Recommendations

No works are recommended for implementation in Zone 1.

6.3 ZONE 2: UPSTREAM OF BARINA AVENUE

6.3.1 Rationale

The capacity of the channel and piped drainage system downstream of Lake Heights Road is inadequate and the flood waters pass through several properties. Flooding within this zone is a major problem due to the lack of a defined overland flow path through the properties fronting Barina Avenue.

Significant ponding of floodwaters occurs at the headwall at the start of the piped drainage system. This is due to the configuration of the headwall with respect to the surface levels of the surrounding area. Any changes to the piped drainage system would only be effective in small storm events and therefore have not been considered further.

Options in this zone are based on the provision of an overland flow path to convey flows from downstream of Lake Heights Road to the Barina Park detention basin.

An easement exists within the property at 68 Barina Avenue, adjacent to the boundary with 66 Barina Avenue. This easement is located above the existing stormwater pipes within the property.

Investigations were made to assess the feasibility of directing overland flows along this easement. Due to the magnitude of the flows in this area, a concrete lined rectangular channel would be required to convey the flows within the available space. To contain a significant proportion of the flows, the channel would have to be approximately 1 m deep and 2 m wide. The house on the 68 Barina Avenue is located very close to the easement. Therefore the creation of a concrete channel would significantly impact on the house and residents. It would also affect the existing piped drainage system under the easement. Therefore this option is not recommended and has not been investigated further.

Three options for Zone 2 have therefore been based on providing an overland flow path through the zone by voluntary purchase and subsequent demolition of the house and shed at 68 Barina Avenue and creating a floodway through the resulting vacant block.

The floodway has been sized to convey the flow for events up to the 1% AEP event without flood extents impacting on adjacent properties. Associated with the floodway, it would be necessary to augment the existing pipe (1.2 m diameter) or provide a culvert under Barina Avenue to convey the flow to Barina Park. The hydraulic modelling indicates that flows would continue to pass over Barina Avenue in events larger than the 20% AEP event.

The house at 68 Barina Avenue is constructed on piers and the walls are constructed from cladding. House raising would therefore be feasible for this building. As this is the only property that suffers from above-floor flooding in this zone, for events smaller than the PMF, this would then be effective in reducing the damages for the zone. This was investigated as Option Z2-4.

A summary of each option that was investigated in this zone is provided below:

- Option Z2-1 examines the creation of a grass-lined floodway, with 1V: 4H side slopes over the full width of property, two new 1.5 m diameter culverts under Barina Avenue and continuation of the floodway to convey flows into Barina Park;
- Option Z2-2 proposes the construction of a rock-lined channel through the property, two new 1.5 m diameter culverts under Barina Avenue and continuation of a floodway to convey flows into Barina Park;
- Option Z2-3 considers the resulting vacant block at 68 Barina Avenue with no further works; and
- Option Z2-4 investigates house raising at 68 Barina Avenue.

Each of the four options is illustrated in Figure 6-1.

6.3.2 Hydraulic performance

Voluntary purchase and demolition of the property at 68 Barina Avenue (Option Z2-3) results in a slight reduction (100 - 200 mm) of peak flood levels for larger events in this zone, due to removal of the house which currently obstructs flow. If a floodway or channel is provided (Options Z2-1 or Z2-2) then flood levels are reduced downstream of Lake Heights Road to Barina Avenue. This reduction is due to the regrading of the invert levels along the creek bed, to remove the ponding that currently occurs upstream of the start of the piped drainage system (ie. upstream of 68 Barina Avenue). Neither Option Z2-1 or Z2-2 has a significant affect on flood levels within Barina Park for large flood events. In more frequent events, such as the 20% AEP event, the reduction in flood levels within Barina Park is sufficient to slightly reduce flood levels downstream of the basin due to a reduction in flow over the embankment.

Construction of a channel results in ponding of water upstream of Barina Avenue. For large events, flows over Barina Avenue are virtually unchanged from existing conditions. Two new 1.5 m diameter culverts would have sufficient capacity to convey the 20% AEP event under Barina Avenue.

Velocities of the floodwaters in this zone would be impacted by the proposed modifications associated with Options Z2-1 and Z2-2. Velocities upstream of 68 Barina Avenue would be slightly increased, whilst directly upstream of Barina Avenue velocities would decrease due to ponding at the culverts.

If Option Z2-3 were to be implemented then flood levels would be reduced in the immediate vicinity of 68 Barina Avenue as a result of the removal of fences and other obstructions to flow. There would be no further reductions in flood levels upstream or downstream of this property.

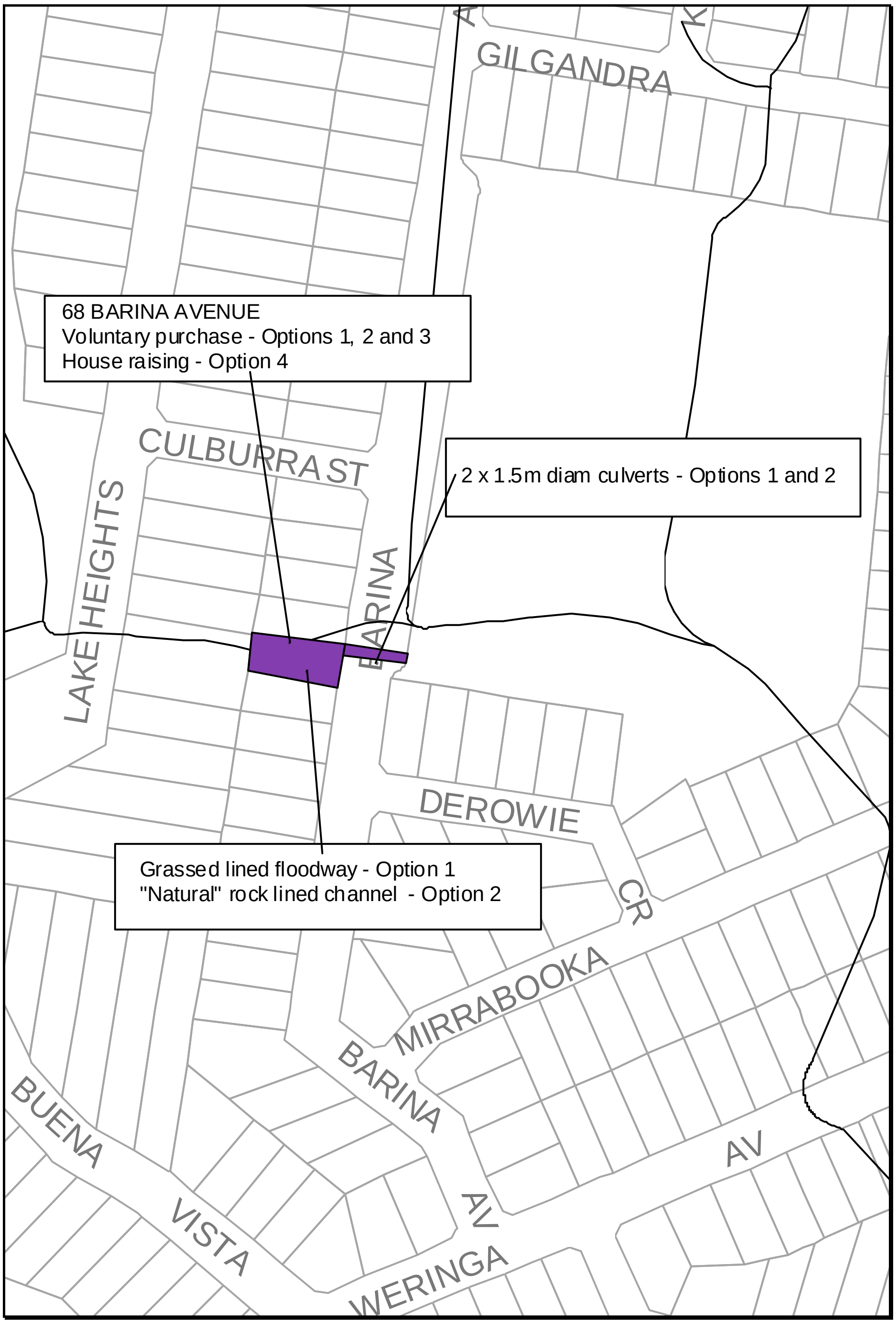


Figure 6-1 Zone 2 Management Options

Option Z2-4 does not lead to any changes in the flood behaviour. However, reductions to the damages caused by flooding are achieved by increasing the floor level of the flood affected house.

6.3.3 Economic evaluation

The benefits and costs of each of the options for this zone are presented in Table 6-1.

Table 6-1 Economic evaluation of options for Zone 2

Option Name	Z2-1	Z2-2	Z2-3	Z2-4
AAD	$47,700	$47,200	$56,600	$58,900
Net present worth of benefit (compared to existing conditions)	$220,000	$230,000	$100,000	$70,000
Estimated cost	$433,000	$522,000	$260,000	$54,000
Benefit-cost ratio	0.51	0.44	0.38	1.29

The property at 68 Barina Avenue does not meet Council's voluntary purchase criteria, as the depth of flooding is approximately 0.5 m in the 1% AEP event. This is reflected in the low benefit-cost ratios for options in this zone involving voluntary purchase.

6.3.4 Qualitative asse ssment

Only a limited section of the community is currently affected by flooding within this zone. The major impacts of the proposed mitigation options would be felt by the residents of 68 Barina Avenue, who would be affected either by house raising or voluntary purchase. House raising allows the residents to remain in their property to which they may have strong sentimental attachment. However, as property flooding would not be eliminated the residents would still suffer from the costs and stress associated with flooding.

Table 6-2 shows the number of properties in the catchment affected by above-floor and below-floor flooding and the effects of each of the Zone 2 options on the total number of affected properties.

Table 6-2 Number of properties affected by flooding for Zone 2 mitigation options

Option Name	Properties affected by above-floor flooding					Total properties affected by flooding (above or below-floor)				
	PMF	1%	2%	5%	20%	PMF	1%	2%	5%	20%
Existing Conditions	20	17	17	13	5	59	48	44	43	35
Zone 2 Option 1	19	16	14	11	4	57	46	41	39	31
Zone 2 Option 2	19	16	14	11	4	57	46	41	39	31
Zone 2 Option 3	19	16	16	12	4	57	47	43	42	33
Zone 2 Option 4	19	16	16	12	4	59	48	44	43	35

Community concerns could result from required modifications to Barina Park to match the proposed channel and culvert structures into the natural surface levels within the park. This would not be required for Options Z2-3 and Z2-4, and therefore these options may be more attractive from this perspective. However, with adequate landscaping around any proposed works at 68 Barina Avenue or within Barina Park, there would only be limited impact on the visual amenity of the area from each of the options.

Changes to the flow regime of Minnegang Creek, such as increased ponding, would result from each of the first three options. However, the creek is piped under this location at present, so any further changes would not impact on the *natural* state of the creek. Scour within Barina Park downstream of the proposed culverts could be a concern and suitable scour protection would be required.

It is not envisaged that the proposed works would have any long term impacts on flora and fauna or the heritage value of the area. There would be some impacts (noise, erosion and sedimentation) during construction of the proposed options, but these could be eliminated or reduced using appropriate mitigative measures.

6.3.5 Recommendations

Raising of the house at 68 Barina Avenue is the only economically viable alternative for this zone. This option would also cause only relatively limited social disruption. Therefore, Option Z2-4 is recommended for implementation.

6.4 ZONE 3: MELINDA GROVE TRIBUTARY

6.4.1 Rationale

Options to address flooding within this zone are limited by the highly developed nature of the area. No options have been proposed to address the flooding which occurs along the boundaries of the properties between Karrabah Crescent and Mirrabooka Road. This is because flows are small and shallow and damages are minimal. Damage in this zone from previous flood events has been limited to the fences along the boundaries between properties on Karrabah Crescent and Mirrabooka Road. Development controls on fencing types may reduce future damages if redevelopment occurs in the area.

This zone contains one of the areas with existing flooding problems that have been identified in the catchment. This is where the Minnegang Creek tributary passes under Gilgandra Street. At present a 3 m wide easement exists along the western boundary of 7 Gilgandra Street. The only option proposed for this zone is to widen this to a 4 m wide easement, with a view to containing the flows within a defined overland flow path, and hence reducing the flood damage at this property. This would involve the construction of a concrete v-drain along the easement, with a depth of approximately 0.5 m, the removal of the carport and shed, which are currently located along the boundary of the property, and removal of the concrete driveway. This option is shown in Figure 6-2.

Community education is also a viable option in this zone, with the aim of educating residents on likely flow paths through their properties. This would apply to residents on Karrabah Crescent, Mirrabooka Road and Gilgandra Street.

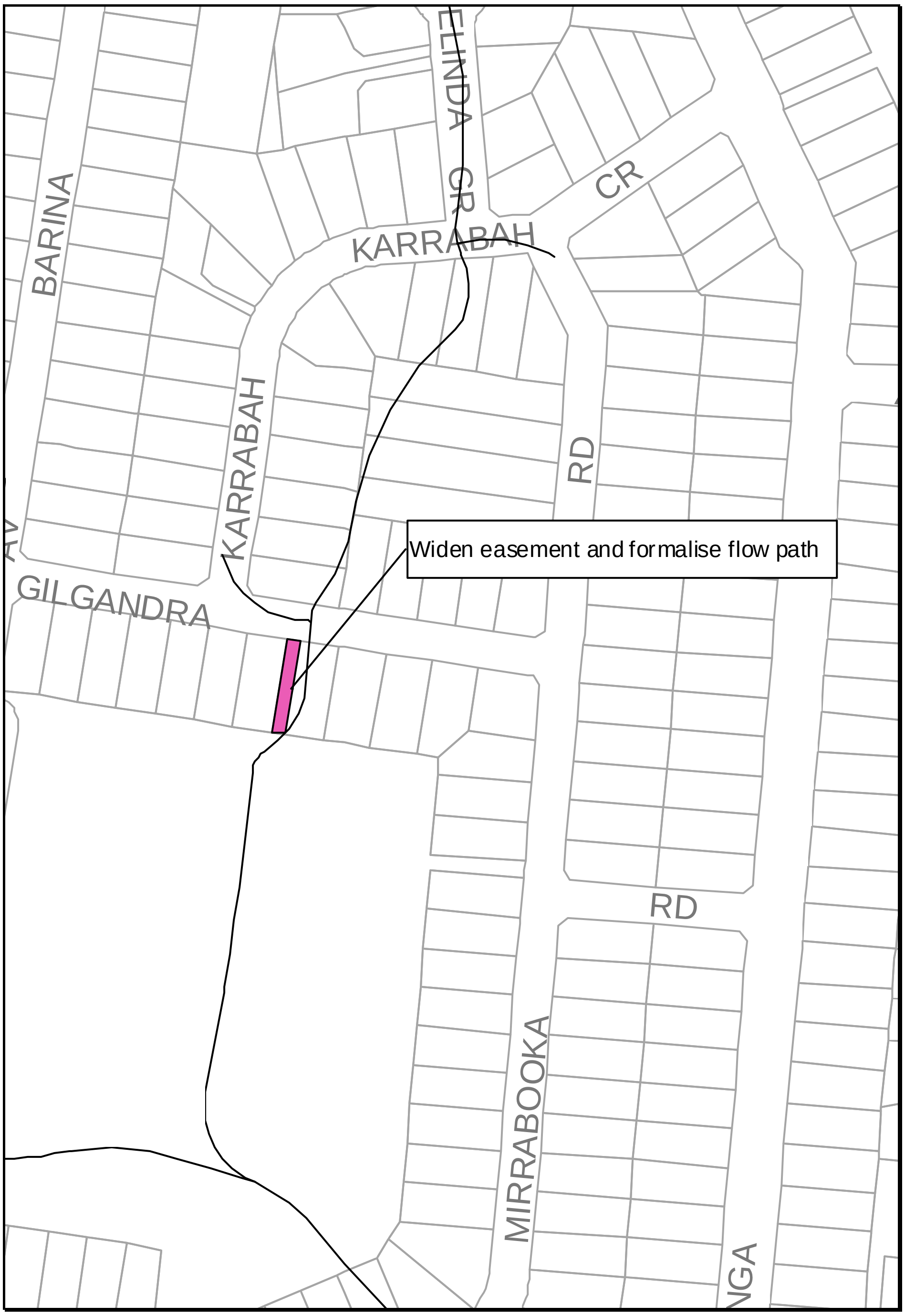


Figure 6-2 Zone 3 Management Options

6.4.2 Hydraulic performance

Construction of the concrete drain leads to a decrease in flood levels at 7 Gilgandra Street. The decrease in flood levels would be sufficient to prevent external property flooding at this location in all events up to and including the PMF event.

The modelling indicates that the drain would lead to effectively no changes to peak flood flows or the timing of the peak through this part of the catchment. This means that the changes would have no impact on flood levels or flows within Barina Park or downstream of the detention basin embankment.

6.4.3 Economic evaluation

Modelling of the option shows that the damages suffered by the residents at 7 Gilgandra Street would be completely eliminated by the construction of the proposed mitigation options. However, the reduction in total damages for the catchment is negligible due to the minimal damages for existing flooding in this zone. Therefore the present value of benefits of the option is zero and hence the benefit-cost ratio is also zero for this option.

The proposed works would cost approximately $7,700 to construct.

6.4.4 Qualitative assessment

Due to the localised nature of the proposed mitigation options for this zone, there are no significant adverse impacts associated with the option. The general community would not be impacted by the proposed option. The existing easement is currently covered by a concrete driveway and carport. Therefore there would be limited on the visual amenity of the area from the proposed option, as the concrete driveway would be replaced by a concrete v-drain. The property owners of 7 Gilgandra Street would experience a reduction in external property damages but would also lose effective property area and amenity value.

6.4.5 Recommendations

The assessment indicates that the proposed option of a concrete v-drain through an extended easement within 7 Gilgandra Street is not economically feasible and has uncertain social benefits. Furthermore, it is likely that flooding on the Melinda Grove tributary would be considered a *local drainage* issue (as defined in the FMM) by DIPNR and therefore outside the scope of flood risk management works to be considered for State funding.

Community education, as part of a catchment-wide program, would be a viable option for reducing the actual damages in a flood event and this area should be one of the focus areas of any education programs that are developed for the catchment. Community-wide flood education is discussed further in Section 6.11.

6.5 ZONE 4: BARINA PARK DETENTION BASIN

6.5.1 Rationale

Three options have been investigated to augment the capacity of the Barina Park detention basin and are shown in Figure 6-3.

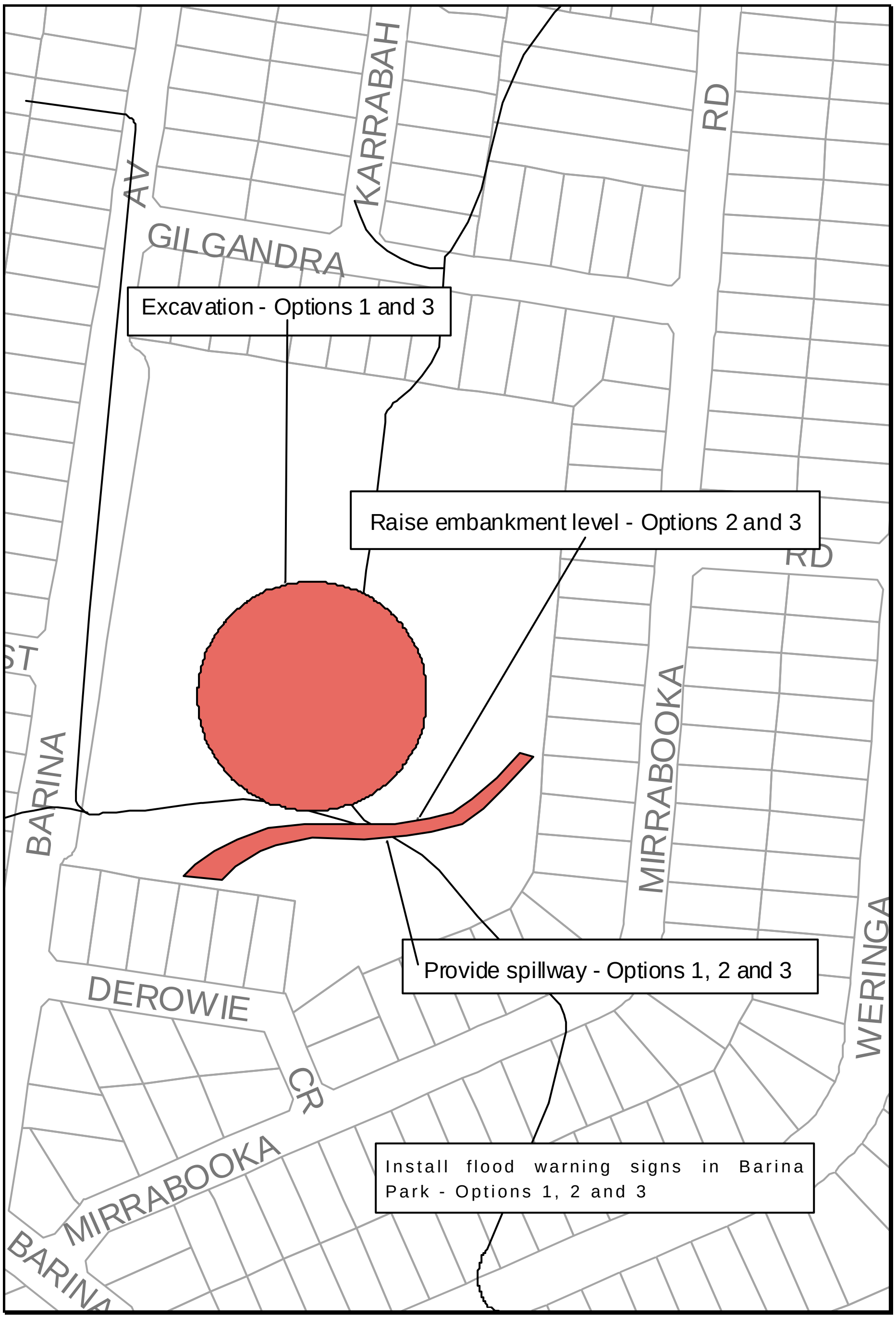


Figure 6-3 Zone 4 Management Options

The three options are as follows:

- Option Z4-1: excavation to increase the storage capacity
- Option Z4-2: raising of the basin embankment to increase storage capacity
- Option Z4-3: a combination of the above two options.

Option Z4-1 investigates the effects of excavation. The proposed excavation would maintain the invert level of the basin at the current level but increase the area over which water is stored within the playing fields. The storage volume of the basin could be increased from approximately 5,400 m^3 to 11,000 m^3. This is only a preliminary sizing for the basin and does not consider the required grading within the basin to allow the playing fields to be retained.

Option Z4-2 was modelled with the height of the basin embankment increased to RL 27.0 m from RL 26.5 m. This increases the area over which water is stored within the basin. A level of 27.0 m was adopted for the embankment crest level as this ensures that water stored within the basin would not extend into Barina Avenue and would not affect properties upstream of the basin.

Option Z4-3 models the effects of increasing the embankment height to RL 27.0 m and also excavating within the playing fields to further increase the available storage volume.

All three options would involve the installation of warning signs to alert park users that the area is subject to flash flooding following heavy rainfall. All options would also include the provision of a spillway to direct flows over the basin embankment.

6.5.2 Hydraulic performance

Table 6-3 summarises the hydraulic impacts of augmentation of the Barina Park detention basin. All three options would have a positive impact in reducing the peak discharge over the embankment.

The time to peak flow would be substantially increased for the more frequent events, indicating a significant improvement in the attenuation capacity of the basin. As clear culverts and pipes may be assumed in the 20% AEP event, the basin has sufficient capacity to detain this event following implementation of any of the options.

In larger events, the reduction in peak flows and increased time to peak flow would have beneficial effects downstream of the basin as the flood levels would be substantially decreased. This would reduce the damages suffered by properties on Mirrabooka Road and Weringa Avenue. There is little change in the PMF flows downstream of the basin.

There would be no impact on properties upstream of the basin and the extent of flooding resulting from the new basin configurations would be confined to the existing area of Barina Park.

6.5.3 Economic evaluation

Table 6-4 shows a comparison of the benefits and costs of each option for augmenting the capacity of the detention basin. The benefit-cost ratios show that increasing the level of the basin embankment is the most attractive alternative, although none of the options can be justified from a purely economic viewpoint.

Table 6-3 Hydraulic performance of Barina Park detention basin

	Existing	Option Z4-1	Option Z4-2	Option Z4-3
Embankment crest (mAHD)	26.5	26.5	27.0	27.0
Storage volume (m^3)	5400	11075	9300	17900
20% AEP Performance				
Peak Water Level (mAHD)	26.65	26.52	26.72	26.55
Peak Discharge (m^3/s)	0.5	0	0	0
Time to Peak Flow (min)	78	n/a	n/a	n/a
5% AEP Performance				
Peak Water Level (mAHD)	26.98	26.92	27.41	27.35
Peak Discharge (m^3/s)	15.1	10.6	7.9	5.2
Time to Peak Flow (min)	45	51	57	81
2% AEP Performance				
Peak Water Level (mAHD)	27.03	26.97	27.45	27.40
Peak Discharge (m^3/s)	19.3	14.2	12.7	7.4
Time to Peak Flow (min)	45	48	51	69
1% AEP Performance				
Peak Water Level (mAHD)	27.06	27.01	27.50	27.42
Peak Discharge (m^3/s)	23.5	18.2	17.2	9.6
Time to Peak Flow (min)	45	48	48	60
PMF Performance				
Peak Water Level (mAHD)	27.43	27.41	27.98	27.95
Peak Discharge (m^3/s)	51.4	50.4	50.5	48.7
Time to Peak Flow (min)	42	45	45	45

Notes:

1. 'Peak Discharge' and 'Time to Peak Flow' refer to the peak flow in each event over the detention basin embankment

2. Modelling assumes the basin outlet is blocked in events larger than the 20% AEP event

Table 6-4 Economic evaluation of options for Zone 4

Option Name	Z4-1	Z4-2	Z4-3
AAD	$50,300	$54,000	$43,700
Net present worth of benefit (compared to existing conditions)	$190,000	$130,000	$280,000
Estimated cost	$530,000	$234,000	$632,000
Benefit-cost ratio	0.36	0.56	0.44

The cost to raise the level of the basin embankment is difficult to determine at this stage. One of the preliminary costs associated with these works would be geotechnical investigations to determine the nature and suitability of the material from which the existing embankment is constructed. The final costs to raise the embankment would depend on the results of these investigations.

6.5.4 Qualitative assessment

There are a number of factors to consider associated with augmentation of the detention basin in Barina Park.

Safety is one of the major issues related to increasing the storage capacity of the basin. The safety of the community is affected in two main ways. Option Z4-2 leads to increases in the depth of stored water within the basin. A recommended maximum depth of water for detention basins is 1.2 m (IEAust 1985) where suitable land is available. However, the depth of water in the Barina Park detention basin is approximately 2.5 - 3.0 m under existing conditions. IEAust (1985) recommends that in this case suitable safety provisions such as fences and warning signs should be provided. Therefore all three options would involve such safety provisions, although these would be more important for Options Z4-2 and Z4-3 where the maximum depth of water increases to 3.5 m in the PMF event.

Safety of the residents downstream of the basin also needs to be considered in case of failure of the basin embankment. Increased storage volumes upstream of the embankment will cause much more significant flooding downstream of Barina Park if failure were to occur. This would primarily affect properties on Mirrabooka Road and Weringa Avenue. If options to augment the basin were to be adopted, then a hazard rating for the basin in accordance with ANCOLD guidelines and the NSW Dams Safety Committee guidelines (DSC 2002) would need to be determined for the new basin arrangement.

The safety of the residents occupying properties on Mirrabooka Road and Weringa Avenue that lie in the direct path of floodwaters which overtop the basin must play a major role in determining the optimum flood mitigation strategy for both Zone 4 and Zone 5. It may be necessary to adopt mitigation options with benefit-cost ratios of less than one to ensure the safety of residents downstream of the basin.

At present, when the basin is overtopped, water spills over the embankment along most of its length. Works in Zone 4 could also reduce the extent of the flood hazard downstream by providing a defined spillway on the basin embankment to ensure high level outflows are directed along any channels or floodways proposed in Zone 5. An allowance for such spillway works has been included in the costing for all options. The spillway has not been modelled however this would be required for detailed design of any proposed works for the basin.

Works within the detention basin provide an opportunity to enhance the dual use of the basin. Currently the playing fields in the basin are often closed after rain in the catchment due to the poor drainage of the fields. If excavation were to be undertaken then it is recommended that subsoil drainage should be installed to improve the drainage of the fields after rain. Grading of the playing fields within the basin is also important to ensure adequate drainage. Costs for subsoil drainage have not been included in the costing of options. Detailed design of the basin would also need to consider the required size and layout of the playing fields to ensure that the grounds are a useful resource for the community.

Table 6-5 shows a decrease in the number of properties affected by above-floor flooding following implementation of the Zone 4 options. Although this is partially reflected in the economic assessment of the options, there are also significant positive but intangible impacts that are not accounted for in the economic evaluation.

Table 6-5 Number of properties affected by flooding for Zone 4 mitigation options

Option Name	Properties affected by above-floor flooding					Total properties affected by flooding (above or below-floor)				
	PMF	1%	2%	5%	20%	PMF	1%	2%	5%	20%
Existing Conditions	20	17	17	13	5	59	48	44	43	35
Zone 4 Option 1	20	14	12	9	5	59	45	41	38	33
Zone 4 Option 2	20	15	13	10	5	59	46	43	40	33
Zone 4 Option 3	20	10	9	8	5	59	42	37	37	34

6.5.5 Recommendations

If works to this zone are considered in isolation from the remainder of the catchment, then Option Z4-2 is the most economically feasible. However, changes to the detention basin will have impacts on the mitigation options to be considered in Zone 5, immediately downstream of the detention basin. The interaction between these two zones is further discussed in Section 7.

6.6 ZONE 5: DOWNSTREAM OF BARINA PARK

6.6.1 Rationale

An overland flow path is the key requirement in this zone, to convey flows from downstream of the detention basin in Barina Park to the start of the open section of Minnegang Creek, downstream of Weringa Avenue. Flows for the 20% AEP event and larger events spill over the embankment of the detention basin and therefore must be directed to Minnegang Creek along a defined flow path.

As for Zone 2, house raising or voluntary purchase of properties could be implemented to reduce the damages resulting from flooding within this zone. House raising would prevent flood flows passing through houses although property flooding would still occur, and the risk to personal safety inherent with residing within a floodway would remain.

Table 6-6 shows the properties affected by above-floor flooding within Zone 5 and assesses their suitability for house raising. House raising is generally only considered economically feasible for timber-framed houses constructed on piers. The maximum depth of above-floor flooding has also been included in the assessment of the feasibility of house raising. Where the depth of above-floor flooding is negligible for the 1% AEP event it was considered that the potential reduction in flood damage would not be significant enough to justify house raising as a feasible mitigation option at that particular property.

It should be reiterated that house raising would not provide a formal overland flow path. However, a voluntary purchase scheme would provide space for the construction of a dedicated flow path, and the current risks imposed on the population inhabiting the floodplain in this part of the catchment would be removed. In order to ensure sufficient space for the conveyance of floodwaters along a dedicated flow path, six properties must be purchased (42, 63, 65 Mirrabooka Road and 96, 98, 99 Weringa Avenue).

Table 6-6 Feasibility of house raising within Zone 5

Property	Wall construction	Foundation	Maximum above-floor flooding depth		House raising feasible?
			1% AEP	PMF	
40 Mirrabooka Road	Cladding	Piers	0.1 m	0.4 m	Yes
42 Mirrabooka Road	Brick	Piers	0.5 m	0.8 m	No
61 Mirrabooka Road	Brick	Slab on ground	0.1 m	0.5 m	No
63 Mirrabooka Road	Cladding	Piers	0.6 m	1.0 m	Yes
65 Mirrabooka Road	Cladding	Piers	0.8 m	1.2 m	Yes
67 Mirrabooka Road	Cladding	Piers	0.6 m	1.0 m	Yes
69 Mirrabooka Road	Cladding	Piers	0.3 m	0.7 m	Yes
71 Mirrabooka Road	Cladding	Piers	0	0.1 m	No
97 Weringa Avenue	Fibro	Piers	0.1 m	0.5 m	Yes
98 Weringa Avenue	Fibro	Piers	0.2 m	0.6 m	Yes
99 Weringa Avenue	Cladding	Piers	0.2 m	0.6 m	Yes
100 Weringa Avenue	Cladding	Piers	0.1 m	0.5 m	Yes
101 Weringa Avenue	Fibro	Piers	0.1 m	0.4 m	Yes
102 Weringa Avenue	Brick Veneer	Piers	0	0.1 m	No

Table 6-7 shows that none of these properties meet Council's primary criteria for voluntary purchase, mainly due to the depth of above-floor flooding for the 1% AEP event being less than 1.0 m. However, beyond the primary criteria there are other reasons why voluntary purchase remains a valid and appropriate option for flood mitigation in Zone 5. Most importantly these include:

- the current lack of a dedicated flow path through a residential area; and
- extremely short flood warning times - the time between the start of spilling over the basin embankment and peak flood levels through Zone 5 is in the order of 10-15 minutes for all design flood events, with floodwaters rising at a rate of approximately 0.1 m/min during this time.

Table 6-7 Properties considered for voluntary purchase

Property	Frequent above-floor flooding? (5% AEP event)	Depth of above-floor flooding (1% AEP event)	Meets voluntary purchase criteria?
42 Mirrabooka Road	Yes	0.5 m	No
63 Mirrabooka Road	Yes	0.6 m	No
65 Mirrabooka Road	Yes	0.8 m	No
96 Weringa Avenue	No	0	No
98 Weringa Avenue	Yes	0.2 m	No
99 Weringa Avenue	Yes	0.2 m	No

One property (96 Weringa Avenue) is not significantly flood-affected but would be a necessary acquisition in order to create the space necessary to open up a dedicated floodway through Zone 5.

A major constraint on the creation of an overland flow path through Zone 5 is the location of Mirrabooka Road and Weringa Avenue. The flow path needs to allow water to cross these roads. This could be achieved by the construction of culverts under the roads (Option Z5-1 and Z5-2) or by converting the existing 1.35 m diameter pipe under each road to a culvert (Option Z5-6).

Culverts under the roads could be avoided in two ways. The first technique would be to construct the floodway by using levees along the property boundaries. This would prevent excavation of a channel and therefore avoid the need for culverts under Mirrabooka Road and Weringa Avenue. The second alternative would be to create a continuous open channel extending from Barina Park to Minnegang Creek. Both options would require permanent closure of Mirrabooka Road and Weringa Avenue to traffic adjacent to the channel.

Preliminary sizing indicated that a floodway would need to be approximately 30 m wide, based on an assumption of 0.5 m high levees. This would require the purchase of ten properties within the zone. Due to the topography of the area, any levees would need to be prefabricated to reduce the required footprint. The construction of levees would also require flood flows to pass over the roads. There would also be considerable drainage problems associated with the conveyance of local runoff collecting outside the levees. It is likely this would lead to localised flooding at some properties. Due to these problems, levees are not considered a feasible option and were not further investigated.

The existing 135 m diameter pipe from Barina Park to Minnegang Creek places constraints on the creation of an overland flow path. This pipe is close to the surface throughout the zone, with cover of less than 100 mm in some locations. Options involving excavation for a channel would require the removal of this pipe. Option Z5-6 investigates removing the pipe, except for the sections that pass under Mirrabooka Road and Weringa Avenue, which would be retained as culverts.

Options investigated for this zone are as follows:

- Option Z5-1: voluntary purchase of 42, 63 and 65 Mirrabooka Road and 96, 98 and 99 Weringa Avenue, and construction of a grassed floodway with culverts sized for the 20% AEP event under Mirrabooka Road and Weringa Avenue.
- Option Z5-2: voluntary purchase of 42, 63 and 65 Mirrabooka Road and 96, 98 and 99 Weringa Avenue, and construction of a rock lined channel with culverts sized for the 20% AEP event under Mirrabooka Road and Weringa Avenue.
- Option Z5-3: voluntary purchase of 42, 63 and 65 Mirrabooka Road and 96, 98 and 99 Weringa Avenue with no associated construction works.
- Option Z5-4: house raising at properties affected by above floor flooding, where feasible (as listed in Table 6-6).
- Option Z5-5: voluntary purchase of 42, 63 and 65 Mirrabooka Road and 96, 98 and 99 Weringa Avenue and construction of a rock lined channel from Barina Park to

Minnegang Creek. This option assumes that Mirrabooka Road and Weringa Avenue would be permanently closed to traffic to avoid the need for culverts.

- Option Z5-6: voluntary purchase of 42, 63 and 65 Mirrabooka Road and 96, 98 and 99 Weringa Avenue, and construction of a channel using the existing 135 m diameter pipes to convey water under Mirrabooka Road and Weringa Avenue.

Each of these options is illustrated in Figure 6-4.

6.6.2 Hydraulic performance

Options Z5-1 to Z5-3, which involve voluntary purchase, lead to a reduction in flood levels upstream of Weringa Avenue and also at the downstream extent of the zone, where the piped drainage system discharges to Minnegang Creek. For Options Z5-1 and Z5-2, this is partially due to the effects of regrading the inverts along the flow path through this zone.

Two 1.5 m diameter culverts under Mirrabooka Road and under Weringa Avenue would have sufficient capacity to convey the 20% AEP event. In other events, ponding due to the assumed blockage elevates flood levels upstream of the culverts, although this does not represent an increase relative to existing conditions.

Option Z5-3 leads to a reduction in flood levels from Barina Park to Mirrabooka Road. Flood levels are unchanged directly upstream of Weringa Avenue. However, flood levels decrease from existing conditions within the properties between Weringa Avenue and the start of the Minnegang Creek.

Option Z5-5 also leads to a substantial reduction in flood levels between Barina Park and Weringa Avenue. This is due to the drop in invert levels to create a formalised channel along the flow path. Immediately upstream of the existing headwall at the start of Minnegang Creek, flood levels are increased due to the need to regrade this area to continue the constant slope of the channel from Barina Park.

In the case of Option Z5-6, the existing 1.35 m diameter pipes can convey approximately 5 m^3/s. This leads to flows of approximately 2 m^3/s over Mirrabooka Road and Weringa Avenue in the 20% AEP event. Some slight ponding occurs upstream of the culverts. In the remainder of Zone 5 flood levels are significantly decreased from existing conditions due to the reduction in invert levels.

Velocities along the channel are reasonably high and constant along the length of the channel. Velocities range from approximately 1.5 m/s to 3.0 m/s for the 20% AEP to PMF events respectively.

6.6.3 Economic evaluation

Table 6-8 shows the net present value and the cost of each of the options for the zone. Each of the options leads to a benefit-cost ratio in the order of 0.21 to 0.52.

Figure 6-4 Zone 5 Management Options

Table 6-8 Economic evaluation of options for Zone 5

Option Name	Z5-1	Z5-2	Z5-3	Z5-4	Z5-5	Z5-6
AAD	$31,900	$33,000	$36,900	$43,500	$32,500	$33,000
Net present worth of benefit (compared to existing conditions)	$440,000	$420,000	$370,000	$280,000	$430,000	$420,000
Estimated cost	$1,962,000	$1,936,000	$1,551,000	$541,000	$2,006,000	$1,883,000
Benefit-cost ratio	0.22	0.22	0.24	0.52	0.21	0.22

6.6.4 Qualitative assessment

The assessment of options within this zone needs to consider the safety of the population residing within the floodplain downstream of the Barina Park detention basin. Although this is obviously a key consideration for flood mitigation options in all situations, it is particularly relevant here due to the lack of a dedicated flow path through this residential area, very short flood warning times and the magnitude of flood flows which spill from the Barina Park detention basin.

House raising would reduce above-floor flooding and associated damages, reduce the danger to personal safety and reduce post-flood trauma for residents. A voluntary purchase scheme would eliminate all flooding for the worst affected properties, eliminate trauma and the danger to personal safety for the worst affected residents, and reduce trauma and danger for surrounding residents. However, the additional benefits of voluntary purchase clearly come at a greater cost.

Options Z5-1, Z5-2 and Z5-6 rely on culverts to pass flow under the roads in the zone. The culverts modelled in Options Z5-1 and Z5-2 have sufficient capacity to convey the 20% AEP event without flow passing over the roads. The smaller pipes modelled as the culverts for Option Z5-6 lead to overtopping of the roads in the 20% AEP event. The maximum flow is approximately $2m^3/s$. This corresponds to a width of flow across the road of approximately 20 m and a maximum flow depth of around 100 mm.

Options Z5-2, Z5-5 and Z5-6 would require less land than Option Z5-1 to create a channel to convey the 1% AEP event. More land would therefore be available to landscape the areas adjacent to the channel. This could have positive impacts in encouraging the community to enjoy the creek and its surrounds.

Option Z5-5 requires closure of Mirrabooka Road and Weringa Avenue. Mirrabooka Road is generally only used by local traffic. Weringa Avenue on the other hand is often used as a thoroughfare through Lake Heights. Its closure may therefore impact on significant parts of the community. Council does not support this option.

It can be seen from Table 6-9 that all of the options lead to significantly fewer houses being affected by above-floor flooding. This will have extensive positive impacts on the social intangible damages resulting from flooding within the catchment, as well as those tangible damages which are reflected in the economic assessment.

Table 6-9 Number of properties affected by flooding for Zone 5 mitigation options

Option Name	Properties affected by above-floor flooding					Total properties affected by flooding (above or below-floor)				
	PMF	1%	2%	5%	20%	PMF	1%	2%	5%	20%
Existing Conditions	20	17	17	13	5	59	48	44	43	35
Zone 5 Option 1	7	5	5	5	4	47	37	33	31	27
Zone 5 Option 2	7	5	5	5	4	47	37	34	32	28
Zone 5 Option 3	13	7	7	6	4	51	41	37	35	31
Zone 5 Option 4	11	7	7	6	4	59	48	44	43	35
Zone 5 Option 5	6	5	5	5	4	44	33	31	30	28
Zone 5 Option 6	7	5	5	5	4	47	37	34	32	28

There are limited adverse environmental impacts associated with the proposed options in Zone 5, due to the existing highly developed nature of the area. The most significant impacts, other than relocation of residents, would result during construction and would only be temporary in nature. It is expected that these impacts (other than relocation and road closures) could be reduced or eliminated through the implementation of appropriate mitigation measures.

As noted in the hydraulic assessment of the options, velocities are expected to increase downstream of Weringa Avenue in Minnegang Creek. The properties at 11 and 13 Denise Street already suffer from erosion along the rear property boundaries due to the current flow and morphological regime in Minnegang Creek. Increased velocities may exacerbate this problem without the use of appropriate bank protection and/or stabilisation measures. These types of issues would need to be addressed at the detailed design stage.

6.6.5 Recommendations

It is recommended that a voluntary purchase scheme and the associated creation of a dedicated flow path from Barina Park to Minnegang Creek be implemented for Zone 5. Options Z5-2 and Z5-6 are recommended for further consideration. Option Z5-5 is not recommended due to Council's lack of support.

The damages and hence benefit-cost ratios for this zone are highly dependent on the flows from Barina Park. Therefore, the recommended option needs to be considered in conjunction with works to Barina Park to establish the most feasible scheme for the catchment. This is further discussed in Section 7.

6.7 ZONE 6: MINNEGANG CREEK

6.7.1 Rationale

There are opportunities in this area (refer Figure 6-5) to improve the aesthetics and ecology of Minnegang Creek by undertaking clearing and replanting works for the vegetation in the area. The creek is currently very overgrown, mainly with weed species. These works would aim to improve the visual amenity and ecological values of the area and to provide some reduction in flood levels along the creek due to a reduction in hydraulic resistance and corresponding increase in flow conveyance.

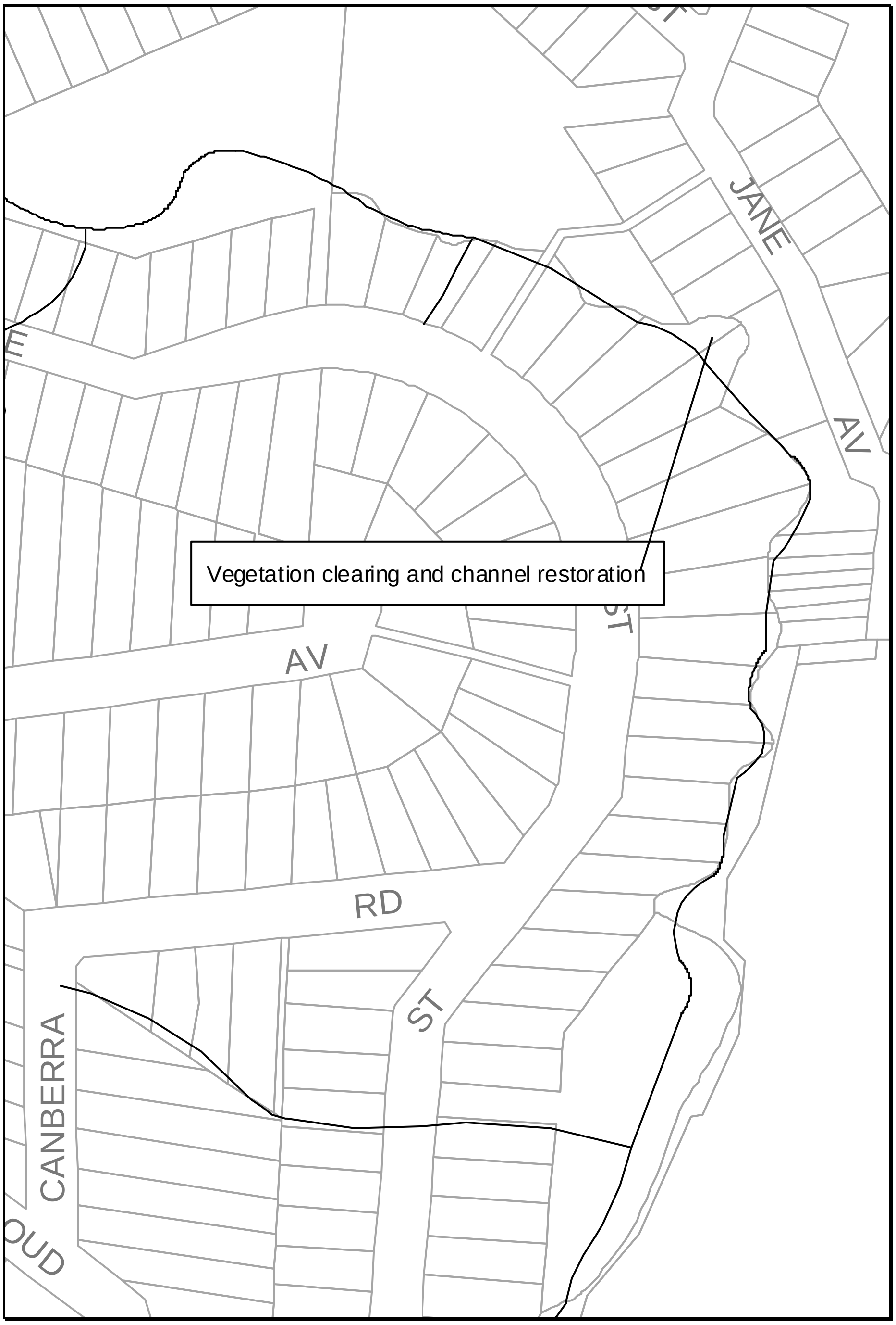


Figure 6-5 Zone 6 Management Options

6.7.2 Hydraulic performance

The proposed Option Z6-1 leads to a reduction in flood levels within the lower sections of Minnegang Creek by approximately 100 - 300 mm. This is associated with an increase in flow velocity and conveyance along the creek for all flood events.

6.7.3 Economic evaluation

Due to the minimal reduction in flooding at individual properties, there is no reduction in AAD for the overall catchment after the implementation of this option. This leads to a benefit-cost ratio of zero. The proposed option would cost approximately $48,000 to implement.

6.7.4 Qualitative assessment

At present, the vegetation along the creek banks is mainly comprised of weed species and other introduced species. Replanting would provide an opportunity to re-introduce native species to the creek corridor, which would increase the ecological value of the area.

Vegetation works would also improve the visual amenity of the area, which could have positive impacts in encouraging the community to enjoy the creek and its surrounds.

Increases to the velocities within the creek may introduce morphological changes to the creek. Some sections of the creek in this zone are already subject to erosion. The changes to the velocities may exacerbate the existing problems. Creek improvements should therefore be examined holistically with regard to ecological, morphological and social impacts.

6.7.5 Recommendations

While improvements to the vegetation within the creek corridor in Zone 6 have definite positive impacts in terms of increased ecological value and visual amenity, such works cannot be economically justified for the purpose of flood mitigation. Furthermore, the reduction in hydraulic resistance and corresponding increase in flow conveyance would be dependent on continual maintenance. Option Z6-1 is therefore not recommended for implementation.

Creek maintenance works as part of a catchment-wide flood mitigation strategy, which would incorporate some aspects of the works proposed in Option Z6-1, are discussed further in Section 6.11.

6.8 ZONE 7: UPSTREAM OF LAKE ILLAWARRA

6.8.1 Rationale

Analysis of the results of the *Minnegang Creek Flood Study* (KBR 2002) indicates that the culverts in the Illawarra Yacht Club carpark creates a constriction to flow that leads to increased flood levels upstream of the culvert. This is undesirable because it leads to regular flooding over Northcliffe Drive as a result of the small head difference upstream and downstream of the Northcliffe Drive culverts.

Therefore, one of the proposed options for this zone is to remove the culverts from the carpark (Option Z7-1). This would also involve the provision of vehicle access to the carpark directly from Northcliffe Drive to enable continuing use of the area for parking.

The second option investigated for Zone 7 (Option Z7-2) is to augment the capacity of the yacht club culverts. This would reduce the constriction to flow at this location and increase the effectiveness of the Northcliffe Drive culverts. Based on the available space in the vicinity of the existing culverts, a third 1.65 m diameter culvert was investigated to augment the existing structure. This would include associated excavation directly upstream to direct flows through all three culverts.

A third option (Option Z7-3) for this area is to divert flows in excess of the capacity of the yacht club culverts through the yacht club carpark to the west of Minnegang Creek. This would be achieved through the construction of a bypass channel adjacent to Minnegang Creek, downstream of Northcliffe Drive. Existing ground levels elevate this area above surrounding land, however, if the raised areas were removed then high flows could be diverted from Minnegang Creek through the bypass channel to Lake Illawarra. A weir would ensure that flows above a certain level are directed through the bypass channel.

Due to the complex tailwater effects and two-dimensional flood behaviour, Option Z7-3 was not modelled in MIKE 11. It has been assessed qualitatively for comparison with Options Z7-1 and Z7-2.

The three options considered within Zone 7 are shown in Figure 6-6.

6.8.2 Hydraulic performance

Following implementation of either Option Z7-1 or Z7-2, Northcliffe Drive continues to be flooded in all the modelled events. Both Option Z7-1 and Z7-2, reduce the flow over Northcliffe Drive compared to existing conditions in the 20% AEP event. Option Z7-1 is more effective than Option Z7-2 with peak flows of 2 m^3/s and 8 m^3/s respectively. Option Z7-1 leads to lower flood levels than Option Z7-2 for approximately 100 m upstream of Northcliffe Drive and downstream to the confluence with Lake Illawarra. Both options lead to a reduction in flood levels, and a corresponding increase in velocity compared to existing conditions.

It is expected that Option Z7-3 could be as effective as Option Z7-1 or Z7-2 in reducing flood levels and increasing flood conveyance through this zone.

6.8.3 Economic evaluation

Table 6-10 shows that Option Z7-1 is the more economically feasible option for this zone, with a reasonably significant reduction in the AAD for the catchment. Option Z7-2 does not result in any benefits compared to existing conditions over the expected life of 50 years, despite a slight reduction in AAD. This leads to a benefit-cost ratio of zero.

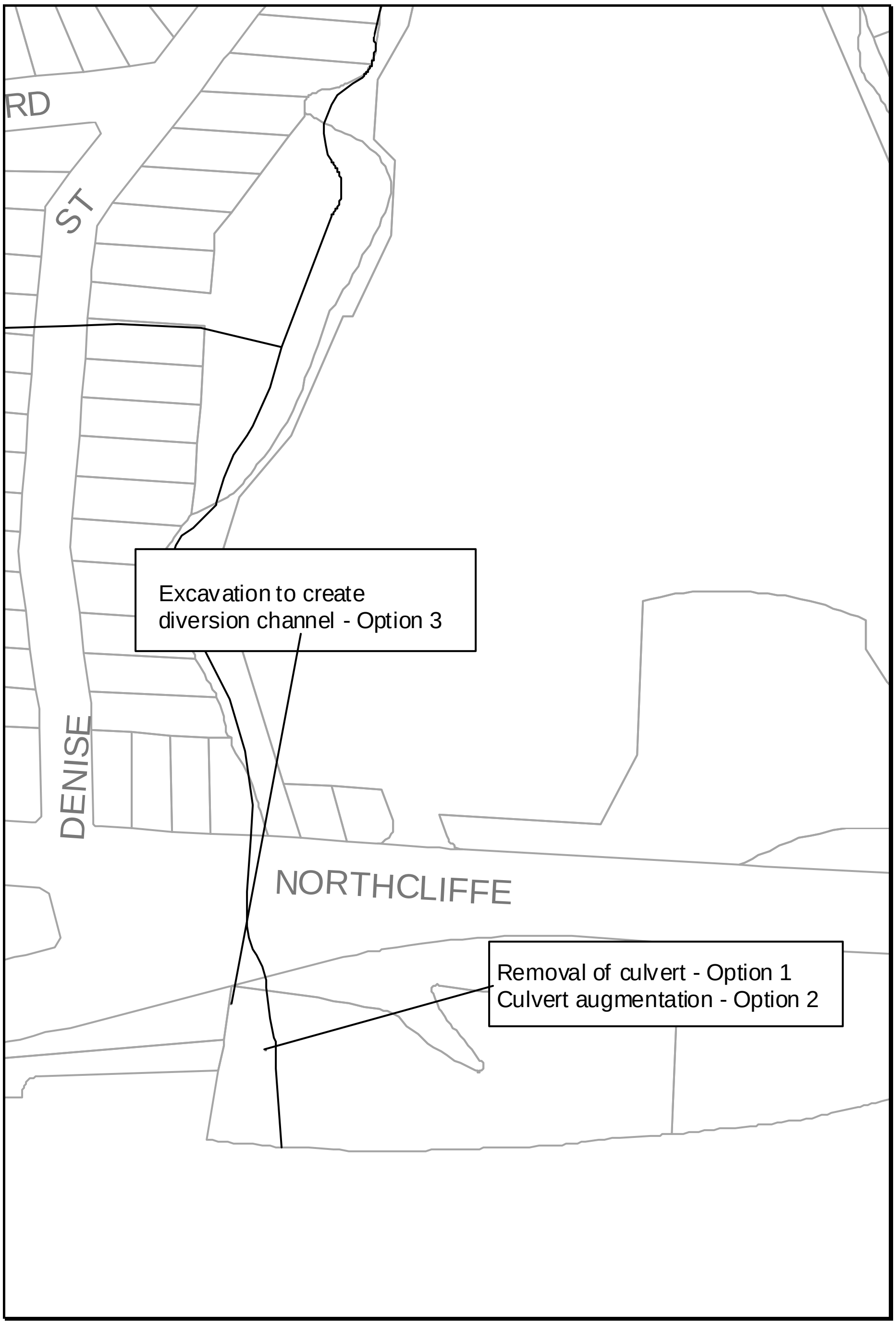


Figure 6-6 Zone 7 Management Options

Table 6-10 Economic evaluation of options for Zone 7

Option Name	Z7-1	Z7-2
AAD	$57,500	$63,500
Net present worth of benefit (compared to existing conditions)	$90,000	$0
Estimated cost	$35,600	$24,300
Benefit-cost ratio	2.53	0

6.8.4 Qualitative assessment

The *Lake Illawarra Flood Study* (Lawson & Treloar 2000) indicates that if Lake Illawarra is flooded, then Minnegang Creek will be flooded by the lake for several hundred metres upstream of the confluence of the lake and the creek. Therefore, for storm events over the whole of the Illawarra region when Lake Illawarra floods, any option in Zone 7 will only have a limited effect.

The primary adverse impact of Option Z7-1 would be on the members of the Illawarra Yacht Club. Access to the Yacht Club building would be more difficult from the carpark if the road over Minnegang Creek were removed. It is uncertain whether this option would be viewed positively by patrons of the Yacht Club. Option Z7-2 would have limited impact on the community and the patrons of the Yacht Club.

Sight distances for the proposed new entrance as part of Option Z7-1 to Northcliffe Drive from the western part of the carpark meet the required standards for carpark exits (Standards Australia 1993).

A reduction of flows and flooding frequency over Northcliffe Drive would have positive benefits for the community. This may also have positive impacts on emergency response management in the Lake Heights area. However, as Northcliffe Drive is also subject to flooding in other locations, outside the Minnegang Creek catchment, a larger scale approach to flood mitigation along Northcliffe Drive may be required.

Both options would result in changes to the nature of Minnegang Creek directly upstream of the existing location of the yacht club culverts. There is significant growth of reeds and other grasses within the creek bed at this location. This is due to the ponding of water upstream of the culvert. If either option were to be implemented, then flows and velocities would increase through this area and may impact on the creek vegetation.

6.8.5 Recommendations

As Northcliffe Drive remains flooded in the 20% AEP event, and there are uncertain social and economic benefits, neither Option Z7-1 nor Z7-2 is recommended for implementation. Option Z7-3 may be feasible but without more detailed hydraulic modelling this option cannot be recommended.

However, the relatively minor levels of damage and other adverse impacts of flooding which occur in the lower part of the catchment under existing conditions create a situation in which there is little potential for significant gains to be made through implementation of flood mitigation works. Flooding in this part of the catchment is also significantly influenced by the behaviour of Lake Illawarra, which would effectively control flooding in this zone for storm events which affect a much larger area than the Minnegang Creek catchment.

For these reasons, further investigation of flood mitigations works in Zone 7 is not recommended.

6.9 ZONE 8: RANCHBY AVENUE TRIBUTARIES

6.9.1 Rationale

Flooding in this zone is isolated and only affects the properties located on tributaries and minor branches of Minnegang Creek. Therefore the options proposed for this zone are designed to reduce the flooding at these properties providing a formalised overland flow path to contain the flow within an easement and hence reduce property damage.

In each case it is proposed that an easement be created along the property boundary where a drain could be constructed. For the first five options, this would not mean significant changes to the flow paths as they exist at present. However for Option Z8-6, the easement should be created through 5 Gordon Crescent, 24 Kingsley Drive and 72 Ranchby Avenue. This would require a significantly different flow path to be constructed. This could not be modelled in MIKE 11. Therefore a qualitative assessment only has been carried out for this option.

Concrete drains were proposed as the most efficient method of conveying flows through private properties and into Minnegang Creek. Although a grass swale would have aesthetic benefits, the increased hydraulic roughness of grass over concrete means that the reduction in flood levels is less than for concrete. This means for the options where the concrete drain does not lead to reductions in the damages from flooding, then a grass swale will also be ineffective at reducing damages. The exception to this occurs for Option Z8-2 at 16 Ranchby Avenue, where the reduction in below-floor flood damages at the neighbouring 14 Ranchby Avenue property is sufficient to justify the investigation of a grassed swale (Option Z8-7).

The concrete v-drain would be 3 m wide and have side slopes of 1V:4H. The details of the options that have been investigated for this zone are as follows:

- Option Z8-1: construct a concrete v-drain approximately 100 m long, through 1 and 2 Ranchby Avenue to join to Minnegang Creek.
- Option Z8-2: construct a concrete v-drain approximately 80 m long, between 14 and 16 Ranchby Avenue to stop at Ranchby Avenue as there is vacant land downstream of Ranchby Avenue.
- Option Z8-3: construct a concrete trapezoidal channel approximately 3m wide, 0.5 m deep and 80 m long, within 21 and 30 Ranchby Avenue to join to Minnegang Creek.
- Option Z8-4: construct a concrete v-drain approximately 40 m long through 29 Ranchby Avenue to join Ranchby Avenue and Minnegang Creek.
- Option Z8-5: construct a concrete v-drain approximately 50 m long through 53 Ranchby Avenue from Ranchby Avenue to Minnegang Creek.

- Option Z8-6: construct a concrete v-drain approximately 100 m long to join Gordon Crescent and Ranchby Avenue.
- Option Z8-7: similar to Option Z8-2, with a grass swale proposed instead of a concrete v-drain.

Each option is shown in Figure 6-7.

6.9.2 Proposed development of Lots 1 & 2, DP 881387, Noble Parade

A development application was approved in late 2000 which allows for the subdivision of the land between Ranchby Avenue, Flagstaff Drive, Hilltop Avenue and Noble Parade. The approved development, proposed by Kenheights Pty Ltd, has thirty eight lots, an increase from the four existing lots covering the area. The proposed lots range in size from 600 m^2 to 1400 m^2.

A Flood Study (Jones Nicholson 2001) has been carried out to assess the impact of the proposal on flooding, both within the development site and further downstream. To ensure that peak flows are not increased above existing conditions, the proposed development includes two detention basins. These basins are located upstream of the tributaries termed RANCHBY1 and RANCHBY2 in the *Minnegang Creek Flood Study* (KBR 2002).

The flows that have been estimated for these tributaries by Jones Nicholson differ from those predicted in the *Minnegang Creek Flood Study*. Basin 1 is sized for a much larger peak flow in the 1% AEP event (2.11 m^3/s) than the peak flow predicted in the RANCHBY2 tributary in the *Minnegang Creek Flood Study* (0.51 m^3/s). Basin 2 (on the RANCHBY1 tributary) is sized for a peak flow of 0.56 m^3/s (for the 1% AEP event). The *Minnegang Creek Flood Study* predicted the 1% AEP peak flow at this location to be 0.66 m^3/s.

Other works proposed as part of the development of this area include the purchase of 20 Ranchby Avenue to create a second access road to the development. This will have no impact on the current Floodplain Management Study as this property is not flood affected. The flows through the vacant block at 42 Ranchby Avenue will be reduced by the new development (Jones Nicholson 2001) due to regrading and the proposed road through which will direct flows out of the development. This may cause increased flows in the minor branch of Minnegang Creek (RANCHBY4 tributary) which drains through 53 Ranchby Avenue.

Any potential benefits from the works proposed as part of this development, have not been considered in the damage assessment for the flooding of the Minnegang Creek catchment due to uncertainty with their eventual implementation.

6.9.3 Hydraulic performance

Each of the options leads to a slight reduction in flood levels in the immediate vicinity of the works. These effects do not extend further downstream into Minnegang Creek for any of the options. Peak flows in each option are also unchanged by the works.

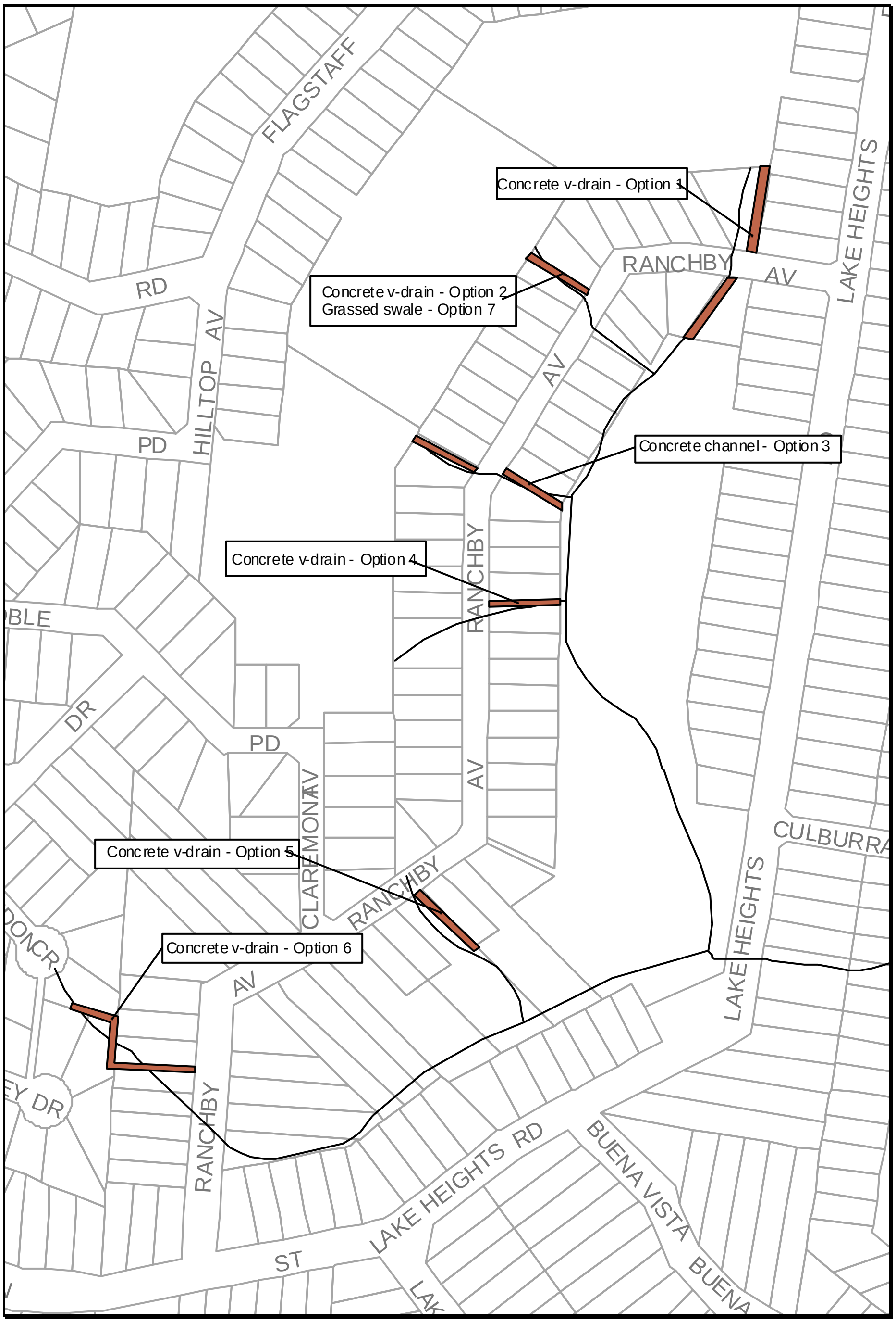


Figure 6-7 Zone 8 Management Options

6.9.4 Economic evaluation

Table 6-11 shows the economic evaluation of each option in Zone 8. Options Z8-2 and Z8-7 have a net present value of $10,000. Based on the preliminary costing this gives a benefit-cost ratio of 2.0 for Option Z8-2 and 2.3 for Option Z8-7. None of the remaining options provide any benefits compared to damages from existing flooding within the catchment, leading to a benefit-cost ratio of zero.

Table 6-11 Economic evaluation of options for Zone 8

Option Name	Z8-1	Z8-2	Z8-3	Z8-4	Z8-5	Z8-6	Z8-7
AAD	$63,600	$62,700	$63,600	$63,600	$63,600	n/a	$62,700
Net present worth of benefit (compared to existing conditions)	$0	$10,000	$0	$0	$0	n/a	$10,000
Estimated cost	$6,100	$5,000	$9,200	$2,500	$3,100	$6,100	$4,300
Benefit-cost ratio	0	2.02	0	0	0	n/a	2.34

6.9.5 Qualitative assessment

The proposed options would have limited impact on the general community in Minnegang Creek. Impacts would be limited to the residents who currently are affected by flooding and who would be impacted by the proposed concrete drains.

The concrete drains would have a visual impact resembling a concrete driveway. They would not be out of place given the highly developed nature of the catchment. The grassed swale proposed as Option Z8-7 would have less visual impact on the adjacent properties and may therefore be more acceptable to the residents at 16 Ranchby Avenue. However, there is currently a double garage and concrete driveway at 16 Ranchby Avenue which would make implementation of Option Z8-2 or Z8-7 difficult and adversely impact on the amenity of this property.

6.9.6 Recommendations

Despite favourable benefit-cost ratios for Option Z8-2 and Option Z8-7, structural flood mitigation options are not recommended for implementation in Zone 8. Neither option is able to reduce the number of properties affected by above-floor level flooding in this zone. Furthermore, the amenity of 16 Ranchby Avenue (the property in which either of these options would be constructed) would be unreasonably affected given the current state of development of that property.

Flooding on the Ranchby Avenue tributaries is also likely to be considered a *local drainage* issue (as defined in the FMM) by DIPNR and therefore outside the scope of flood risk management works to be considered for State funding.

Although Options Z8-2 and Z8-7 would reduce nuisance flooding and localised damages caused by yard flooding, property damages could also be reduced through increased flood awareness and community education programs.

6.10 ZONE 9: LOWER CATCHMENT TRIBUTARIES

6.10.1 Rationale

The existing alignment of the Canberra Avenue tributary does not take advantage of the vacant block located between 75 and 77 Denise Street, which is currently owned by Council and zoned for public recreational use. Option Z9-1 proposes locally regrading Denise Street in the vicinity of the vacant block to ensure that flows are directed through this land. This would also require removing the kerb and gutter to allow floodwaters to flow through this area without building up on Denise Street.

The damage assessment for existing conditions in the catchment indicates that the property at 30 Trevor Avenue is affected by above-floor flooding. The proposed Option Z9-2 attempts to reduce or eliminate this flooding by providing a defined overland flow path, in the form of a grassed swale adjacent to 30 Trevor Avenue, to contain the flows.

The options considered for Zone 9 are shown in Figure 6-8.

6.10.2 Hydraulic performance

Option Z9-1 leads to a reduction in flood levels in the Canberra Avenue tributary. These reductions do not have any impact on flood levels within Minnegang Creek because the peak flood level of the tributary occurs before the peak in Minnegang Creek. Changes to the peak flow within the Canberra Avenue tributary and Minnegang Creek are negligible.

Option Z9-2 also leads to a local reduction in flood levels, with no impact on upstream or downstream areas.

6.10.3 Economic evaluation

Table 6-12 shows the economic evaluation for both the options proposed for this zone. It can be seen that Option Z9-1 is not economically feasible. The reduction in damages achieved from implementation of the proposed works for Option Z9-2 makes these works economically feasible.

Table 6-12 Economic evaluation of options for Zone 9

Option Name	Z9-1	Z9-2
AAD	$63,600	$62,600
Net present worth of benefit (compared to existing conditions)	$0	$20,000
Estimated cost	$30,100	$8,600
Benefit-cost ratio	0	2.33

6.10.4 Qualitative assessment

Option Z9-1 has no impact on the number of flooded properties in the catchment. Option Z9-2 reduces flooding at 30 Trevor Avenue for smaller events but minor above-floor level flooding would still occur at that property.

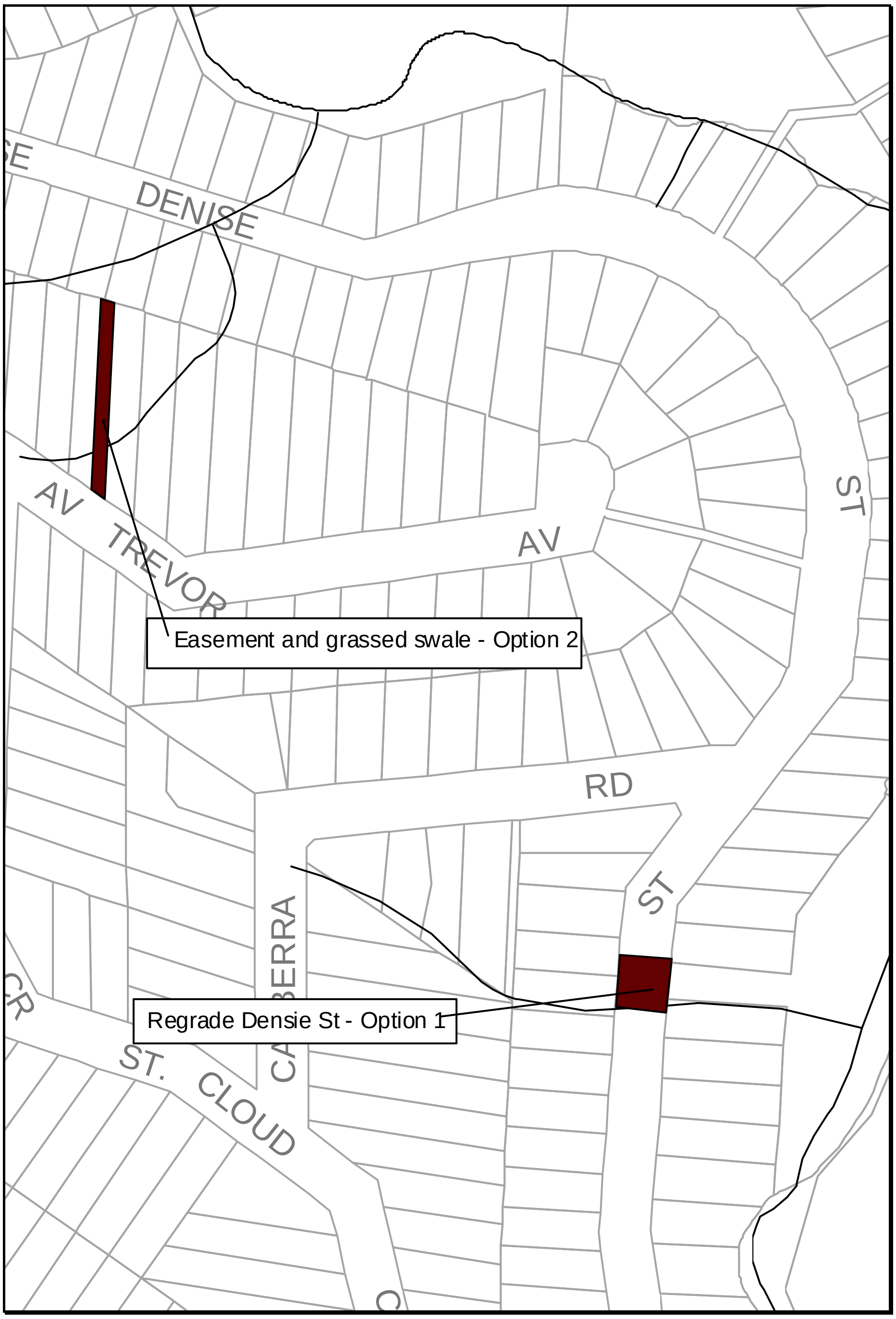


Figure 6-8 Zone 9 Management Options

Due to the highly developed nature of the zone, it is not expected that either option would have significant environmental impacts. The feasibility of Option Z9-2 is questionable given that the proposed channel would need to continue through to Denise Street, then be conveyed across the road and finally connected into Minnegang Creek (note that the estimated cost for this option in Table 6-12 does not include these additional works).

If flows were to be redirected through the vacant block between 75 and 77 Denise Street, as part of Option Z9-1, it would be important to preserve the existing conveyance through this area through regular maintenance.

6.10.5 Recommendations

Implementation of Option Z9-1 cannot be justified on economic grounds or in terms of improving existing flood affectation of properties and is therefore not recommended.

Option Z9-2 is not considered to be feasible due to the scope of work that would be required to provide limited flood relief for 30 Trevor Avenue.

Flooding on the lower catchment tributaries is also likely to be considered a *local drainage* issue (as defined in the FMM) by DIPNR and therefore outside the scope of flood risk management works to be considered for State funding.

6.11 CATCHMENT WIDE MITIGATION OPTIONS

In addition to the mitigation options that have been defined above for each zone, some mitigation options are required over the whole catchment and these are discussed in this section.

6.11.1 Community education

Aims

Education programs can be used to increase the flood awareness of the community and contribute to reducing the actual damages that would occur during a flood event. The Local Flood Plan for Wollongong LGA could be a source for much of the information required by the community. Education programs should concentrate on the following aspects of flooding within the Minnegang Creek catchment:

- residents should be aware of the degree of flood risk affecting their respective properties. This should be based upon the results from the Flood Study (KBR 2002) carried out for the Minnegang Creek catchment;
- describing the rainfall events that are likely to cause flooding within the catchment and a discussion of the warning time that would be available prior to a flood event occurring and the implications of the short duration of warning times;
- likely flow paths through affected properties and through the catchment in general;
- likely road closures and alternative routes for access during a flood;
- residents should be aware of the tasks that should be undertaken in the case of flooding including moving vehicles, raising electrical and other items above floor

level and ensuring that children and pets are safe. This could also provide encouragement for residents to produce an individual "flood plan", for example a checklist of actions to take in the case of flooding; and

- information on who to contact for help during and after a flood event.

Recommended program

The following activities are recommended for a community education program for the Minnegang Creek catchment:

- pamphlets and brochures aimed at the general population in the catchment with information about road closures and other flood affected areas;
- targeted information for residents whose properties are at risk of flooding (approximately 60 households) with more specific information about the flood risk and the actions that can be taken to reduce the damages suffered. This should also include information on contact points for Council, SES and other emergency services;
- periodic community forums to give residents an opportunity to identify problem areas and share information about flooding with each other and with Council. These would also serve as a data collection exercise for Council after storm events. It has been assumed that this would occur after a 50% AEP event or larger; and
- periodic displays of flooding information at community facilities or shopping centres to act as a reminder of the flood risk which faces the community.

New residents, prospective builders and home buyers need to be made aware of the flood risk within the catchment and at individual properties. Council should therefore maintain a reserve of brochures to be handed out when new residents or prospective builders make inquiries at Council.

The issuing of certificates to the owners of flood-affected properties, in accordance with Section 149 of the *Environmental Planning and Assessment Act 1979*, would also assist in the flood education and awareness process. This is discussed further in Section 8.9.

Table 6-13 summarises the options described above and lists the timing and likely costs for each activity. The costs have been based on the assumption of a ten year program of activities.

Community education initiatives must also attempt to convey important information regarding flooding in multiple languages and/or pictorially to ensure that all residents have access to information on flooding.

Council should also consider flood education programs over the whole LGA. Possible activities could include:

- periodic articles in the local press including discussions of the risk of flooding, the likely effects of flooding and contact points for further information; and
- wide availability of the Local Flood Plan and flood reminder brochures at Council Chambers, libraries, schools, council information centres and other appropriate locations.

Table 6-13 Community education program activities

Activity	Timing	Cost over ten years
General flood brochures (double sided A4, colour) to be distributed to 900 households	Once every two years	$13,890
Directed flood information for flood-affected properties (double sided A4, colour) to be distributed to 60 households	Once every two years	$5,675
Information to be held at Council for new residents/builders (assume same brochure as above)	Continuing	$750
Community forums/ data collection after large storm events	Once every two years	$36,300
Information displays regarding flooding	Once every two years	$33,800
TOTAL		**$90,415**

6.11.2 Council maintenance

Maintenance of public areas and open space, including creek corridors within publicly owned and managed land, can play an important role in reducing both localised and mainstream flooding within the catchment. This is particularly true within the Wollongong LGA given their past experiences with structure blockage during periods of flooding. Key areas within the catchment where ongoing maintenance should be focused, to ensure vegetation growth does not significantly reduce the conveyance of flow paths and that potential obstructions are removed from flow paths, include:

- Minnegang Creek, from Lake Illawarra extending upstream of Lake Heights Road to the Ranchby Avenue tributaries;
- Barina Park, where removal of grass clippings and rubbish should be undertaken to prevent or reduce blockage of the detention basin outlet; and
- grassed stormwater easements, such as between 97 and 99 Weringa Avenue and 75 and 77 Denise Street, which should be kept mown and clear of obstructions.

Given the number of easements dedicated to drainage in the catchment, and their important role in conveying flood waters through essentially fully developed and privately-owned land, Council should also undertake inspections to ensure these easements are kept free of unapproved development and/or obstructions.

The estimated cost for initial investigation of flow paths (including easements) is $5,000. Ongoing maintenance costs would need to be met by Council's internal maintenance budget allocations.

6.11.3 Emergency management

As discussed in Section 4.6, generalised flood emergency management measures for the entire Wollongong LGA are documented in the Local Flood Plan.

The Minnegang Creek catchment comprises one of the eight floodplain management areas identified in the Local Flood Plan. Although the smallest in terms of catchment area, flood prone land area and population at risk of flooding, the unique nature of flooding in each of the eight areas requires individual consideration of emergency management issues in the context of overall floodplain risk management.

The key input to emergency management planning from the floodplain risk management process is improved flood intelligence for:

- emergency services, to assist in their responsibilities for flood warning, mobilisation of resources and evacuation; and
- the community, to enable those at risk of flooding to understand likely flood behaviour and take appropriate action prior to the emergency service response.

To this end, flood inundation plans for the Minnegang Creek catchment should be provided to all relevant emergency service providers to assist in the development of flood intelligence that describes flood behaviour and its likely impact on the community at risk of flooding. Other relevant information gathered or produced as a result of the floodplain risk management process, such as likely road inundation and depths of flooding, could also be provided as required. The costs associated with provision of this information and liaison with emergency services is considered to be negligible and would be met by internal Council budget allocations.

Community awareness and preparedness is an important factor in flood warning and appropriate flood response, particularly for Minnegang Creek where the small catchment size, steep terrain and urbanised nature result in short, sharp flood peaks with very little warning time (less than normally required to mobilise an SES team response). The issue of community education and awareness is discussed in Section 6.11.1.

6.11.4 Recovery planning

Immediately after a flood event, the following actions are likely to be required (NSW Government 2001):

- Council and other authorities will need to clean up and restore their assets;
- individuals will have to clean up buildings and belongings damaged during the flood. Residents may expect Council to assist in the clean up process by, for example, providing collection services for the disposal of flood affected items; and
- emergency and ongoing welfare services may be required from authorities such as the SES and the Department of Community Services.

The flood event can also provide an opportunity for evaluating the response of the community, Council and other affected stakeholders to flooding. Meetings may be useful for residents to share their flood experiences and subsequent problems.

Community meetings would also provide a forum for the collection of further data relating to flooding within the catchment. Information collected after a flood event could include:

- hydraulic information including indicative flow rates and velocities, peak flood levels and areas inundated by flood waters;
- damages suffered by residents and businesses; and
- evaluation of the effectiveness of any actions taken during and after the flood by stakeholders.

It has been assumed that this information could be collected as part of the community forums included in the community education program.

6.11.5 Debris control structures

The feasibility of debris control structures upstream of culvert and bridge structures in the catchment was investigated. However, in all locations there is insufficient land adjacent to Minnegang Creek to provide a high level bypass channel. Without a bypass channel, no reductions in the blockage factors applied to the culverts may be assumed and therefore debris control structures are not economically feasible.

7 Preferred Schemes

7.1 INTRODUCTION

The modelling of individual mitigation options for each zone was discussed in Chapter 6. This process identified the options that would be economically feasible and effective in reducing flood risk, and in particular flood affectation of private property, within the Minnegang Creek catchment. This section presents a short list of the recommended options to be adopted and provides details and results of hydraulic modelling of mitigation schemes for the catchment.

7.2 MITIGATION SCHEMES

7.2.1 Mitigation options shortlist

The full range of mitigation options modelled was discussed in Chapter 6. Table 7-1 presents a summary of the options, which were recommended for each zone. These recommendations were primarily based on the benefit-cost ratio for the option. However, the recommendations also included consideration of the hydraulic, social and environmental impacts of each option. Personal safety issues played a critical role in determining the recommended options for each zone.

Table 7-1 Mitigation options shortlist

Zone	Option Number	Description	Benefit-cost ratio
1	n/a	n/a	n/a
2	4	House raising at 68 Barina Avenue	1.29
3	n/a	n/a	n/a
4	2	Raising level of detention basin embankment, provision of spillway and installation of flood warning signs	0.56
5	2 or 6	Voluntary purchase of six properties and rock lined channel from Barina Park to Minnegang Creek with culverts under roads	0.22
6	n/a	n/a	n/a
7	n/a	n/a	n/a
8	n/a	n/a	n/a
9	n/a	n/a	n/a
Catchment-wide		Community education program	n/a
Catchment-wide		Maintenance of catchment flow paths	n/a
Catchment-wide		Emergency management	n/a

As can be seen in Table 7-1 there are many zones where no options have been recommended, due to the low benefit-cost ratios or the ineffectiveness of the proposed options. For most of the remaining zones, the effects of mitigation options are independent and therefore the recommended options from each zone may be implemented without adverse effects on other parts of the catchment.

The exception to this is Zones 4 and 5, where flooding problems are interrelated. Flooding in Zone 5 is caused by flows overtopping the Barina Park detention basin embankment. Mitigation options in Zone 5 have been sized to convey the existing flows from Barina Park. Although consideration was given to implementation of Zone 4 works in conjunction with a reduced scope of works for Zone 5 (ie. a reduction in the number of properties targeted for voluntary purchase), a key constraint lies in the need to acquire sufficient space to open up a dedicated flow path through Zone 5. The selection of the six property scheme outlined in Section 6.6 was based on preliminary investigations which took into account this space requirement. These investigations also considered the need to provide cost-effective flood protection and a significant reduction in the current threat to personal safety for residents inhabiting a floodway with very little warning of impending activation.

The most effective Zone 5 options eliminate above-floor flooding at all but one property within the zone in the PMF event. Flood mitigation is offered to the same properties by works considered in Zone 4, however, the degree of mitigation and protection is significantly higher for Zone 5 works, albeit at greater cost. Undertaking works in Zone 4 in addition to those in Zone 5 will not provide any further improvements to the flood situation. These considerations effectively rule out implementation of significant works in both Zone 4 and Zone 5.

Based on these considerations, preliminary investigations and the outcome of more detailed analysis as documented in Chapter 6, it is recommended that the proposed flood mitigation scheme for Minnegang Creek catchment include works in Zone 5, which are considered to provide the optimum outcome in terms of flood protection, reduction in the current threat to personal safety and the long-term management of flood prone land in the catchment. Therefore, the only works recommended for Zone 4 involve the provision of a spillway, to ensure that flows are directed over the basin embankment into the proposed channel, and the installation of flood warning signs in Barina Park.

7.2.2 Mitigation schemes

The independence of options means that there are only a limited number of feasible schemes that can be implemented within the Minnegang Creek catchment.

Based on the short list and the comments above, two mitigation schemes have been investigated for the catchment. These are listed in Table 7-2. The difference in the schemes is the option recommended for Zone 5.

Table 7-2 Proposed mitigation schemes

Zone	Scheme 1	Scheme 2
1	n/a	n/a
2	House raising - 68 Barina Avenue	House raising at 68 Barina Avenue
3	n/a	n/a
4	Spillway for detention basin and flood warning signs	Spillway for detention basin and flood warning signs
5	Voluntary purchase of six properties and rock lined channel from Barina Park to Minnegang Creek with new culverts under Mirrabooka Road and Weringa Avenue	Voluntary purchase of six properties and rock lined channel from Barina Park to Minnegang Creek with existing pipes used as culverts under roads
6	n/a	n/a
7	n/a	n/a
8	n/a	n/a
9	n/a	n/a
Catchment-wide	Community education program	Community education program
Catchment-wide	Maintenance of catchment flow paths	Maintenance of catchment flow paths
Catchment-wide	Emergency management	Emergency management

7.3 RESULTS AND DISCUSSIONS

7.3.1 Hydraulic performance

The hydraulic effects of each scheme are essentially a combination of the effects of the individual options.

Each scheme leads to similar flood levels and flows to existing conditions in the upper parts of Minnegang Creek down to Barina Park. The spillway and proposed channel in Zone 5 ensures that the flows over the weir of the detention basin are conveyed effectively to Minnegang Creek. Flood levels in this area are substantially reduced over existing conditions due to the lowering of the invert levels along the channel compared to the existing configuration. Levels along the lower part of Minnegang Creek are not changed significantly from existing conditions. For both schemes, the Jane Avenue bridge continues to only be overtopped in the PMF event.

The only difference between the schemes is the existing 135 m pipes retained as culverts in Scheme 2 do not have sufficient capacity to convey the 20% AEP event under Mirrabooka Road and Weringa Avenue. The 1.5 m diameter culverts proposed as Scheme 1 ensure that no flows pass over these roads in the 20% AEP event. The slight attenuation of floodwaters upstream of the Weringa Avenue culvert in Scheme 2, leads to a small reduction in downstream flood levels compared to Scheme 1.

Figures 7-1 to 7-4 show the design flood profile for the 1% AEP event and the extent of inundation, for the 1% AEP and PMF events, compared to existing conditions for both schemes.

7.3.2 Effects of flooding

The results of the modelling of the mitigation schemes indicate a substantial decrease in the impact of flooding within the Minnegang Creek catchment. The number of properties affected by flooding for each event is shown in Table 7-3 for both mitigation schemes, which indicates that schemes provide flood protection to the same properties within the catchment.

Table 7-3 Flood affected properties

Option Name	Properties affected by above-floor flooding					Properties affected by below-floor flooding				
	PMF	1%	2%	5%	20%	PMF	1%	2%	5%	20%
Existing Conditions	20	17	17	13	5	59	48	44	43	35
Scheme 1	6	4	4	4	3	48	38	35	33	28
Scheme 2	6	4	4	4	3	48	38	35	33	28

7.3.3 Economic evaluation

In assessing the damages caused by flooding, it was assumed that the actual damages suffered in a flood event would be less than the potential damages due to the community education program implemented in the mitigation schemes. This improvement is due to the education program raising community awareness of what can be done to reduce damages. Actual damages were assumed to be 80% of the potential damages. This is considered a reasonable reduction based on research that shows residential damages can be reduced by up to 25% with action by householders (Handmer et al 1988).

Table 7-4 presents a summary of the economic assessment carried out for each of the mitigation schemes. The preliminary cost calculations are provided in Appendix H. Damage assessment summaries for the two schemes are provided in Appendix I.

Table 7-4 Economic evaluation of mitigation schemes

Option Name	Scheme 1	Scheme 2
Existing AAD	$63,600	$63,600
AAD with works in place	$23,000	$23,000
Net present worth of benefit (compared to existing conditions)	$560,000	$560,000
Estimated cost	$2,147,000	$2,093,000
Benefit-cost ratio	0.26	0.27

7.3.4 Recommendations

With a benefit-cost ratio of less than one, neither of the schemes can be justified from a purely economic viewpoint. However, the intangible benefits which cannot be quantified (and are therefore not taken into account in the economic evaluation) are considered to be highly significant.

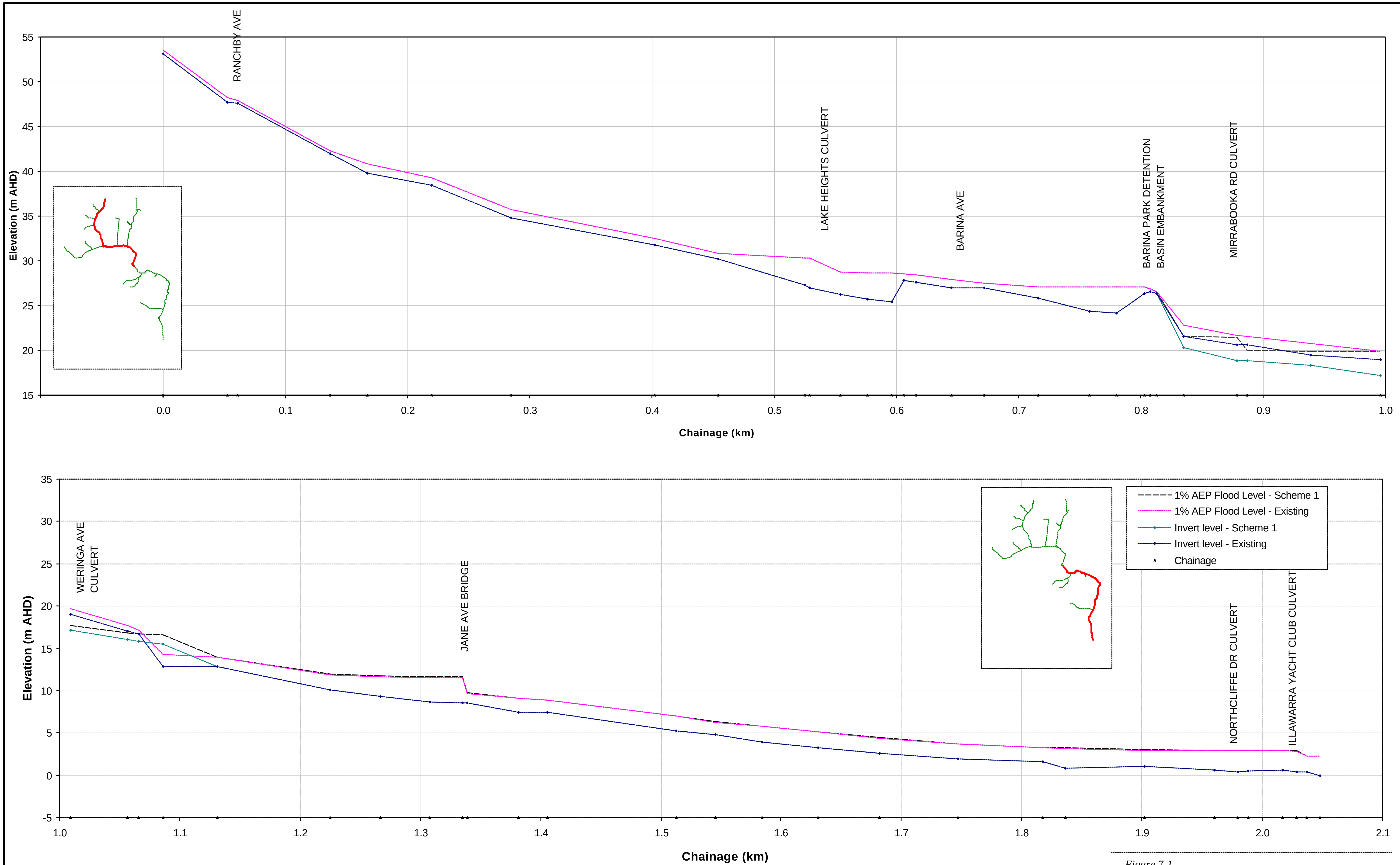


Figure 7-1

1% AEP EVENT FLOOD PROFILES
SCHEME 1 AND EXISTING CONDITIONS

Minnegang Creek Floodplain Risk Management Study

LEGEND

- Scheme 1 - 1% AEP extent
- Scheme 1 - PMF extent
- Existing - 1% AEP extent
- Existing - PMF extent

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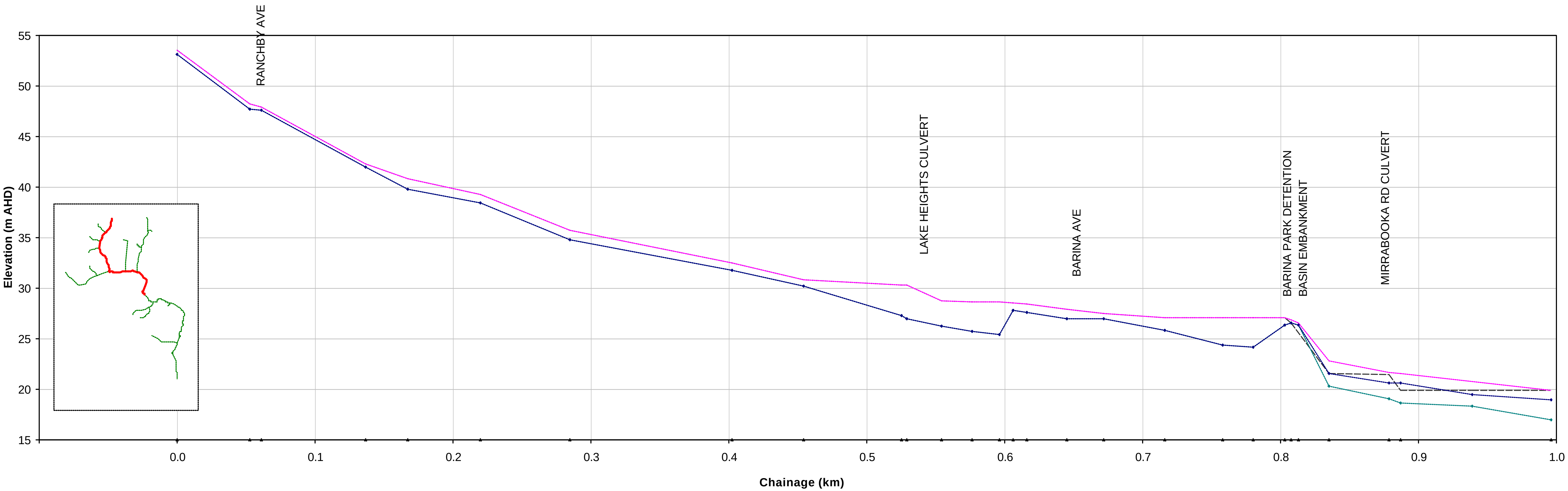
1:6000 @ A3

Figure 7-2

SCHEME 1 - EXTENT OF INUNDATION

Minnegang Creek Floodplain Risk Management Study



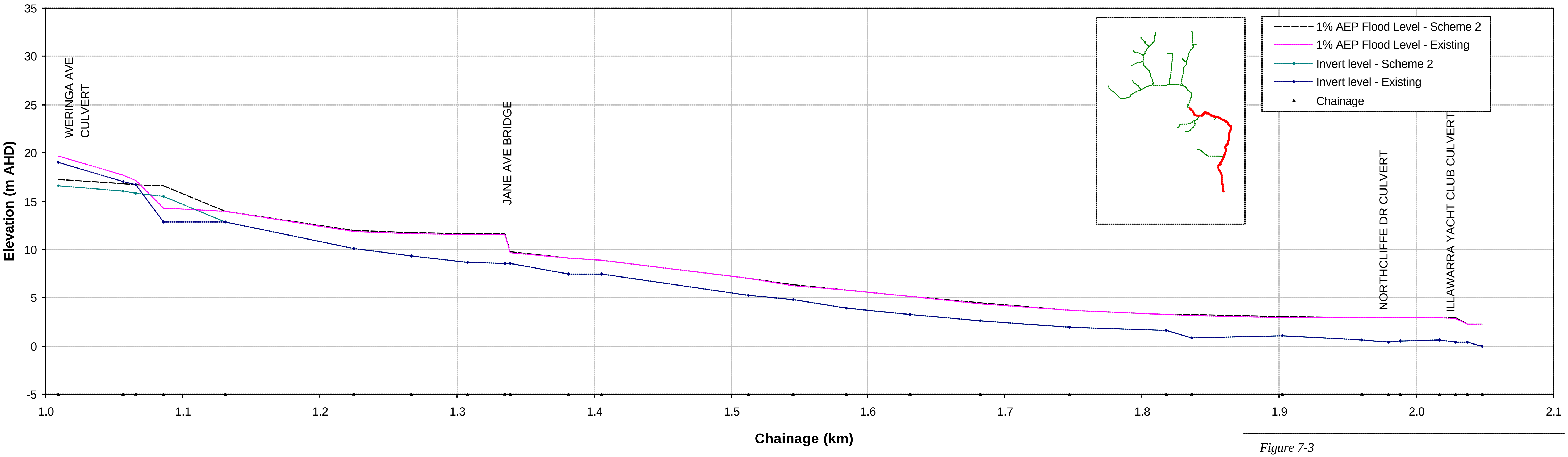


Figure 7-3

1% AEP EVENT FLOOD PROFILES
SCHEME 2 AND EXISTING CONDITIONS

Minnegang Creek Floodplain Risk Management Study

As a result, overall assessment of the proposed mitigation works, taking into account the existing flood situation, risk to life and property and long-term management of flood prone land in the catchment, is deemed to justify the need for the proposed works. Therefore, with the lowest overall cost, Scheme 2 is recommended for implementation.

7.4 COMMUNITY FEEDBACK

Community feedback on the preliminary floodplain management options, based on the recommended Scheme 2, was only received from those residents directly affected by the proposed voluntary purchases. Concerns related primarily to:

- the valuation of properties affected and likely price that Council would offer as part of a voluntary acquisition; and
- the timeframe for implementation of the FRMP.

The current owners of the six properties included in the voluntary purchase scheme are understandably concerned that selling may leave them in a worse financial position. However, the residents were also generally unaware of the magnitude of the flood risk in the catchment and the level of damage that their properties would be likely to sustain if a significant flood event were to occur. Overall, the residents affected by the voluntary purchase scheme indicated general support for flood risk management in the catchment.

8 Planning and Development Controls

8.1 INTRODUCTION

Recommendations for land use planning and development controls for the Minnegang Creek catchment have been determined using results of the Flood Study for the catchment and Council's *Draft Development Control Plan 54 "Managing Our Flood Risks"* (DCP 54) (Wollongong Council 2003). Each floodplain within the Wollongong LGA is covered by the general provisions of DCP 54 as well as catchment specific provisions. Specific provisions for each floodplain are determined as part of the Floodplain Risk Management Plan process.

The majority of the Minnegang Creek catchment is fully developed within the respective zoning entitlements. Therefore the main applications of planning and development controls are likely to be redevelopment of existing lots and proposed development of the large area of currently vacant land between Ranchby Avenue, Hilltop Avenue and Flagstaff Road.

8.2 FLOOD RISK PRECINCTS

To provide a basis for strategic planning and development control within the Wollongong local government area, Council has defined three levels of Flood Risk Precinct (FRP) in DCP 54.

The three FRPs are defined as follows:

- High FRP (and Interim Riverine Corridor) - defined as the area within the envelope of land subject to a high hydraulic hazard in a 1% AEP event together with all land within a corridor 10 m from the top of the creek bank. In addition, islands surrounded by the High FRP are deemed part of the High FRP because of evacuation problems. High hydraulic hazard is determined in accordance with the provisional criteria represented by Figure G2 in the FMM.
- Medium FRP - defined as land extending from the boundary of the High FRP to the extent of land defined by the 1% AEP level plus 0.5 m freeboard.
- Low FRP - defined as all other land within the extent of the PMF, not identified as in either a High or Medium FRP.

Figure G2 of the FMM provides thresholds for both depth (1.0 m) and velocity (2.0 m/s). Where flood behaviour results in the exceedance of *one* of these thresholds, the provisional hydraulic hazard category is deemed to be high (though it should be noted that other factors may influence overall flood hazard). The depth threshold has particular relevance to the Minnegang Creek catchment due to the existence of the Barina Park detention basin. Flood waters ponding within Barina Park create a zone of high hazard due to the significant depth of water, regardless of the fact that the flow velocity is negligible.

Figure 8-1 presents sketches illustrating the above FRP definitions for typical cross sections. The top of creek bank for each cross section was defined from the surveyed creek cross sections. In locations where the surveyors were unable to adequately define the top of bank, the 20% AEP flood event was assumed to approximate the bankfull capacity of Minnegang Creek. The 20% AEP flood level was therefore used to estimate the top of bank, in these locations.

FRP mapping has been carried out for existing flooding within the catchment. The resulting map is shown in Figure 8-2. The FRPs after the implementation of the mitigation schemes are shown in Figure 8-3. It has been assumed that due to the similarity of the two schemes, that the FRPs would be the same for either scheme.

To calculate the FRPs the flood hazard must be defined. This requires a calculation of depth multiplied by velocity across the width of the cross section. As MIKE 11 is a one-dimensional model it produces a depth averaged velocity at each cross section. To enable the hydraulic hazard to be calculated, this average velocity has been distributed across the width of each cross section by considering the conveyance of different parts of the cross section (Verwey 1994).

The FRPs shown in Figure 8-2 and Figure 8-3 are based on interpolation from the MIKE 11 cross sections used to define the floodplain. This has implications in terms of the level of accuracy that can be assumed from the mapping. At the cross section location, the definition of the FRPs is expected to be reasonably accurate. However, between cross sections, interpolation does not take account of the true topography and hence would only be of limited accuracy.

8.3 FLOOD PLANNING LEVELS

The FMM states that "Flood Planning Levels are used to determine the extent of land that is subject to flood related development controls". As Council has defined FRPs, which are used to define development controls for the catchment, Flood Planning Levels do not need to be defined for the Minnegang Creek Catchment.

8.4 DEVELOPMENT CONTROLS

Planning and development controls form an important part of the Property Modification measures described in the FMM. The development controls listed in the FMM have been grouped into six categories to form part of DCP 54. The categories and types of development controls that they include are described below.

8.4.1 Flood affectation

This examines the effects of a proposal on flooding elsewhere in the catchment. Fill or excavation may change the flow pattern of a flood. The cumulative impact of a number of similar proposals should also be considered.

Figure 8-2 Flood Risk Precincts (Existing)

Figure 8-3 Flood Risk Precincts (After Implementation of Proposed Mitigation Works)

8.4.2 Management and design

This category covers controls on the design of developments, especially those within the Medium FRP. It considers storage of goods, including materials that may potentially be hazardous during a flood, with respect to flood levels.

8.4.3 Evacuation

Access during a flood event must be addressed in subdivision and building design. Local topography and flood behaviour must be considered in developing requirements and controls. Vehicular and pedestrian access should be considered with respect to flood levels.

8.4.4 Floor level

Minimum floor levels have been set to reduce the frequency and extent of damage caused by flooding. In addition a freeboard of 0.5 m has been adopted. According to the FMM this acts as a factor of safety and covers uncertainties such as:

- increases in flood levels due to wave action
- uncertainties in flood levels due to modelling methodology
- changes in rainfall patterns as a result of the greenhouse effect
- the cumulative effect of subsequent infill development.

Controls have also been developed to cover minor development for existing buildings.

8.4.5 Building components

Controls have been set on building materials to ensure that they are flood compatible if they are likely to be flooded. Flood compatible building materials are defined in Schedule 1 of DCP 54. Flood compatible materials are those which are less susceptible to damage by flood waters or are easier to clean up after a flood (NSW Government 2001).

8.4.6 Structural soundness

Flood waters can impact upon the structural soundness of buildings in a number of ways relating to flow velocities and depths and associated debris loads. Structural soundness is assessed by considering the forces on a building and the buoyancy of the building. An engineer's report is required to certify the soundness of buildings within a High FRP, whilst for Medium and Low FRPs the applicant must demonstrate that the building is structurally sound when flooded.

8.4.7 Fencing

Fencing has not been included in the list of development controls for the catchment due to its inclusion as a separate item in DCP 54. Prescriptive controls on fencing have been defined in DCP 54, which restrict the use and type of fencing within different FRPs across the LGA.

8.5 LAND USE CATEGORIES

Council has defined eight land use categories in DCP 54. These categories and indicative uses are listed below:

- **Sensitive Uses and Facilities:** community centre which may provide an important contribution to the notification or evacuation of the community during flood events.
- **Critical Utilities and Uses:** essential to evacuation during periods of flood or if affected during flood events would unreasonably affect the ability of the community to return to normal activities after flood event; telecommunication facilities; utility which may cause pollution of waterways during flooding.
- **Subdivision:** subdivision of land which involves the creation of new allotments.
- **Residential:** houses and other dwellings, which includes long-term camping or caravan sites, housing for aged or disabled persons, health consulting rooms, utility installations (other than critical utilities).
- **Commercial or Industrial:** shops, offices and industrial facilities including motels, recreation facilities and places of worship.
- **Tourist Related Development:** short-term camping or caravan sites.
- **Recreation or Non-urban Uses:** agriculture, mining and leisure/recreation areas including minor ancillary structures.
- **Concessional Development:** in the case of residential development - an addition or alteration to an existing dwelling of not more than 10% or 30 m^2 (whichever is the lesser) of the habitable floor area, or the construction of an outbuilding with a maximum floor area of 20 m^2, or redevelopment for the purposes of substantially reducing the extent of flood affectation on the existing building.

8.6 DEVELOPMENT AND PLANNING CONTROLS MATRIX

FRPs have been used to determine appropriate development controls for each of the above land use categories. The FRPs are defined for the catchment in Figure 8-2 for existing conditions and Figure 8-3 following implementation of the preferred scheme of mitigation options.

Table 8-1 is a matrix showing the planning considerations and development controls that are recommended for the catchment according to the different land uses and FRP categorisation. The matrix is designed for inclusion as a schedule to DCP 54. With a few minor revisions, the controls adopted for each land use and FRP category are the same as those adopted for the Towradgi Creek catchment, the catchment for which the matrix was originally developed.

8.7 ON-SITE STORMWATER DETENTION

Council has an on-site stormwater detention (OSD) policy which applies to new development and redevelopments. This policy is currently under review.

Table 8-1 Planning and development control matrix

Flood Risk Precincts

Low Flood Risk

Planning and Development Consideration	Sensitive Uses and Facilities	Critical Utilities and Uses	Subdivision	Residential	Commercial or Industrial	Tourist Related Development	Recreation or Non-urban Uses	Concessional Development
Floor Level	Unsuitable landuse	3	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant
Building Components	Unsuitable landuse	2	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant
Structural Soundness	Unsuitable landuse	3	Not relevant	2	Not relevant	2	Not relevant	Not relevant
Flood Affectation	Unsuitable landuse	2	2	Not relevant	2	2	Not relevant	Not relevant
Evacuation	Unsuitable landuse	2,4	*	3,4	4	3,4	Not relevant	Not relevant
Management and Design	Unsuitable landuse	4,5	1	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant

Medium Flood Risk

Planning and Development Consideration	Sensitive Uses and Facilities	Critical Utilities and Uses	Subdivision	Residential	Commercial or Industrial	Tourist Related Development	Recreation or Non-urban Uses	Concessional Development
Floor Level	Unsuitable landuse	Unsuitable landuse	Not relevant	2	2 or 5	2	1	2,4
Building Components	Unsuitable landuse	Unsuitable landuse	Not relevant	1	1	1	1	1
Structural Soundness	Unsuitable landuse	Unsuitable landuse	Not relevant	2	2	2	2	2
Flood Affectation	Unsuitable landuse	Unsuitable landuse	1	2	2	2	2	2
Evacuation	Unsuitable landuse	Unsuitable landuse	*	3,4	1,4	3,4	1	1 or 3
Management and Design	Unsuitable landuse	Unsuitable landuse	1	Not relevant	2,3,5	2,3,5	2,3,5	2,3,5

High Flood Risk (and Interim Riverine Corridor)

Planning and Development Consideration	Sensitive Uses and Facilities	Critical Utilities and Uses	Subdivision	Residential	Commercial or Industrial	Tourist Related Development	Recreation or Non-urban Uses	Concessional Development
Floor Level	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	1	2,4
Building Components	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	1	1
Structural Soundness	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	1	1
Flood Affectation	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	1	1
Evacuation	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	1	1
Management and Design	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	Unsuitable landuse	2,3,5	2,3,5

Not relevant   Unsuitable landuse   * Refer to 'Management and Design' consideration for Subdivision

Freeboard equals an additional height of 500 mm

Notes:
1. Filling of the site, where acceptable to Council, may change the FRP considered to determine the controls applied in the circumstances of individual applications.
2. Terms in italics are defined in the glossary of this Plan and Schedule 2 specifies development types included in each land use category. These development types are generally as defined within Environmental Planning Instruments applying to the local government area.

Floor Level

1 All floor levels to be equal to or greater than the 5% AEP *flood* level plus *freeboard* unless justified by site specific assessment
2 *Habitable floor* levels to be equal to or greater than the 1% AEP *flood* level plus *freeboard*
3 All floor levels to be equal to or greater than the *PMF flood* level plus *freeboard*
4 Floor levels to be as close to the *design floor level* as practical and no lower than the existing floor level when undertaking alterations or additions
5 Floor levels of shops to be as close to the *design floor level* as practical. Where below the *design floor level*, more than 30% of the floor area is to be above the *design floor level* or premises to be flood-proofed below the *design floor level*

Building Components and Method

1 All structures to have *flood compatible building components* below or at the 1% AEP *flood* level plus *freeboard*
2 All structures to have *flood compatible building components* below or at the *PMF flood* level plus *freeboard*

Structural Soundness

1 Engineers report to certify that any structure can withstand the forces of floodwater, debris and buoyancy up to and including a 1% AEP *flood* plus *freeboard*
2 Applicant to demonstrate that any structure can withstand the forces of floodwater, debris and buoyancy up to and including a 1% AEP *flood* plus *freeboard*
3 Applicant to demonstrate that any structure can withstand the forces of floodwater, debris and buoyancy up to and including a *PMF flood* plus *freeboard*

Flood Affectation

1 Engineers report required certifying that the development will not increase *flood* affectation elsewhere
2 The impact of the development on flooding elsewhere to be considered

Note: When assessing *flood* affectation, the following must be considered:
1. Loss of storage area in the *floodplain*
2. Changes in *flood* levels and velocities caused by alteration of conveyance of *flood* waters

Evacuation

1 *Reliable access* for pedestrians required during a 1% AEP *flood*
2 *Reliable access* for pedestrians and vehicles required during the *PMF flood*
3 *Reliable access* for pedestrians or vehicles is required from the building, commencing at a minimum level equal to the lowest *habitable floor* level to an area of refuge above the *PMF flood* level, or a minimum of 40% of the gross floor area of the dwelling to be above the *PMF flood* level
4 The development is to be consistent with any relevant *flood evacuation strategy* or similar plan

Management and Design

1 Applicant to demonstrate that potential development as a consequence of a subdivision proposal can be undertaken in accordance with this Plan
2 Site Emergency Response Flood Plan required (except for single-dwelling houses) where floor levels are below the *design floor level*
3 Applicant to demonstrate that area is available to store goods above the 1% AEP *flood* level plus *freeboard*
4 Applicant to demonstrate that area is available to store goods above the *PMF flood* level plus *freeboard*
5 No external storage of materials below the *design floor level* which may cause pollution or be potentially hazardous during any *flood*

8.8 ZONING

For the majority of the Minnegang Creek catchment, the current zoning is considered to be appropriate due to the limited extent of the floodplain. However, conflicts between flood-compatible land uses and current land zoning do exist in certain locations. The current zoning and the FRPs following implementation of the preferred structural flood mitigation works are overlayed in Figure 8-4.

Three main areas of conflict occur between the FRPs and residential areas. These areas are:

- properties along the eastern side of Denise Street in the lower catchment;
- the property immediately downstream of the Lake Heights Road culvert (71 Lake Heights Road); and
- properties between Barina Park and Minnegang Creek, to be acquired by voluntary purchase under the preferred flood mitigation scheme (42, 63, 65 Mirrabooka Road and 96, 98, 99 Weringa Avenue).

Rezoning in the lower part of the catchment, and immediately downstream of the Lake Heights Road culvert, is not justified given the limited flood-affectation of these properties. Although some conflict occurs and unlimited development could exacerbate the existing flood problem, appropriate flood-related development controls exist within the proposed planning and development control matrix (refer Table 8-1) to ensure that future redevelopment of these properties is compatible with the flood risk.

It is recommended that, ultimately, the six properties acquired by voluntary purchase are rezoned from the current <u>2(a) Low Density Residential</u> to <u>6(a) Public Recreation.</u> Such a change would formally recognise the land's flood prone nature and continuing role as a key floodway linkage between the Barina Park detention basin and Minnegang Creek. However, the proposed structural works recommended following purchase of these properties are permissible with development consent under the current zoning therefore no changes should be required specifically to facilitate the implementation of these works.

8.9 FLOOD CERTIFICATION

Council has indicated that it intends issuing updated Section 149 Certificates, in accordance with s149 of the *Environmental Planning and Assessment Act 1979*, to the owners of flood-affected properties in the Minnegang Creek catchment.

Currently, Section 149(2) Certificates do not contain information relating to flood risk or flood affectation. The proposed update will attach DCP 54 to the Certificate, which has the effect of identifying properties that are considered to be flood-affected and, as a result, have flood risk related development controls which apply to the property in question. DCP 54 will also indicate the applicable controls through the planning and development matrix.

Section 149(5) Certificates currently provides the following information for flood affected properties:

FLOOD HAZARD – AFFECTED

Council's flood hazard/flood assessment maps show that the land is located in an area where flooding has occurred or is suspected. The services of a suitably qualified engineer should be sought to ascertain the likely effect, if any, on the land.

The proposed information to be included on updated Section 149(5) Certificates is as follows:

FLOOD HAZARD - AFFECTED

1. Classification of Flood Risk

Council records indicate that this property is located within a Low/Medium/High Flood Risk area.

Land that is potentially subject to inundation is classified as low, medium or high flood risk. Council has prepared a development control plan known as DCP 54 "Managing Our Flood Risks" that provides details of flood related development controls that may be applicable.
Where the owner/applicant has detailed survey available which identifies the property to be within another risk precinct or not in one at all, it may be presented to Council for amendment.

2. Estimated Flood Levels

Flood levels in the vicinity of this property have been extracted from [*insert appropriate reference*].

Size of Flood *	**Flood Level (mAHD)**
Probable Maximum Flood	x
100 Year Flood	x
50 Year Flood	x
20 Year Flood	x
5 Year Flood	x

** Note:*

The Probable Maximum Flood (or PMF) is extremely rare.

A 100 year flood is a large flood. It has a 1 in 100 (ie 1%) chance of occurring in any year.

A 50 year flood has a 1 in 50 (ie 2%) chance of occurring in any year.

A 20 year flood has a 1 in 20 (ie 5%) chance of occurring in any year.

A 5 year flood is more frequent. It has a 1 in 5 (ie 20%) chance of occurring in any year.

Figure 8-4 Flood Risk Precincts (After implementation of Proposed Mitigation Works) and Existing Zoning

Figure 8-1 Flood Risk Precinct Definitions

8.10 RECOMMENDATIONS

Recommendations in relation to planning and development controls are as follows:

- the Planning and Development Control Matrix for Minnegang Creek catchment should be incorporated into DCP 54;
- the six properties to be acquired by voluntary purchase should ultimately be rezoned to 6(a) Public Recreation; and
- Section 149 certificates should be issued to the owners of flood-affected properties to (1) indicate that there are flood risk related development controls which apply to the property in question, and (2) provide indicative flood levels in the vicinity of the property for a range of design flood events.

9 Conclusions

Based on the findings of this study, the draft Floodplain Risk Management Plan for Minnegang Creek is to be formulated as the next stage of the floodplain management process.

It is recommended that the draft Floodplain Risk Management Plan incorporate the following flood risk management measures:

- voluntary purchase of six properties (42, 63, 65 Mirrabooka Road and 96, 98, 99 Weringa Avenue);
- house raising at 68 Barina Avenue;
- construction of a channel connecting the Barina Park detention basin to Minnegang Creek, retaining the existing pipes under Mirrabooka Rd and Weringa Av as culverts with new headwalls to be installed;
- provision of formal spillway in Barina Park detention basin to direct flood flows into the proposed channel;
- flood warning signs in Barina Park;
- community education and flood awareness initiatives for the entire catchment, but focused on properties at direct risk from flooding;
- maintenance of public areas and enforcement of existing drainage easements;
- provision of inundation plans and other flood intelligence to emergency service providers to assist in development and implementation of the Local Flood Plan;
- incorporation of the Planning and Development Control Matrix into DCP 54;
- ultimate rezoning of the six properties to be acquired by voluntary purchase to 6(a) Public Recreation; and
- update and reissue Section 149 Certificates to the owners of flood-affected properties in the catchment.

The draft Floodplain Risk Management Plan will include details on the priority and funding sources for these works.

Appendix A

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Appendix A
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Appendix B

GLOSSARY

Appendix B

Glossary

Annual Exceedence Probability (AEP)	the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage.
Australian Height Datum (AHD)	a common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	the long-term average number of years between the occurrence of a flood as big as or larger than the selected event, eg. floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
cadastral base	information in map and/or digital form showing the extent and usage of land including streets, lot boundaries, water course.
catchment	the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to a specific location.
discharge	the rate of flow of water measured in terms of volume per unit time.
flood	relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam and/or overland runoff before entering a watercourse and/or coastal inundation resulting for super elevated sea levels and/or waves overtopping coastline defences.
floodplain	area of land which is subject to inundation by floods up to the probable maximum flood event ie. flood prone land.

hydraulics	term given to the study of water flows in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	a graph which shows how the discharge or stage/flood level at any particular location changes with time during a flood.
hydrology	term given to the study of the rainfall and runoff processes; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
MIKE 11	the unsteady one dimensional hydraulic model used for this study.
peak discharge	the maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	the largest possible flood that could conceivably occur at a particular location. The PMF defines the extent of flood prone land, ie the floodplain.
Probable Maximum Precipitation (PMP)	the greatest depth of precipitation for a given duration meteorologically possible over a given size storm at a particular location at a particular time of the year, with no allowance made for long-term climatic trends. It is the primary input to the estimation of the probable maximum flood.
RAFTS	the hydrologic model used for this study (Runoff Analysis & Flow Training Simulation).
runoff	the amount of rainfall which actually ends up as streamflow.
stage	equivalent to water level. Measured with reference to a specified datum.

Appendix C

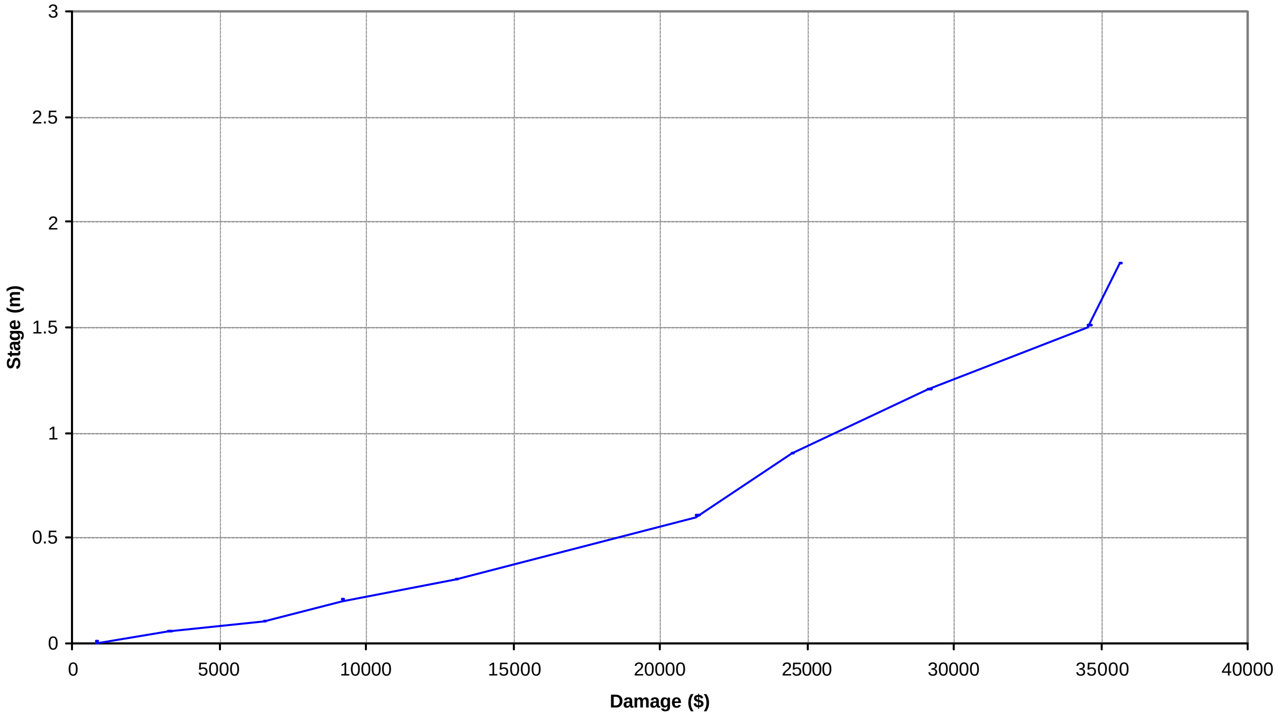
STAGE-DAMAGE CURVES

Appendix C

Stage-damage curves

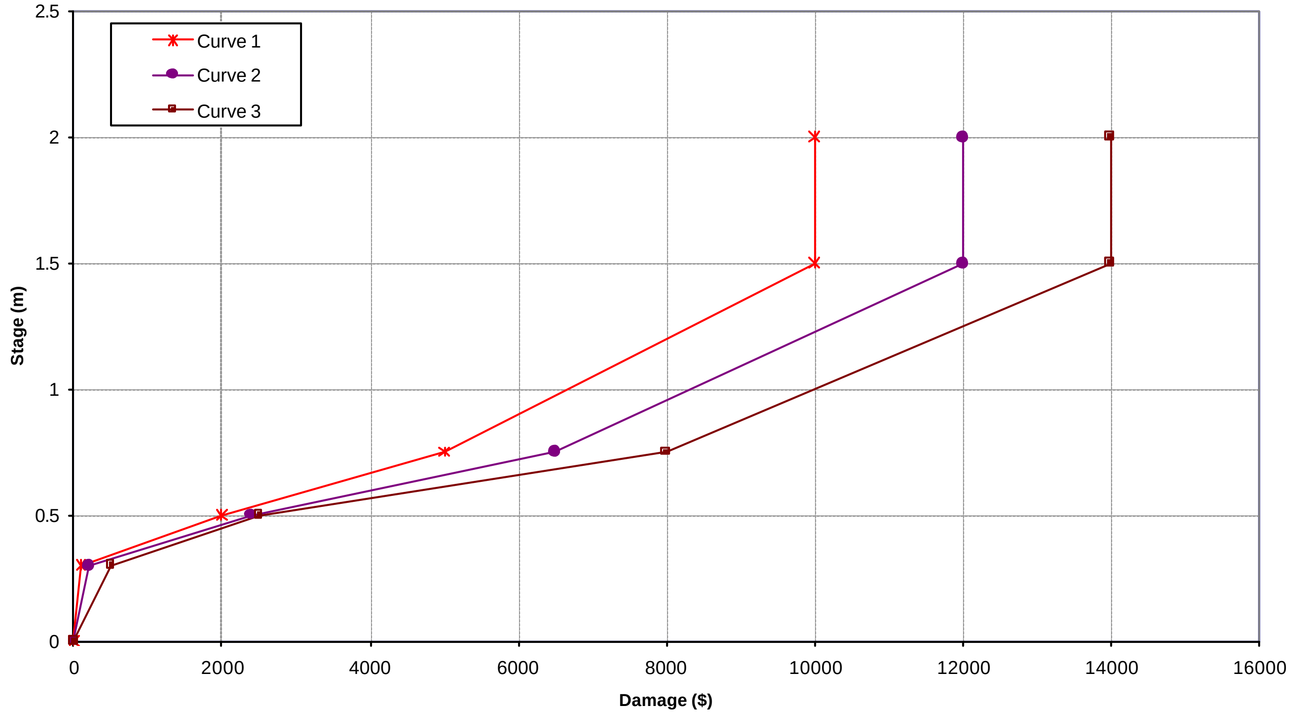
ABOVE FLOOR FLOODING STAGE DAMAGE CURVE

Figure C1 - Above floor flooding stage-damage curve



BELOW FLOOR FLOODING STAGE DAMAGE CURVES

Figure C2: Below floor flooding stage-damage curves



NOTES

Curve 1 - properties with no storage facilities

Curve 2 - properties with some storage facilities (eg shed, garage or underfloor storage)

Curve 3 - properties with some storage facilities and some other type of structure(s) on the property (eg chicken sheds, entertainment area etc)

Appendix D

UNIT RATES FOR CONSTRUCTION

Appendix D
Unit rates for construction

Table D-1 Unit rates for construction

Item	Description	Unit	Rate ($)
1	**House costs**		
1.1	Property acquisition (voluntary purchase)	Item	210,000
1.2	House raising	Item	45,000
2	**Excavation**		
2.1	Demolish exis ting structures including transport within 10 km	m^2	40
2.2	Clear and remove vegetation	m^2	0.40
2.3	Strip topsoil (light soil)	m^2	4.25
2.4	Excavation to reduce levels (light soil)	m^3	16.10
2.5	Excavation for proposed channel including support and dewatering	m^3	40
2.7	Placement and compaction of fill	m^2	6
2.8	Construction of rock lining	m^3	70
2.9	Construction of concrete v-drain	m^3	180
3	**Culvert installation**		
3.1	Excavate (pavement and subsoil)	m^3	40
3.2	Supply and install 1.5m diam RCP (includes backfill with excavated	m	650
3.3	Reinstate pavement	m^2	100
3.4	Headwall for 1.5 m culvert	Item	2,600
3.5	Headwall for 1350 mm culvert	Item	2,000
4	**Landscaping**		
4.1	Trim and grade to final levels	m^2	2.20
4.2	Spread topsoil and seed	m^2	7
4.3	Level, grade, prepare and seed playing fields	ha	27,000
5	**Miscellaneous**		
5.1	Erosion and sedimentation controls	Item	70
5.2	Flood depth indicators	Item	250
5.3	Flood warning signs	Item	280
5.4	Geotechnical investigation	Item	10,000
5.5	Spillway for detention basin	Item	40,000
5.6	Barriers to close roads	Item	500
5.7	Community education program	Item	90,415
5.8	Maintenance of catchment flow paths (initial investigation)	Item	5,000
6	**Contingencies**		20%

Appendix E

MITIGATION OPTIONS - MODELLING AND ASSESSMENT

Appendix E

Mitigation options - modelling and assessment

MODELLING METHODOLOGY

Zone 2

The options in Zone 2 were modelled by adjusting the cross sections in the MIKE 11 model between Lake Heights Road and Barina Park.

The changes in the MIKE 11 model for Options Z2-1 and Z2-2 were:

- addition of a broad-crested weir along Barina Avenue and culverts under Barina Avenue. This was achieved by adding a new branch to the model, BARWEIR, with cross sections copied from MINNEGAN 0.645 and MINNEGAN 0.672;
- removal of weir at MINNEGAN 0.606 (above the start of the piped drainage system); and
- adjustments to cross sections from MINNEGAN 0.576 to MINNEGAN 0.716.

Options Z2-1 and Z2-2 required new initial conditions to be established for the model due to the addition of another branch to the model. These initial conditions were then used as a "hotstart" for modelling the design events through the catchment

Option Z2-3 was modelled by reducing the roughness of the cross section MINNEGAN 0.616 in the existing model. This aimed to reflect the removal of obstructions to the flow that would result from the demolition of the structures (buildings and fences) on 68 Barina Avenue.

To model the effects of house raising, the assessment for Option Z2-4 used the result files from existing conditions in the catchment. However, the damage assessment was modified by increasing the floor level of the house at 68 Barina Avenue to reflect the effects of house raising.

Zone 3

The changes proposed to this zone were modelled by modifications to the cross sections in the vicinity of 7 Gilgandra Street, specifically MELINDA 0.282 and MELINDA 0.328 and GILGAND 0.058.

Zone 4

Modelling for Option Z4-1 involved modifying all the cross sections located within Barina Park to reflect the new contour plan of the park. Changes were made to MELINDA 0.328, 0.384, 0.427, 0.467 and 0.514 and MINNEGAN 0.716, 0.756 and 0.780.

To model the effects of raising the embankment within Barina Park (Option Z4-2), the levels along the embankment weir (MINNEGAN 0.808) were increased and a new stage-width relationship calculated. The levels along the cross sections upstream and downstream of the weir were also increased. Finally, sections along the MINNEGAN branch which intersect the embankment were modified to reflect the increased height of the embankment.

Option Z4-3 was modelled using the modified sections from Option Z4-1 and the new stage-width relationship determined in Option Z4-2 for the weir along the basin embankment.

Zone 5

The options in Zone 5 were modelled by adjusting the cross sections in the MIKE 11 model between Barina Park and downstream of Weringa Road, at the outlet to the piped drainage system into Minnegang Creek.

The changes in the MIKE 11 model for Options Z5-1 and Z5-2 were:

- the addition of broad-crested weirs along Mirrabooka Road and Weringa Avenue and culverts under each of these roads. This was achieved by adding two new branches to the model, MIRRWEIR, with cross sections copied from MINNEGAN 0.879 and MINNEGAN 0.887 and WERWEIR, with cross sections copied from MINNEGAN 0.996 and MINNEGAN 1.009;
- an additional cross section halfway between Mirrabooka Road and Weringa Avenue along the property boundaries - MINNEGAN 0.939; and
- adjustments to cross sections from MINNEGAN 0.835 to MINNEGAN 1.057.

Options Z5-1 and Z5-2 required new initial conditions to be established for the model due to the addition of new branches to the model. These initial conditions were then used as a hotstart for modelling the design events through the catchment

Option Z5-3 was modelled by reducing the roughness along the flow path of cross sections through this zone. This aimed to reflect the removal of obstructions to the flow that would result from the demolition of the buildings for properties where voluntary purchase has been proposed.

To model the effects of house raising, the assessment for Option Z5-4 used the result files from existing conditions in the catchment. Where house raising was identified as feasible, the floor level of the property was raised by 1.0 m in the damage assessment.

Option Z5-5 was modelled by removing the weirs from the MIKE 11 model which were used in the existing conditions to represent Mirrabooka Road and Weringa Avenue. As for Options Z5-1 and Z5-2, an additional cross section (MINNEGAN 0.939) was added to the model. The profile of each of the cross sections between MINNEGAN 0.835 and MINNEGAN 1.086 was also adjusted to reflect the rock lined channel. These changes required new initial conditions to be established for the model. These initial conditions were used to hotstart the modelling of design events.

Zone 6

The lower section of Minnegang Creek is represented in the MIKE 11 model by the cross sections along the MINNEGAN branch from chainage 1.086 to 1.960. The Manning's n for existing conditions in these cross sections range from 0.045 to 0.07 to represent the creek. Values of 0.1 were adopted to model the fences at the rear of the properties.

To model the changes to the vegetation, the following Manning's n values were adopted for the cross sections:

- main channel - 0.04 to represent clean, winding stream with some pools and shoals
- channel edges - 0.05 to represent scattered bushes
- overbank - 0.035 to represent short grass typical of a residential garden

At the location of any fences in the cross sections, a value of 0.1 was maintained from the existing model.

Zone 7

To model the effects of removing the culvert (assessed as Option Z7-1), the MIKE 11 model was changed by removing the ILLAWEIR branch, which modelled the weir above the culvert. The culvert structure was also removed from the model.

These changes required new initial conditions to be established for the model due to the removal of a branch from the model. These initial conditions were then used as a hotstart for modelling the design events through the catchment.

Option Z7-2 was modelled by adding a third culvert into the culvert structure at MINNEGAN 1.971. The cross sections directly upstream of the culverts (namely MINNEGAN 2.017 and 2.029) were modified to reflect excavation within the channel to direct flows through the three culverts.

Option Z7-3 was not modelled due to the complex two dimensional flow and tailwater conditions in Minnegang Creek and Lake Illawarra.

Zone 8

The options have been modelled in MIKE 11 by modifying the cross sections on each tributary to reflect the proposed changes to levels and hydraulic roughness. The modified cross sections for the modelling of each option are shown in Table E-1.

Table E-1 Changes to MIKE 11 model from proposed options in Zone 8

Option	Modified cross sections
Zone 8 Option 1	MINNEGAN 0.000, 0.053, 0.061
Zone 8 Option 2 and 7	RANCHBY1 0.000, 0.045
Zone 8 Option 3	RANCHBY2 0.000, 0.044, 0.052
Zone 8 Option 4	RANCHBY3 0.049, 0.057
Zone 8 Option 5	RANCHBY4 0.008, 0.057

Note: Zone 8 Option 6 was not modelled in MIKE 11

Zone 9

Modelling changes to this zone is difficult as the existing overland flow path passes through numerous properties. If a defined easement and flow path was to be provided, then it would be more reasonable to create this through one property only to contain the flood extents and reduce the property damages.

Option Z9-1 was modelled by reducing the roughness of the cross section at CANBERRA 0.155 to model the effect of the vacant block between 75 and 77 Denise Street. The roughness was decreased from 0.1 (to model obstructions to flow) to 0.035 to represent the short grass in the vacant block.

Option Z9-2 was modelled by modifying the cross section at DENISE2 0.073 to include a grassed swale, approximately 4 m wide and 0.5 m deep.

ECONOMIC ASSESSMENT AND FLOOD AFFECTED PROPERTIES

Table E-2 shows the number of properties affected by above-floor and yard flooding after implementation of each of the management options. It also presents a summary of the economic assessment for each management option.

Table E-2 Economic assessment and flood-affected properties

Option	AAD	NPV	Cost	B/C ratio	Above-floor flooding					Property flooding				
					PMF	1%	2%	5%	20%	PMF	1%	2%	5%	20%
Exist	$ 63,600	-	-	-	20	17	17	13	5	59	48	44	43	35
Z2-1	$ 47,700	$ 220,000	$ 433,023	0.51	19	16	14	11	4	57	46	41	39	31
Z2-2	$ 47,200	$ 230,000	$ 521,808	0.44	19	16	14	11	4	57	46	41	39	31
Z2-3	$ 56,600	$ 100,000	$ 260,482	0.38	19	16	16	12	4	57	47	43	42	33
Z2-4	$ 58,900	$ 70,000	$ 54,336	1.29	19	16	16	12	4	59	48	44	43	35
Z3-1	$ 63,600	$ -	$ 7,690	0.00	20	17	17	13	5	59	48	44	43	35
Z4-1	$ 50,300	$ 190,000	$ 529,584	0.36	20	14	12	9	5	59	45	41	38	33
Z4-2	$ 54,000	$ 130,000	$ 233,761	0.56	20	15	13	10	5	59	46	43	40	33
Z4-3	$ 43,700	$ 280,000	$ 631,776	0.44	20	10	9	8	5	59	42	37	37	34
Z5-1	$ 31,900	$ 440,000	$ 1,961,876	0.22	7	5	5	5	4	47	37	33	31	27
Z5-2	$ 33,000	$ 420,000	$ 1,936,150	0.22	7	5	5	5	4	47	37	34	32	28
Z5-3	$ 36,900	$ 370,000	$ 1,550,736	0.24	13	7	7	6	4	51	41	37	35	31
Z5-4	$ 43,500	$ 280,000	$ 540,840	0.52	11	7	7	6	4	59	48	44	43	35
Z5-5	$ 32,500	$ 430,000	$ 2,005,930	0.21	6	5	5	5	4	44	33	31	30	28
Z5-6	$ 33,000	$ 420,000	$ 1,882,870	0.22	7	5	5	5	4	47	37	34	32	28
Z6-1	$ 63,600	$ -	$ 47,902	0.00	20	17	17	13	5	59	48	44	43	35
Z7-1	$ 57,500	$ 90,000	$ 35,616	2.53	20	16	16	12	5	59	48	43	43	34
Z7-2	$ 63,500	$ -	$ 24,276	0.00	20	17	17	13	5	59	48	43	43	34
Z8-1	$ 63,600	$ -	$ 6,133	0.00	20	17	17	13	5	59	48	44	43	35
Z8-2	$ 62,700	$ 10,000	$ 4,940	2.02	20	17	17	13	5	59	48	44	43	35
Z8-3	$ 63,600	$ -	$ 9,221	0.00	20	17	17	13	5	59	48	44	43	35
Z8-4	$ 63,600	$ -	$ 2,511	0.00	20	17	17	13	5	59	48	44	43	35
Z8-5	$ 63,600	$ -	$ 3,139	0.00	20	17	17	13	5	59	48	44	43	35
Z8-6	$ 63,600	$ -	$ 6,134	0.00	20	17	17	13	5	59	48	44	43	35
Z8-7	$ 62,700	$ 10,000	$ 4,277	2.34	20	17	17	13	5	59	48	44	43	35
Z9-1	$ 63,600	$ -	$ 30,084	0.00	20	17	17	13	5	59	48	44	43	35
Z9-2	$ 62,600	$ 20,000	$ 8,590	2.33	19	16	16	12	4	58	47	43	42	34

Appendix F

HYDROLOGIC MODELLING

Appendix F
Hydrologic Modelling

INTRODUCTION

Hydrologic modelling of the Minnegang Creek catchment was carried out as part of the Minnegang Creek Flood Study using RAFTS v 5.1 (WP Software 1996). The hydrology of the catchment is unaffected by changes to the creek through the implementation of potential mitigation options. Therefore, no changes to the hydrologic modelling were required as part of the Floodplain Risk Management Study. Full details of the hydrologic modelling were provided in the Minnegang Creek Flood Study. This section provides a summary of the important features of the modelling.

MODEL CONSTRUCTION

Catchment and sub-catchment boundaries

The catchment boundary was determined from the map of the Minnegang Creek catchment provided by Council. Sixty-four sub-catchments were defined, based on contour and cadastral maps, aerial photography and the requirements of the hydraulic modelling.

Hydraulic roughness

The hydraulic roughness of each sub-catchment is represented by a Manning's n value. The following roughness values were adopted for use in the model:

- 0.015 - impervious area (typical of asphalt or rough concrete surface)
- 0.025 - pervious area (typical of short grass)

The impervious area of each sub-catchment was determined by measuring the developed area within the catchment as well as the area of roads. The impervious area was then calculated using the following assumed percentage imperviousness:

- 95% imperviousness for roads
- 40% imperviousness for developed areas (largely medium density residential)

Rainfall losses

Rainfall losses were modelled using the initial/continuing loss method. The adopted losses are presented in Table F-1.

Table F-1 Initial and continuing losses

	Impervious areas	Pervious areas
Initial loss (mm)	1.5	15
Continuing loss (mm/hr)	0.0	2.5

RAINFALL DATA

Council's intensity-frequency-duration (IFD) data for the Wollongong area was used for storm durations of 30 minutes, 60 minutes, 2 hours, 3 hours and 6 hours. The intensities for the 90 minute storm events were derived in RAFTS using the IFD coefficients for Wollongong. Temporal patterns for all storm durations were generated by RAFTS in accordance with methods described in *Australian Rainfall and Runoff (AR&R)* (IEAust, 1987). The Probable Maximum Precipitation (PMP) was derived in accordance with the Generalised Short - Duration Method as described in *Bulletin 53: The estimation of Probable Maximum Precipitation in Australia* (Bureau of Meteorology, 1994).

CALIBRATION AND SENSITIVITY ANALYSIS

Due to the absence of any streamflow gauging stations within the Minnegang Creek catchment, it was not possible to calibrate the RAFTS model to match recorded discharges. Therefore the Probabilistic Rational Method (PRM) was used to check the flows obtained form the RAFTS model.

PRM estimates of the flow for the entire catchment were determined for the 1%, 5% and 20% AEP events. These were then compared to the peak flow determined for these events from RAFTS. The flows from RAFTS compared well with the PRM flows.

The parameters used in the RAFTS model, such as rainfall losses, imperviousness and Manning's n value, were varied to assess the sensitivity of the model to the adopted parameters. The results indicated that reasonable variations to the adopted parameters would not significantly alter the results and the parameters discussed above were therefore adopted for the modelling.

Appendix G

HYDRAULIC MODELLING

Appendix G

Hydraulic modelling

INTRODUCTION

Hydraulic modelling for the *Minnegang Creek Flood Study* (KBR 2002) was undertaken using MIKE 11 v3.2 (Danish Hydraulic Institute 1998). Full details of the model set up, verification and limitations are provided in the flood study. This section provides a brief summary of the information on hydraulic modelling that was included in the flood study.

To model each of the mitigation options, the MIKE 11 model was modified to represent the changes to the creek and/or overland flow paths proposed as part of this Floodplain Risk Management Study. Details of the changes made to represent each mitigation option are provided in Section 6 of this report.

EXTENT OF MODELLING

Although the RAFTS model was required to cover the entire catchment area contributing to generation of runoff, the extent of the MIKE 11 model was limited to those areas requiring detailed investigation as part of the study, including:

- Minnegang Creek, from its headwaters upstream of Ranchby Avenue to Lake Illawarra;
- The tributary from Gordon Crescent, under Ranchby Avenue and confluencing immediately upstream of Lake Heights Road;
- The tributary from Melinda Grove, under Gilgandra Street and confluencing at the southern end of Barina Park;
- The three minor branches draining the undeveloped area between Ranchby Avenue and Hilltop Avenue; and
- The minor branch draining the area between Canberra Road and Minnegang Creek.

In addition to these overland flow paths, two branches of the catchment's piped drainage system were also incorporated into the MIKE 11 model. The first branch runs from the grated inlet pit at the southern end of Barina Park, under Mirrabooka Road and discharges into Minnegang Creek at an outlet downstream of Weringa Avenue. The second branch conveys a section of Minnegang Creek from the eastern end of the vacant lot between Lake Heights Road and Barina Avenue, linking into the first piped drainage branch approximately 20m downstream of the grated inlet pit in Barina Park.

MODEL CONSTRUCTION

A total of 20 river branches, 137 cross sections, 14 culverts and 14 weirs were used in the MIKE 11 model to describe the topography of the catchment and existing structures to a suitable level of detail.

River branches

River branches are used to define the various flow paths in the model. For this study, branches describe three main types of flow path:

- overland flow paths
- weir flow over roadways with a culvert crossing
- a branch of the piped drainage system.

The hydraulic characteristics of each flow path are represented by cross sections and structures located along each branch in the model.

Cross sections

Cross sections through the overland flow system within the Minnegang Creek catchment were generally in the form of survey strings created by G.A. Goodman Surveys in accordance with survey briefs provided to Council by KBR.

Cross sections within Barina Park were extracted from a full detailed survey of the park performed by G.A. Goodman Surveys as part of the July 2000 survey. Cross section locations were determined such that the full extents of the park and variation in natural surface levels were incorporated into the cross sections. This ensured the most accurate representation of the detention storage available within the park in the MIKE 11 model.

Structures

Culvert details for the Minnegang Creek crossings under Lake Heights Road and Northcliffe Drive, specifically culvert sizes, lengths and invert levels, were sourced from the two surveys of the catchment. A third culvert, located underneath a carpark access road adjacent to the Lake Illawarra Yacht Club, was also incorporated into the model. The stage/discharge relationship for each culvert is automatically calculated by MIKE 11 based on the geometry of the culvert and the adjacent cross sections.

Cross sections with the potential to act as weirs were identified from a field inspection by KBR carried out in July 2000 and entered into the MIKE 11 model as broad-crested weirs. Weir locations generally consist of cross sections along a roadway crown that effectively form a control point for flow, ponding water on one side of the road until the weir level is exceeded. A weir was also located along the embankment crest of the Barina Park detention basin, which forms the high level outlet for the basin.

The concrete pedestrian bridge between Jane Ave and Denise Street was modelled in MIKE 11 as a weir and irregular culvert. The weir was defined as a broad-crested weir, using a profile along the centre of the bridge structure. The culvert was defined using the irregular culvert option in MIKE 11, which requires a depth-width relationship. This was determined from the survey of the creek carried out by Council's surveyors in December 2001.

Roughness coefficients

Manning's n values for each cross section were derived from field inspections of the study area, photographs from the detailed survey, recognised hydraulics reference texts and previous experience on projects of this nature. Typical Manning's n values used in the MIKE 11 model are shown in Table G-1.

Table G-1 Typical Manning's n values used in the hydraulic model

Description	Manning's n value
Road and driveway surfaces	0.018
Short length grass	0.035
Long length grass	0.04 – 0.06
Main creek channel	0.04 – 0.07
Vegetated overbank areas	0.05 – 0.08
Residential blocks (including structures and gardens)	0.1

BOUNDARY CONDITIONS

Boundary conditions are generally specified as either *water levels* to simulate tailwater levels, or *discharges* to simulate runoff entering the model.

Tailwater levels

Tailwater levels were derived from the *Lake Illawarra Flood Study* (Lawson & Treloar 2000). For the purposes of this study, a lake level of corresponding AEP to the flood event in the Minnegang Creek catchment has been adopted. The levels correspond to a point located approximately 750m south east of the mouth of Minnegang Creek within Griffins Bay, and are summarised in Table G-2.

Table G-2 Tailwater levels adopted for hydraulic modelling

Annual exceedence probability	Lake level (m AHD)
20%	1.40
5%	1.81
2%	2.03
1%	2.30
PMF	3.24

Discharges

MIKE 11 also requires that boundary conditions, in the form of runoff hydrographs, be specified at the upstream extent of all model branches that are not otherwise connected at a junction. For this study, additional hydrographs have been specified at appropriate locations within the model in order to increase the definition of the model and thus more accurately simulate the flooding response of the catchment. Thus, flow hydrographs for local sub-catchments generated by the RAFTS model were inserted at the corresponding locations within the MIKE 11 model.

INITIAL CONDITIONS

In order to avoid start-up instabilities, it was necessary to use two base flow runs to wet the model and establish a steady state prior to introducing a design event. The first base flow run was used to establish a steady flow through the model. This involved:

- high initial water levels throughout the catchment, sufficient to flood the entire catchment;
- constant discharges of 0.1 m^3/s in all model branches; and

- a time-varying lake level, reducing from the initial high water level down to 1.0 m AHD.

Reducing the lake level at a controlled rate allowed water to slowly drain out of the model, avoiding instabilities that result from rapidly increasing or decreasing water levels. The conditions at the end of this run were then used as initial conditions to 'hot start' a second base flow run to establish the model tailwater level as the lake level corresponding to the AEP of each design event. This involved:

- constant discharges of 0.05 m^3/s in all model branches; and
- a time-varying lake level, increasing from 1.0m AHD to the tailwater level corresponding to each design event (ranging from 1.40m AHD for the 20% AEP design event to 3.24 m AHD for the PMF event).

A separate run was undertaken for each design event to be modelled, creating conditions that were then used to "hot start" each event run.

When running the design events, it was necessary to modify the input hydrographs at the upstream extent of all branches in order to maintain the stability of the model established during the base flow runs. To do this, base flows of 0.05 m^3/s were maintained in the hydrographs until they were exceeded by flood flows. While early flood levels are likely to be elevated by this technique, peak flood levels are not significantly affected since the excess flows will have drained away by the time the peak occurs.

CALIBRATION AND VERIFICATION

Due to the absence of any streamflow gauging stations within the Minnegang Creek catchment, it was not possible to undertake a full calibration of the hydrologic and hydraulic models.

However, due to the importance of confirming that the MIKE 11 model is at least providing a realistic simulation of the catchment response to rainfall, a limited verification procedure was undertaken for the 17 August 1998 event. This was the only storm event for which continuous rainfall data and peak flood levels were available for the catchment.

The verification procedure involved:

- generating runoff hydrographs with the RAFTS model using historical rainfall data sourced from Council;
- routing the hydrographs through the MIKE 11 model; and
- comparing the resulting peak water levels with the recorded flood levels.

Peak flood levels for this event were recorded at four locations within the catchment, all of which lie along Minnegang Creek. Table G-3 lists the recorded flood levels and provides a description of each location. It also presents the results of the verification procedure.

The tailwater level in the MIKE 11 model was set at 1.2m for this verification based on the level of Lake Illawarra in August 1998 as recorded in the *Lake Illawarra Flood Study* (Lawson & Treloar 2000).

Table G-3 Recorded flood levels for the 17 August 1998 event

Point	Location	Recorded peak water level (m AHD)	Modelled peak water level (m AHD)	Difference (m)
A	Immediately upstream of the Lake Heights Road culvert	29.58	29.34	-0.24
B	At the boundary of No. 68 Barina Avenue and No. 71 Lake Heights Road	27.68	27.99	+0.31
C	At the boundary of No. 63 Mirrabooka Road and No. 94 Weringa Avenue	19.79	19.73	-0.06
D	Behind the rear boundary of No. 61 Denise Street	4.93	4.99	-0.06

Summary of the verification

The verification procedure outlined above has served to confirm that the MIKE 11 model, constructed to represent existing conditions in the catchment, is appropriately simulating the response of the catchment to the 17 August 1998 event.

The differences between the recorded and modelled flood levels can be explained by:

- interpolation of modelled levels between surveyed cross sections; or
- blockage scenarios, which could reasonably have occurred during the 1998 event.

It should be noted that the implications of culvert blockage in the catchment was addressed in accordance with Council's *Conduit Blockage Policy* (Wollongong City Council 2001a) during the modelling of design events in the catchment. As discussed in the main report, the floodplain management study has adopted a more practical application of this policy, resulting in the revision of design flood levels for the 20% AEP event. However, the revised levels are only used in the context of the floodplain management study, specifically for use in the assessment of flood mitigation options.

MODEL SENSITIVITY ANALYSES

Sensitivity analyses were undertaken as part of the modelling process in order to gauge the impact of the adopted hydraulic roughness parameters and tailwater levels on the flood levels predicted by the MIKE 11 model.

Hydraulic roughness

Hydraulic roughness, in terms of Manning's n values, is specified in MIKE 11 in two ways. Firstly, a global roughness factor is set as a default value, which applies to all cross sections in the model. This can then be modified at any point on any cross section by specifying a relative resistance factor. The MIKE 11 model developed for this study is based on a global roughness factor of 0.01, which allows the required relative resistances to be determined quite easily. In order to carry out a sensitivity analysis on the hydraulic roughness, the global roughness parameter was varied while the relative resistance factors remained unchanged.

Decreasing the global roughness, resulted in a decrease in flood levels, although this attenuating effect was small and limited to those sections of Minnegang Creek confined to a formalised channel and relatively unaffected by hydraulic structures. Increasing the global roughness resulted in a significant increase in flood levels, however, again this was limited to those sections of the creek confined to a formalised channel.

Although the results of this analysis serve to illustrate that there is a moderate degree of sensitivity to the adopted roughness values, the original estimates of the Manning's n values are considered appropriate for the Minnegang Creek catchment based on previous experience on projects of this nature.

In addition to checking the sensitivity of the model to variations in the global roughness, the value adopted to represent the roughness of residential properties was varied while keeping the global roughness constant. This revealed that adopting the more conservative value of 0.15 had little impact on resulting flood levels, which further justified the use of what was considered a more reasonable value of 0.1.

Tailwater levels

A separate sensitivity analysis was undertaken to determine the impact of the adopted tailwater level in Lake Illawarra on the modelled flood levels in Minnegang Creek for the 1% AEP design event. The tailwater levels used for the comparison were the 50% AEP flood level of 1.11 m AHD and the PMF flood level of 3.24 m AHD.

The results show that the adopted tailwater level has very little effect on flooding within the catchment. Impacts are limited to the lower reaches of Minnegang Creek where the lake level encroaches on cross sections before the rainfall event has translated downstream.

CRITICAL STORM DURATION ANALYSIS

The critical storm duration for the catchment, based on the peak flow rates generated by the RAFTS modelling, was found to be the 2 hours for each flood event modelled.

In order to verify the RAFTS result, since the critical storm duration is more appropriately determined from a comparison of peak flood levels in the catchment, the storm durations modelled in RAFTS were also modelled in MIKE 11. Accordingly, the 30 minute, 60 minute, 90 minute, 2 hour, 3 hour and 6 hour storm durations for the 1% AEP event were modelled. The subsequent analysis of the results showed that the 2 hour storm duration was generating the critical flood levels in the catchment.

Appendix H

MITIGATION SCHEMES - PRELIMINARY COSTING

Scheme 1					
Item	**Description**	**Unit**	**Quantity**	**Rate**	**Cost**
1.0	**House costs**				
1.1	Property purchase	Item	6	$210,000	$1,260,000
1.2	House raising	Item	1	$45,000	$45,000
2.0	**Excavation**				
2.1	Demolish existing structures including transport within 10 km	m^2	800	$40	$32,000
2.2	Clear and remove vegetation	m^2	2,010	$0.40	$804
2.3	Strip topsoil (light soil)	m^2	2,010	$4.25	$8,543
2.4	Excavation to reduce levels (light soil)	m^3	-	$16.10	-
2.4	Excavation for proposed channel including support and dewatering	m^3	2,760	$40	$110,400
2.5	Placement and compaction of fill	m^3	-	$6	-
2.7	Construction of rock lining	m^2	1,920	$70	$134,400
2.8	Construction of concrete v-drain	m^3	-	$180	-
3.0	**Culvert installation**				
3.1	Excavate (pavement and subsoil)	m^3	190	$40	$7,600
3.2	Supply and install 1.5m dia RCP (includes backfill with excavated material)	m	40	$650	$26,000
3.3	Reinstate pavement	m^2	96	$100	$9,600
3.4	Headwalls for culverts	Item	2	$2,600	$5,200
4.0	**Landscaping**				
4.1	Trim and grade to final levels	m^2	2,010	$2.20	$4,422
4.2	Spread topsoil and seed	m^2	2,010	$7	$14,070
4.3	Level, grade, prepare and seed playing fields	ha	-	$27,000	-
5.0	**Miscellaneous**				
5.1	Erosion and sedimentation controls	Item	12	$70	$840
5.2	Flood depth indicators	Item	-	$250	-
5.3	Flood warning signs	Item	2	$280	$560
5.4	Geotechnical investigation	Item	1	$10,000	$10,000
5.5	Spillway construction	Item	1	$40,000	$40,000
	SUBTOTAL				**$1,709,439**
	Contingencies @ 20%				**$341,888**
5.6	Community education programs	Item	1	$90,415	$90,415
5.7	Maintenance of catchment flow paths (initial investigation)	Item	1	$5,000	$5,000
	TOTAL (excluding GST)				**$2,146,742**

Scheme 2					
Item	**Description**	**Unit**	**Quantity**	**Rate**	**Cost**
1.0	**House costs**				
1.1	Property purchase	Item	6	$210,000	$1,260,000
1.2	House raising	Item	1	$45,000	$45,000
2.0	**Excavation**				
2.1	Demolish existing structures including transport within 10 km	m^2	800	$40	$32,000
2.2	Clear and rem ove vegetation	m^2	2,010	$0.40	$804
2.3	Strip topsoil (light soil)	m^2	2,010	$4.25	$8,543
2.4	Excavation to reduce levels (light soil)	m^3	-	$16.10	-
2.4	Excavation for proposed channel including support and dewatering	m^3	2,760	$40	$110,400
2.5	Placement and compaction of fill	m^3	-	$6	-
2.7	Construction of rock lining	m^2	1,920	$70	$134,400
2.8	Construction of concrete v-drain	m^3	-	$180	-
3.0	**Culvert installation**				
3.1	Excavate (pavement and subsoil)	m^3	-	$40	-
3.2	Supply and install 1.5m dia RCP (includes backfill with excavated material)	m	-	$650	-
3.3	Reinstate pavement	m^2	-	$100	-
3.4	Headwalls for 1350mm culverts	Item	2	$2,000	$4,000
4.0	**Landscaping**				
4.1	Trim and grade to final levels	m^2	2,010	$2.20	$4,422
4.2	Spread topsoil and seed	m^2	2,010	$7	$14,070
4.3	Level, grade, prepare and seed playing fields	ha	-	$27,000	-
5.0	**Miscellaneous**				
5.1	Erosion and sedimentation controls	Item	12	$70	$840
5.2	Flood depth indicators	Item	-	$250	-
5.3	Flood warning signs	Item	2	$280	$560
5.4	Geote chnical investigation	Item	1	$10,000	$10,000
5.5	Spillway construction	Item	1	$40,000	$40,000
	SUBTOTAL				**$1,665,039**
	Contingencies @ 20%				**$333,008**
5.6	Community education programs	Item	1	$90,415	$90,415
5.7	Maintenance of catchment flow paths (initial investigation)	Item	1	$5,000	$5,000
	TOTAL (excluding GST)				**$2,093,462**

Appendix I

FLOOD DAMAGE ASSESSMENT SUMMARIES

SUMMARY OF DAMAGES

Existing Conditions

DAMAGES CAUSED BY FLOOD EVENTS

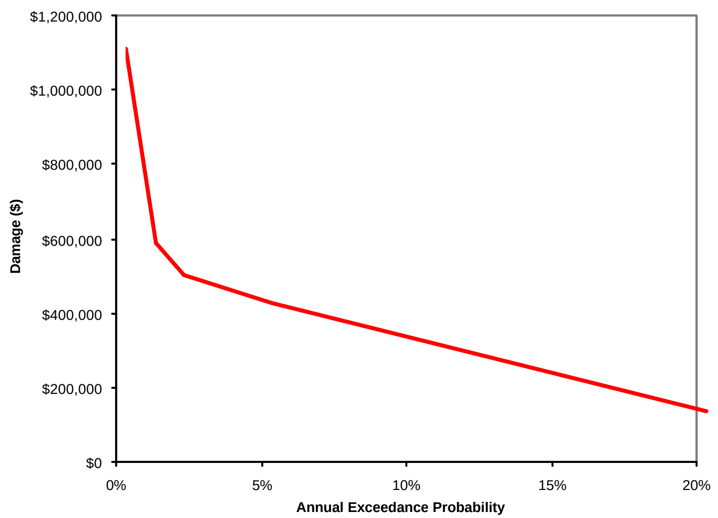
EVENT	TANGIBLE DAMAGES						INTANGIBLE DAMAGES		**TOTAL DAMAGES**
	Damage								
Annual Exceedance Probability	Direct Building Damage	Direct Property Damage	Total Direct Damage	Indirect Residential	Infrastructure Damage	Total Tangible Damages	Residential Dwellings Flooded	Residential Properties Flooded	
20%	$27,000	$33,000	$60,000	$18,000	$30,000	$108,000	5	35	**$108,000**
5%	$129,000	$91,000	$220,000	$66,000	$110,000	$396,000	13	43	**$396,000**
2%	$160,000	$104,000	$264,000	$79,000	$132,000	$475,000	17	44	**$475,000**
1%	$193,000	$118,000	$311,000	$93,000	$156,000	$560,000	17	48	**$560,000**
0%	$350,000	$250,000	$600,000	$180,000	$300,000	$1,080,000	20	59	**$1,080,000**

INDIRECT AND INTANGIBLE

Tangible	
Residential indirect as % of direct	30%
Infrastructure as % of total direct	50%
Intangible	
Social Damage	
Residential as % of direct	N/A
Industrial as % of direct	N/A
Environmental	N/A
Actual damage as % of potential	100%

* The Annual Average Damage has been calculated as the area under the Damages vs AEP graph. The area between the 0 and 1% AEP (PMF and 100yr ARI) events has been calculated using Simpson rule while the remainder has been calculated by trapezoids.

DAMAGES vs AEP



AVERAGE ANNUAL DAMAGE*

For Events of	Damage
20% to 5 % AEP	$37,800
5% to 2% AEP	$13,100
2% to 1% AEP	$5,200
1% AEP to PMF	$7,500
Total Average Annual Damage	
Potential	$63,600
Actual	$63,600
Present Worth of Damage	
Term = 50yrs, Interest = 4%pa	$1,370,000
Term = 50yrs, Interest = 7%pa	**$880,000**
Term = 50yrs, Interest = 10%pa	$630,000

SUMMARY OF DAMAGES

Scheme 1

DAMAGES CAUSED BY FLOOD EVENTS

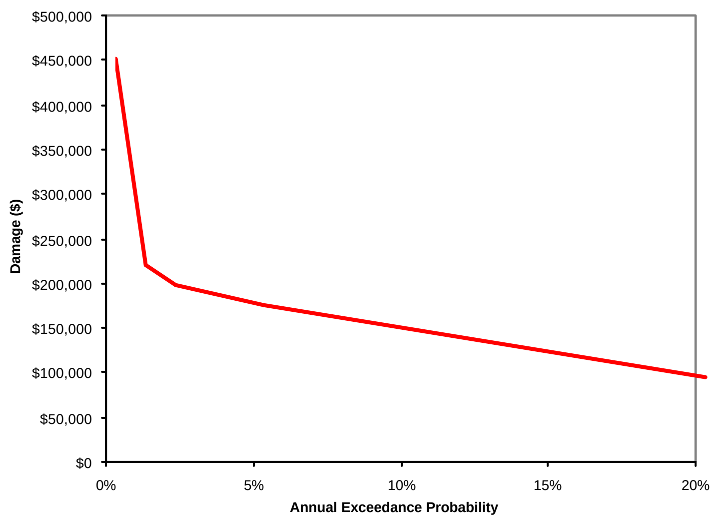
EVENT	TANGIBLE DAMAGES						INTANGIBLE DAMAGES		TOTAL DAMAGES
	Damage								
Annual Exceedance Probability	Direct Building Damage	Direct Property Damage	Total Direct Damage	Indirect Residential	Infrastructure Damage	Total Tangible Damages	Residential Dwellings Flooded	Residential Properties Flooded	
20%	$13,000	$32,000	$45,000	$14,000	$23,000	$82,000	3	28	**$82,000**
5%	$27,000	$64,000	$91,000	$27,000	$46,000	$164,000	4	33	**$164,000**
2%	$31,000	$72,000	$103,000	$31,000	$52,000	$186,000	4	35	**$186,000**
1%	$34,000	$82,000	$116,000	$35,000	$58,000	$209,000	4	38	**$209,000**
0%	$71,000	$173,000	$244,000	$73,000	$122,000	$439,000	6	48	**$439,000**

INDIRECT AND INTANGIBLE

Tangible	
Residential indirect as % of direct	30%
Infrastructure as % of total direct	50%
Intangible	
Social Damage	
Residential as % of direct	N/A
Industrial as % of direct	N/A
Environmental	N/A
Actual damage as % of potential	80%

* The Annual Average Damage has been calculated as the area under the Damages vs AEP graph. The area between the 0 and 1% AEP (PMF and 100yr ARI) events has been calculated using Simpson rule while the remainder has been calculated by trapezoids.

DAMAGES vs AEP



AVERAGE ANNUAL DAMAGE*

For Events of	Damage
20% to 5 % AEP	$18,500
5% to 2% AEP	$5,300
2% to 1% AEP	$2,000
1% AEP to PMF	$2,900
Total Average Annual Damage	
Potential	$28,700
Actual	$22,960
Present Worth of Damage	
Term = 50yrs, Interest = 4%pa	$490,000
Term = 50yrs, Interest = 7%pa	**$320,000**
Term = 50yrs, Interest = 10%pa	$230,000

SUMMARY OF DAMAGES

Scheme 2

DAMAGES CAUSED BY FLOOD EVENTS

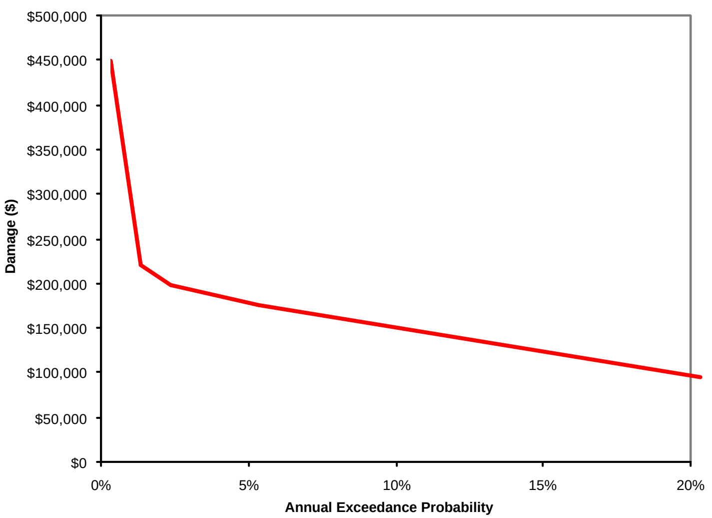
EVENT	TANGIBLE DAMAGES						INTANGIBLE DAMAGES		TOTAL DAMAGES
Annual Exceedance Probability	Damage: Direct Building Damage	Damage: Direct Property Damage	Damage: Total Direct Damage	Damage: Indirect Residential	Infrastructure Damage	Total Tangible Damages	Residential Dwellings Flooded	Residential Properties Flooded	
20%	$13,000	$32,000	$45,000	$14,000	$23,000	$82,000	3	28	**$82,000**
5%	$27,000	$64,000	$91,000	$27,000	$46,000	$164,000	4	33	**$164,000**
2%	$31,000	$72,000	$103,000	$31,000	$52,000	$186,000	4	35	**$186,000**
1%	$34,000	$82,000	$116,000	$35,000	$58,000	$209,000	4	38	**$209,000**
0%	$71,000	$172,000	$243,000	$73,000	$122,000	$438,000	6	48	**$438,000**

INDIRECT AND INTANGIBLE

Tangible	
Residential indirect as % of direct	30%
Infrastructure as % of total direct	50%
Intangible	
Social Damage	
Residential as % of direct	N/A
Industrial as % of direct	N/A
Environmental	N/A
Actual damage as % of potential	80%

* The Annual Average Damage has been calculated as the area under the Damages vs AEP graph. The area between the 0 and 1% AEP (PMF and 100yr ARI) events has been calculated using Simpson rule while the remainder has been calculated by trapezoids.

DAMAGES vs AEP



AVERAGE ANNUAL DAMAGE*

For Events of	Damage
20% to 5 % AEP	$18,500
5% to 2% AEP	$5,300
2% to 1% AEP	$2,000
1% AEP to PMF	$2,900
Total Average Annual Damage	
Potential	$28,700
Actual	$22,960
Present Worth of Damage	
Term = 50yrs, Interest = 4%pa	$490,000
Term = 50yrs, Interest = 7%pa	**$320,000**
Term = 50yrs, Interest = 10%pa	$230,000