GOSFORD CITY COUNCIL

MUDFLAT CREEK FLOODPLAIN RISK MANAGEMENT STUDY

AUGUST 2008

WEBB, McKEOWN & ASSOCIATES PTY LTD

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MUDFLAT CREEK FLOODPLAIN RISK MANAGEMENT STUDY

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FOREWORD

The NSW State Government's Flood Prone Land Policy provides a framework to ensure the sustainable use of floodplain environments. The policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

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

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

1. *Formation of a Floodplain Risk Management Committee*
   - an advisory committee of Council which includes representatives of relevant Government authorities and the community.
2. *Data Collection*
   - compilation of existing data and collection of additional data.
3. *Flood Study*
   - determine the nature and extent of the flood problem.
4. *Floodplain Risk Management Study*
   - evaluates management options for the floodplain in respect of both existing and proposed development.
5. *Floodplain Risk Management Plan*
   - involves formal adoption by Council of a plan of management for the floodplain.
6. *Implementation of the Plan*
   - construction of flood mitigation works to protect existing development,
   - use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Mudflat Creek Floodplain Risk Management Study constitutes the fourth stage of the management process for Mudflat Creek and its catchment area. Webb, McKeown & Associates were commissioned by Gosford City Council to prepare this floodplain risk management study on behalf of Council's Floodplain Risk Management Committee. The study project was jointly funded by Gosford City Council and State and Federal Governments. The report documents the work undertaken and provides a summary of the floodplain management measures investigated.

EXECUTIVE SUMMARY

The NSW Government's Flood Prone Land Policy provides for:
- a framework to ensure the sustainable use of floodplain environments,
- solutions to flooding problems,
- a means of ensuring new development is compatible with the flood hazard.

Implementation of the Policy requires a staged approach, the fourth stage of which is the preparation of a Floodplain Risk Management Study to evaluate potential floodplain management measures.

The Mudflat Creek Flood Study (Stage 3) was initiated as a result of flooding of local roads and residential areas, most recently in July 1988, January 1989, February 1990, February 1992 and February 2002. It was completed by Webb, McKeown & Associates for Gosford City Council in 2006 and incorporates the floodplain between Fraser Road and Brisbane Water.

The specific aims of the present Mudflat Creek Floodplain Risk Management Study are to:
- review the nature and extent of the flood hazard in light of the recently completed Flood Study (2006),
- assess a range of management measures for existing and proposed development,
- determine potential impacts of future development and assess measures to mitigate these impacts (if required).

Description of Creek Systems: Mudflat Creek has a catchment area of approximately 123 hectares and lies entirely within the boundaries of Gosford City Council. It drains into Brisbane Water through the lower area of Killcare.

A large portion of the lower section of the catchment has been developed for residential purposes. This takes in the area bounded by Fraser Road, Stanley Street and Hardys Bay. The upper section of the catchment largely comprises natural bushland or rural land type, although there is some residential development predominantly around Stewart Street, The Scenic Road and Wards Hill Road.

Within the study area there are two road crossings over the creek at Fraser Road and Noble Road. Between these crossings the creek runs through the rear of residential properties. The majority of which contain drainage easements. Overbank areas in many areas are confined due to the presence of fences, garden beds and sheds. Residents have also constructed footbridges to gain access over the creek. Upstream of Fraser Road the creek is confined to a relatively deep and narrow channel on a steep gradient.

Building Floors Inundated and Tangible Flood Damages: The following table indicates the number of building floors inundated and the tangible flood damages.

Table i): Buildings Inundated and Tangible Damages

Design Flood	Building Floors Inundated	Tangible Damages
PMF	22	$890,000
0.5% AEP	6	$105,000
1% AEP	4	$80,000
2% AEP	3	$55,000
5% AEP	3	$40,000
10% AEP	2	$25,000
20% AEP	2	$15,000

Note: The values shown are assuming 100% blockage at Noble Road bridge and Fraser Road culverts. All the buildings affected are residential as there are no commercial or industrial buildings.
These values have changed slightly from those provided in the Flood Study due to re development of 2 Noble Road.

Based on the above values the average annual damages are $15,000.

Floodplain Risk Management Measures: A list of all possible floodplain risk management measures which could be applied in the study area were initially developed. A matrix was prepared to assess them in terms of their suitability and effectiveness for reducing social, ecological, environmental, cultural and economic impacts. As part of this process a number of measures were identified as not being worthy of further consideration. A more detailed assessment of the remaining measures were then undertaken and the results are summarised in Tables ii) and iii). Table ii) provides an overview of the management measures considered and Table iii) provides a matrix of results from the analysis of these management measures.

Table ii): Floodplain Management Measures Considered

Description	Section in Report	To be Considered for Inclusion in Plan
Flood Mitigation Dams	4.2.1	No due to high economic and environmental cost
Construct new Retarding Basins	4.2.2	No due to high economic and environmental cost
On Site Detention	4.2.3	Provides minimal reduction in flood level but will be considered to mitigate the impacts of future development.
Modify Existing Farm Dams	4.2.4	Not practical to use existing farm dams but basin at Wards Hill Road discussed in Section 5.2.5. Dam No. 3 to be removed or modified. DECC/Council to review policies on potential hazard of failure of unregulated farm dams.
Channel Modifications	4.3	Individual measures discussed in Section 5
Levees, Flood Gates, Pumps	4.4	Diversion levees discussed in Section 5.2.3
Local Drainage Issues	4.5	Yes but only in order to identify the problem
Measures to Mitigate Wave Runup	4.6	Considered as part of Brisbane Water Flood/Foreshore Study
Flood Warning	4.7	No too short a warning to be of value
Evacuation Planning	4.8	Yes evaluated by the SES
Public Information and Raising Awareness	4.9	Yes Minimal cost and assumed high benefit cost ratio
Development Control and Flood Planning Levels	4.10	Yes will provide additions to existing Policies
House Raising	4.11	No only suitable house now re developed
Voluntary Purchase of a Property	4.12	No as local residents are unlikely to support this measure

Table iii): Matrix of Floodplain Management Measures Considered

Description	Section in Report	Capital Cost	Recurrent Cost	Reduction in AAD	Benefit Cost Ratio	Reduction in Water Level	Reduction in Tangible Damages	Reduction in Intangible Damages (Risk to Life)	Environmental Impact	Community Acceptance	Value for Money	Total Score	To be Considered for Inclusion in Plan
Flood Modification Measures Upstream of Fraser Road Bridge													
Do Nothing	5.2.1				nil	0	0	0	0	0	0	0	This is a viable alternative
Channelisation	5.2.2	$50,000	$2,000	nil *	nil	3	0	2	-1	0	0	4	No on account of the minimal reduction in flood damages unless combined with other measures
Levee	5.2.3	$50,000	nil	nil *	nil	-2	-1	1	-1	-1	0	-4	No on account of the increase in flood level upstream and likely high community impact
Increase size of Fraser Road culverts or construct a bridge	5.2.4	$100,000	nil	nil *	nil	0	1	1	0	2	0	4	If combined with downstream works (Refer Section 5.3.4)
Wards Hill Road retarding basin	5.2.5	$100,000	nil	yes	0.14	1	1	1	0	0	-2	1	Yes raising the wall to be considered - Low Priority. Initially obtain advice on legal ramifications
Farm dams in upper catchment	4.2.4	unknown	nil	nil	nil	0	0	3	0	1	1	5	Yes remove Dam No 3 and review policies on farm dams
Flood Modification Measures Downstream of Fraser Road Bridge													
Do Nothing	5.3.1				0	0	0	0	0	-3	0	-3	No as some channel works are required even if only for aesthetic, social and/or environmental reasons
Pipe the creek	5.3.2	$690,000	nil	significant reduction	high	3	3	3	-3	-1	-1	4	No due to Water Sensitive Urban Design issues
Provide siltation control, monitoring and review of processes - Estuary Management issue	5.3.3	?	$1,000	nil *	nil	0	0	0	2	2	2	6	Yes - monitor rate and provide siltation controls
Channel works to 20m downstream Noble Road. May consider works upstream of Fraser Rd if prevents overtopping of road	5.3.4	$1,100,000 (inc. Bridge)	see below 5.3.6	significant reduction	0.14	2	1	1	-1	2	1	6	Yes
Works from 20m downstream of Noble Road to Hardys Bay	5.3.4	additional $350,000	see below 5.3.6	very small	0.02	0	0	1	-3	0	-3	-5	No as has major environmental concerns plus provides little additional hydraulic benefit
Realign channel to lower hazard	5.3.5	included as part of 5.3.4	nil	nil *	nil	0	0	0	-1	3	3	5	Yes
Undertake regular creek maintenance	5.3.6	nil	$5,000	nil	nil	0	0	0	-1	3	3	5	Yes
Reduce likelihood of blockage at Fraser and Noble Roads	5.3.7	$30,000	$1,000	yes @	high	0	2	1	0	3	3	9	Yes
Establish or widen drainage easements	5.3.8	$30,000	nil	nil	nil	0	0	0	0	-1	3	2	Yes presumed at minimal cost to Council
Control sheet flow across Fraser Road at secondary flow path	5.3.9	unknown	nil	yes @	low	1	0	1	0	2	1	5	Yes a Design Study proposed
Upgrade access along Stanley Street	5.3.10	up to $100,000	nil	nil	nil	1	0	1	-1	1	-2	0	No as provides little benefit in reducing hazard
Overland Flow along Fraser Road North													
Do Nothing	5.3.11				nil	0	0	0	0	-3	0	-3	No as extent of flood problem is unacceptable
Prevent overtopping of Fraser Road - construct a levee, enlarge channel, upgrade Fraser Road culvert	5.3.11	?	nil	none #	nil	1	0	1	-2	-1	-1	-2	Upgrading of Fraser Rd culvert considered under Section 5.3.4. If undertaken further channel works upstream will be considered.
Divert runoff along Fraser Road to creek - pipes, swale to the creek	5.3.11	?	?	none #	nil	2	0	2	0	2	1	7	Yes a Design Study proposed
Provide improved runoff collection system along Fraser Road	5.3.11	unknown	nil	none #	nil	1	0	1	0	2	2	6	Yes a Design Study proposed
Modify east-west alignment of Fraser Road	5.3.11	?	?	none #	nil	2	0	1	0	2	1	6	Yes a Design Study proposed
Voluntary purchase of a property to provide flow path to creek	5.3.11	$800,000	nil	none #	nil	0	0	2	0	-3	-3	-4	No unlikely to be accepted by Community
General Floodplain Management Measures													
Establish database for local drainage issues	4.5	negligible	negligible	nil	nil	0	0	0	0	3	3	6	Yes undertaken by Council
Mitigate wave runup	4.6	unknown	unknown	small	low	0	1	1	0	2	2	6	Yes undertaken by Council
Improve evacuation planning	4.8	negligible	negligible	small	high	0	0	3	0	3	3	9	Yes undertaken by SES
Improve public awareness	4.9	negligible	negligible	medium	high	0	0	3	0	3	3	9	Yes undertaken by SES & Council
Review development controls	4.10	negligible	negligible	nil	high	0	2	1	0	2	3	8	Yes undertaken by Council, include on-site detention

Notes: none # = no house floors inundated; yes @ = cannot quantify the reduction in damages; nil * = unless combined with other works; ? = depends on nature of works

Description of Scoring System in Matrix

Impact	-3	-2	-1	0	1	2	3
Reduction in Water Level	>100mm increase	50 to 100mm increase	<50mm increase	no change	<50mm decrease	50 to 100mm decrease	>100mm decrease
Reduction in Tangible Damages	major increase	moderate increase	small increase	no change	minor	moderate	major
Reduction in Intangible Damages (Risk to Life)	major increase	moderate increase	small increase	no change	minor	moderate	major
Environmental Impact	major disbenefit	moderate disbenefit	minor disbenefit	neutral	minor benefit	moderate benefit	major benefit
Community Acceptance	majority against	most against	some against	neutral	minor	most	majority
Value for Money	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high

Table iv): Summary of Floodplain Risk Management Measures

MEASURE	REFER SECTION	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
FLOOD MODIFICATION:					
DAMS AND RETARDING BASINS	Section 4.2	Reduce flows from upper catchment areas.	Many issues (cost, environmental, social) would need to be addressed and it is unlikely that constructing new basins would be effective at Mudflat Creek due to the houses being near the mouth of the creek system and because flood levels are dominated by Brisbane Water levels in the lower reaches.	Generally not viable from a purely flooding perspective to construct a new basin. However the use of the "existing" basin on Wards Hill Road is a possibility.	Only viable measure is at Wards Hill Road.
CHANNEL MODIFICATIONS	Section 4.3	Increase waterway conveyance to reduce flood levels.	Many issues (cost, maintenance, environmental, social).	High capital, maintenance and environmental costs.	Some works are required downstream of Fraser Road.
LEVEES, FLOOD GATES AND PUMPS	Section 4.4	Prevents or reduces the frequency of inundation of protected areas, assists in reducing problems with local runoff issues.	There are a number of issues, particularly landtake, access and social. For practical purposes levees are not possible.	Not undertaken.	Not appropriate.
LOCAL DRAINAGE	Section 4.5	To identify and reduce local drainage problems.	The topography of the lower catchment results in ponding and/or diversion of runoff into private properties. No significant damage occurs as a result of these issues but they are an inconvenience to residents. Establishment of a database would enable Council to identify issues and to determine an approach to resolve them.	Low cost.	Recommended that a database be established.
MEASURES TO MITIGATE THE IMPACTS OF WAVE RUNUP	Section 4.6	To identify the effects of wave runup at Mudflat Creek.	In the lower reaches the flood levels are dominated by ocean anomalies (a combination of elevated ocean levels (tides), storm surge and wave runup) and can produce flooding as well as possible foreshore erosion. A study should be undertaken to determine the effects of these factors on flooding and erosion, as well as the structural integrity of any foreshore structures (roads, retaining walls.	Study in progress.	Recommended.

MEASURE	REFER SECTION	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
RESPONSE MODIFICATION:					
FLOOD WARNING	Section 4.7	Enable people to evacuate and take measures to reduce flood damages.	A flood warning system is not possible due to the small catchment size and thus quick response to rainfall.	Low cost.	Not recommended.
EVACUATION PLANNING	Section 4.8	To ensure that any evacuation can be undertaken in a safe and efficient manner.	The SES are reviewing the Evacuation Plans for these areas.	Relatively low cost. At Mudflat Creek the primary emphasis is on “self-help" (due to limited SES resources being spread across the region) so an effective evacuation plan is crucial.	Recommended.
PUBLIC INFORMATION AND RAISING FLOOD AWARENESS	Section 4.9	Educate people to minimise flood damages and reduce the flood risk.	A cheap and effective method but requires continued effort. Examples of methods are provided.	Benefits likely to be significant for relatively low cost. Effectiveness reduces with time since last flooding event.	Recommended.
PROPERTY MODIFICATION MEASURES					
DEVELOPMENT CONTROL PLANNING · Fill (or excavation) · Building Materials · Structural Soundness · Fencing · Public Assets · Flood Planning Levels · Rezoning Land · Climate Change Freeboard	Section 4.10	Ensure all new developments take into account flood hazard.	Refinement of Council’s existing policies.	Relatively low cost.	Recommended.
HOUSE RAISING	Section 4.11	Prevent flooding of existing buildings by raising habitable floor levels.	Potential to be applied to five houses.	High cost per building. May introduce social problems.	No suitable houses.
VOLUNTARY PURCHASE	Section 4.12	Purchase and remove buildings from the floodplain	High cost and generally not acceptable to the community.	High cost per building with low benefit cost ratio.	Not recommended as unacceptable to the community.

1. INTRODUCTION

Mudflat Creek is a 123 hectare catchment which drains to Hardys Bay through the lower Killcare district (refer Figure 1). The lower section of the catchment is predominantly occupied by urban residential development. A natural escarpment divides the lower section of the catchment from the upper plateau area. This upper plateau is predominantly natural or rural land type with some residential development around Stewart Street, The Scenic Road and Wards Hill Road (Figure 1).

In light of reported flooding incidents in the study area, Gosford City Council engaged Webb, McKeown & Associates to undertake a Flood Study (Reference 1). This was completed in November 2006.

The primary objectives of this Flood Study were:

- to define the flood behaviour of the Mudflat Creek catchment by quantifying flood levels, velocities and flows for a range of design flood events under existing catchment and floodplain conditions,
- to assess the hydraulic categories and undertake provisional flood hazard mapping in accordance with the NSW Floodplain Development Manual 2005 (Reference 2),
- to assess the extent of the flooding problem by undertaking a flood damages assessment,
- to formulate suitable hydrologic and hydraulic models that can be used in a subsequent Floodplain Risk Management Study.

Webb McKeown & Associates were subsequently engaged by Gosford City Council to undertake the next stage in the floodplain risk management process, namely the preparation of the Mudflat Creek Floodplain Risk Management Study.

1.1 Floodplain Risk Management Process

As described in the Floodplain Development Manual (Reference 2), the Floodplain Risk Management Process entails six sequential stages:

Stage 1: Formation of Floodplain Risk Management Committee.
Stage 2: Data Collection.
Stage 3: Flood Study.
Stage 4: Floodplain Risk Management Study.
Stage 5: Floodplain Risk Management Plan.
Stage 6: Implementation of the Plan.

The Mudflat Creek Floodplain Risk Management Study constitutes the fourth stage in the process and follows from the Flood Study stage which was completed in November 2006 (Reference 1). In the Flood Study a hydraulic model was used to determine design flood levels for the lower reaches of Mudflat Creek.

2. BACKGROUND

2.1 Catchment Description

The Mudflat Creek catchment is characterised by a distinct upper and lower section (refer Figure 1). The upper section of the catchment is located in the plateau area of Killcare Heights. This section of the catchment comprises of residential development around Wards Hill Road, The Scenic Road and Stewart Street together with a large proportion of natural bushland or rural type land.

From the plateau the catchment slopes very steeply down undeveloped, densely forested slopes to the area bounded by Fraser Road and Hardys Bay. This lower section is relatively flat and low lying. Runoff from the plateau area drains to Fraser Road via two natural gullies. Pipe and overland flow systems convey flows from these natural gullies, through the residential areas to Mudflat Creek. Mudflat Creek then travels through the rear of properties 37-63 Fraser Road before reaching the bridge in Noble Road and its outlet to Hardys Bay.

2.2 Creek Description

The following provides a descriptive overview of the key characteristics of the Mudflat Creek floodplain. Some of the significant features of the creek are illustrated in Photographs 1 to 4.

Photo 1: Noble Road Bridge looking upstream.

Photo 2: Twin 900 mm diameter pipe outlet into Mudflat Creek at rear of 57 Fraser Road. Note siltation covering half of pipes at the outlet.

Photo 3: Looking upstream at rear of 53, 55 and 57 Fraser Road.

Photo 4: Fraser Road culvert looking upstream.

The outlet of the creek into Brisbane Water is a wide mudflat that is dominated by mangroves. Immediately upstream of the outlet a bridge crosses the creek at Noble Road.

Between Noble Road and Fraser Road the creek runs through the rear of residential properties 37-63 Fraser Road and consequently the extent of the overbank area is variable with fences, gardens and sheds representing significant impediments to the overbank flow area. The degree of maintenance varies, with some sections of the creek heavily vegetated while other sections are mowed and maintained by residents. In many cases the same landholders own land on both sides of the creek and a number of footbridges have been constructed for access purposes (refer Photograph 3).

Runoff from the southern section of Wards Hill Road, Stewart Street and The Scenic Road in the plateau area of Killcare Heights is conveyed via a natural gully which drains to Mudflat Creek via a twin 900 mm diameter stormwater pipe before ultimately discharging into the creek at the rear of 57 Fraser Road (Figure 2).

Flows along the main channel are conveyed under Fraser Road (north-south alignment) via a 1950 mm diameter pipe culvert. Immediately downstream of Fraser Road (north-south alignment) the creek is heavily vegetated with a variety of native and introduced plant species. Rock lining of the embankments upstream and downstream of the 1950 mm culvert has been carried out to reduce erosion.

Upstream of Fraser Road along the main channel the creek is markedly deeper and is fringed by natural bushland. The creek forms into a natural gully that drains the area referred to by local residents as "The Triangle". This is the area bounded by Maitland Bay Drive, Wards Hill Road (northern section) and The Scenic Road.

2.3 Land Use Activities

The floodplain of Mudflat Creek downstream of Fraser Road is occupied entirely by approximately 23 detached residential developments with a mix of one/two storey, old/new and brick and non-brick buildings.

Upstream of Fraser Road the buildings are on the northern (high) bank of the creek and thus are not inundated. However their access to Fraser Road will be affected. There is one "cabin" immediately upstream of Fraser Road that will be inundated.

The creek channel runs through private property and residents have constructed fences, bridges and other flow obstructions in their yards (Photograph 3). The bridges are required to obtain access to their property on the other side of the creek.

2.4 Mudflat Creek Flood Study (Reference 1)

The Mudflat Creek Flood Study was initiated as a result of flooding of local roads and residential areas, most recently in July 1988, January 1989, February 1990, February 1992 and February 2002. The specific aims of the study were to:

- define flood behaviour in the Mudflat Creek catchment,
- prepare flood hazard and flood extent mapping,
- prepare a suitable model of the floodplain that can be used in subsequent Floodplain Risk Management Studies and Creek Rehabilitation Studies and Plans.

The key phases that were undertaken are summarised below:

Review all Available Data, namely:

- reports, photographs, Council records,
- questionnaire survey of residents and interviews,
- rainfall data from the Bureau of Meteorology and Manly Hydraulics Laboratory,
- survey data - a comprehensive field survey was undertaken in 1998 and 2004,
- available peak flood level data for historic events.

Determine Approach: Due to the absence of long term historical flood data a rainfall-runoff computer modelling approach was adopted. This involved the setting up of two computer models - a hydrologic model to convert rainfall to runoff and a hydraulic model to convert the runoff to flows, levels and velocities.

Due to limited historical flood level information, it was not feasible to rigorously calibrate the hydrologic and hydraulic models against observed flood events. A limited model calibration was therefore carried out by:

- determining the order of magnitude of the observed storms for which limited historical flood level data were available,
- comparing historical flood level data with the corresponding design flood level data.

Determination of Design Flood Levels: Design rainfall data were input to the hydrologic model to produce inflows for the hydraulic model and the design levels subsequently calculated. The design analysis assumed that both the Fraser Road and Noble Road culverts were blocked by vegetative debris. This approach is consistent with current best management practice following the August 1998 floods in North Wollongong. Sensitivity analyses of the parameters adopted for design modelling were also undertaken.

The full range of design events (20% AEP to PMF) were analysed. Flood contour and hazard maps were developed. In addition a flood damage assessment for the residential buildings was undertaken.

2.5 Public Consultation Program

A rigorous public consultation program was carried out as part of this study. This included:

- an initial newsletter to local residents and stakeholders,
- follow up telephone calls to key respondents (where required),
- floodplain management committee meetings,
- workshop/site inspection and interviews,
- public exhibition of material.

A summary of the responses to the Questionnaire is provided on Figure 3.

3. EXISTING FLOOD PROBLEM

3.1 Flooding Mechanism

Flooding within the Mudflat Creek catchment may occur due to a combination of factors including:

- an elevated water level in Brisbane Water due to tidal influences, rainfall and storm surge,
- elevated water levels within Mudflat Creek as a result of intense rain over the Mudflat Creek catchment. The levels in the creek may also be affected by constrictions along its length (e.g. culverts, blockages, bridges, vegetation),
- local runoff over a small area accumulating (ponding) in low spots. Generally this occurs in areas which are relatively flat with limited potential for drainage. This type of flooding may be exacerbated by inadequate local drainage provisions and elevated water levels at the downstream outlet of the urban drainage (pipe, road drainage) system.

These factors may occur in isolation or in combination with each other. Generally the peak water level in Brisbane Water will occur several hours after the flood peak in Mudflat Creek itself. This is because the peak levels in the Mudflat Creek catchment are typically the result of short duration storms of up to two hours duration. In contrast, the peak levels in Brisbane Water would typically result from longer duration storms of say 6 hours or longer.

Design flood levels were derived in the Flood Study (Reference 1).

3.2 Hydraulic Classification

The Floodplain Development Manual (Reference 2) defines three hydraulic categories which can be applied to areas of the floodplain.

"Floodways are those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels."

Flood storage areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas."

Flood fringe is the remaining area of flood prone land after floodway and flood storage areas have been defined."

Based on these definitions the Flood Study classified the majority of the floodplain as flood fringe with floodway areas along the creek.

3.3 Flood Hazard Classification

Provisional hazard categorisation based on depth and velocity indicate that the majority of the existing developed areas on the floodplain is Low Hazard in the 1% AEP event but High Hazard in the PMF. *Flood hazard* is a measure of the overall adverse effects of flooding. It incorporates threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production. These factors are not included in the provisional (hydraulic) hazard assessment.

For the hazard, land is classified as either *low* or *high* hazard for a range of flood events. The classification is a qualitative assessment based on a number of factors as listed in Table 1.

Table 1: Hazard Classification

Criteria	Weight (1)	Comment
Rate of Rise of Floodwaters	High	Residents will be aware that the river is rising from rainfall observations but may not realise how rapidly the floodplain becomes inundated. The magnitude of ocean storm surge activity will also surprise residents.
Duration of Flooding	Low	The duration of flooding is of the order of several hours. Ocean storm surge may last for a longer period but the peak period (on a high tide) is likely to last a few hours only.
Effective Flood Access	High	Access is only possible via Fraser or Noble Roads, which are both inundated in events of 20% AEP magnitude or greater.
Size of the Flood	High	In a 50% AEP event flooding will cause significant inconvenience.
Effective Warning and Evacuation Times	High	There is no warning system and little time available for evacuation.
Additional Concerns such as Bank Erosion, Debris, Wind Wave Action	Low	There are unlikely to be additional concerns which will significantly increase the potential hazard. Debris and wind wave action may cause damage to structures and increase the risk to life but these were not reported as issues in past events.
Evacuation Difficulties	High	These are likely to be high on account of: • Fraser and Noble Roads will be cut early making access difficult, • the roads will quickly be inundated by up to 1 m depth or greater, • the emergency services (SES, Police) will be “stretched” answering calls throughout the Gosford area.
Flood Awareness of the Community	Medium	The residents are likely to have a moderate level of awareness. However the magnitude of a large flood will surprise many.
Depth and Velocity of Floodwaters	Low	Velocities will be low (1 m/s or less) as will be the depth of floodwaters (generally 1 m or less) in the 1% AEP event.

Note: (1) Relative weighting in assessing the hazard.

However based upon the above, the majority of the floodplain (except for the channel itself) has a Low flood hazard classification for flood events up to the 1% AEP. In larger events the classification would change to High hazard.

Figure 8 provides an updated assessment of the hydraulic and hazard categorisation upstream of Fraser Road for the 1% AEP event. This was derived based on recently acquired Aerial Laser Scanning.

3.4 Flood Damages

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

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

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

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

The standard way of expressing flood damages is in terms of average annual damages (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by taking into account the probability of a flood occurrence. By this means the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods.

A flood damages assessment was undertaken for existing development at Mudflat Creek based on survey of floor levels.

The flood damages are indicative only and should only be used in the context for which they were intended - to give a indication for the magnitude of the flood problem and to provide preliminary estimates of benefit cost ratios for flood mitigation measures.

The summary of residential flood damages is provided in Table i) with the buildings inundated shown on Figure 4.

3.5 Flood History

Unfortunately there is no stream height gauge or other means of reliably determining the level of past flood events in Mudflat Creek. Reliance must therefore be placed on photographic evidence, interviews with residents, previous reports or similar. Based on all available data sources the dates of known flood occurrences in Mudflat Creek are summarised in Table 2.

Table 2: Known Dates of Flooding in Mudflat Creek

Month	Year	Month	Year
unknown	1984	February	1990
unknown	1985	February	1992
April and July	1988	February	1999
January	1989	February	2002

The following flood photographs were collected from reports and local residents. Photographs 18 and 19 are aerial photographs that illustrate the changes in the extent of development over the last 50 years.

Photo 5: Rear of 57 Fraser Road looking upstream - February 1999.

Photo 6: Rear of 57 Fraser Road looking downstream - February 2002.

Photo 7: Rear of 45 Fraser Road - February 1990.

Photo 8: Rear of 45 Fraser Road - February 1990.

Photo 9: Upstream of Noble Road bridge - July 1988.

It is assumed that Photographs 10 to 17 were all taken during the April 1988 event, however it is possible that it was the July 1988 event.

Photo 10: Floodwaters crossing Noble Road and entering Hardys Bay. View looking south.

Photo 11: Noble Road crossing. View looking south.

Photo 12: Floodwaters crossing the north-eastern corner of Fraser Road with No. 37 Fraser Road under renovations. View looking south to culvert.

Photo 13: No's 47, 49 & 51 Fraser Road showing runoff entering from Photograph 12. View looking south.

Photo 14: Looking upstream to Photograph 13. View looking north-east.

Photo 15: Hardys Bay Parade from corner of Noble Road. View looking south-west.

Photo 16: Looking upstream to Noble Road bridge.

Photo 17: At Fraser Road culvert. View looking south.

Photo 18: 1954 Aerial Photograph.

Photo 19: 1999 Aerial Photograph

4. FLOODPLAIN RISK MANAGEMENT MEASURES

4.1 Background

The NSW Government's Floodplain Development Manual (2005) separates floodplain management measures into three broad categories:

Flood modification measures modify the flood's physical behaviour (depth, velocity) and include flood mitigation dams, retarding basins and levees.

Property modification measures modify land use including development controls. This is generally accomplished through such means as flood proofing (house raising or sealing entrances), planning and building regulations (zoning) or voluntary purchase.

Response modification measures modify the community's response to flood hazard by informing flood affected property owners about the nature of flooding so that they can make informed decisions. Examples of such measures include provision of flood warning and emergency services, improved information, awareness and education of the community and provision of flood insurance.

A number of methods are available for judging the relative merits of competing measures. The benefit/cost (B/C) approach has long been used to quantify the economic worth of each option on a relative basis enabling ranking against similar projects in other areas. The benefit/cost ratio is the ratio of the Net Present Worth of the reduction in flood damage (benefit) compared to the cost of the works. Generally the ratio expresses only the reduction in tangible damages as it is difficult to accurately include intangibles such as anxiety, risk to life, ill health and other social and environmental effects. In this study the reduction in tangible damages to public utilities, non-residential and agricultural activities as a result of implementation of a floodplain management measure has not been included.

The potential environmental or social impacts of any proposed flood mitigation measure are of great concern to society and these cannot be evaluated using the classical benefit/cost approach. The public consultation program (Section 2.5) has ensured that identifiable social and environmental factors were considered in the decision making process.

The following sections discuss measures for the management of flooding for the existing residential developments at Mudflat Creek. Section 5 provides a more detailed assessment of the flood modification measures identified in Sections 4.2, 4.3, 4.4 and 4.5.

4.2 Retarding Basins/Farm Dams in the Upper Catchment

4.2.1 Dams

Flood storage dams, or dams which have significant flood storage capabilities, such as Glenbawn Dam on the Hunter River, can significantly reduce downstream peak flood levels. However, they are extremely expensive and can generally only be justified in economic terms if combined with a water supply or power generation function. Construction of a large dam is also likely to have a significant environment effect. For these reasons large flood mitigation dams are not viable for the Mudflat Creek catchment.

4.2.2 Construct New Retarding Basins

These are small dams which reduce peak flows on individual tributaries. Currently there are some 6 existing basins and these are discussed in Section 4.2.4. Retarding basins have been used extensively in western Sydney and elsewhere to mitigate the effects of urbanisation (increase in runoff and decrease in travel time). For a small rural catchment, such as Mudflat Creek, the main drawbacks of retarding basins are:

- the high landtake cost,
- the likely "sterilisation of a significant area of land". In an urban area this land can be used as sporting fields or for passive recreation,
- the likely environmental impact of removal of vegetation,
- the high cost of construction and ongoing maintenance,
- the risk of failure of the structure,
- safety considerations for residents entering the basin during a flood.

For the above reasons creating new retarding basins are not considered a viable and sustainable solution for the existing flood problem downstream of Fraser Road. However consideration of the use or modification of existing basins is discussed in Section 4.2.4.

4.2.3 On-Site Detention (OSD)

On-site detention provides the same function as a retarding basin by distributing the storage over all the contributing lots. OSD has been adopted by many Councils as a means of permitting future catchment development without increasing the flood hazard downstream. It can be applied to any new development although it is more difficult to regulate and maintain for small developments.

For Mudflat Creek this measure could reduce the impacts of future urbanisation but would not reduce existing peak flows. OSD is generally not applied in rural areas as the density of development is such that it cannot be justified.

4.2.4 Existing Retarding Basins/Dams

Preliminary site inspection has identified five farm dams (refer Figure 1, Table 3 and Photographs 20 to 31) within the catchment upstream of Wards Hill Road. In addition there are at least two pseudo basins formed by access roads across the creek. However, these are very small and can be ignored. Based on preliminary inspection of the vegetation it would appear that the five larger dams were formed over 20 years ago. Also Wards Hill Road forms a defacto retarding basin as the road is elevated some 2 m above natural ground with the only opening a 1800 mm diameter pipe.

The contributing catchment to Wards Hill Road is 0.64 km^2 or approximately 70% of the total catchment area to Fraser Road.

Table 3: Dams/Basins Upstream of Wards Hill Road (1)

Location/Identifier on Figure 1	Distance u/s of Wards Hill Rd (2)	Description	Dimension (2)	Photograph
Upstream Wards Hill Road	0 m	Formed by construction of the road possibly 30 years ago. 1800 mm low flow pipe. No data on whether road has ever been overtopped.	2 m deep	20, 21, 22, 23
No. 1	300 m	Used as a farm dam. There is an earthen spillway but no low flow pipe.	2 m deep 30 m long 20 m wide Approximate volume of 1200 m^3	24, 25
No. 2	350 m	Heavily silted with little storage capacity.	<1.5 m deep 20 m by 20 m Approximate volume of 500 m^3	26
No. 3	500 m	This dam is the largest but is not used for any irrigation purposes. The owner has seen it full several times in the last few years. There is an earthen spillway which flows into an incised channel that is gradually moving upstream. The dam wall is known to leak.	3 to 4 m deep 50 m long x 25 m wide Approximate volume of 4500 m^3	27, 28
No. 4	550 m	This dam lies immediately upstream of No. 3 and has no defined spillway.	Unknown depth but probably <1.5 m 20 m long x 15 m wide Approximate volume of 300 m^3	29
No. 5	550 m	This dam lies immediately upstream of No. 3 and north of No. 4. It has no defined spillway.	1.5 m deep 20 m x 20 m Approximate volume of 400 m^3	30

Notes:
(1) It is possible that other dams may be present but we have not been made aware of them.
(2) Dimensions and distances are approximate.

The following photographs provides a description of the above features.

Photo 20: Lowspot on Wards Hill Road with pseudo basin on right

Photo 21: 1800 mm outlet pipe under Wards Hill Road

Photo 22: View to Hardys Bay over cliff 20 m downstream of 1800 mm pipe

Photo 23: Basin No. 3

Photo 24: Basin No. 1

Photo 25: Wall of Basin No. 1

Photo 26: Basin No. 2

Photo 27: Dam Wall of Basin No. 3

Photo 28: Basin No. 3

Photo 29: Basin No. 4

Photo 30: Basin No. 5

Photo 31: Access Road across creek system of Basin No. 5

The main issues regarding the existing basins/dams upstream of Wards Hill Road are summarised below.

What is the risk and consequence of failure of these structures?

Detailed geotechnical analysis and dambreak modelling is required to obtain an accurate assessment of the risk and consequences of failure. However a preliminary review indicates:

- the first downstream habitable dwelling is some 500 m away at Fraser Road. The flood wave is likely to be significantly attenuated over that distance and after falling over the cliff immediately downstream of Wards Hill Road. However any failure will increase flows downstream, cause significant environmental damage and will bring debris and sediment downstream,
- the failure mechanism is likely to occur over several minutes, thus all the water will not be released at one time,
- the "pseudo" basin upstream of Wards Hill Road will provide some form of mitigation for any flood flows from upstream. Whilst this embankment could fail it is thought unlikely, however no geotechnical inspection has been undertaken to detail the likelihood of failure,
- the greatest consequence of failure is probably the increased hazard (including risk to life) at Wards Hill Road and the possibility of vehicles being swept off the road and possibly over the cliff,
- the timing of failure is unknown. Dams can fail with no rain (sunny day dambreak), prior to or after the main flood peak or at the time of the main flood peak. The time of failure will influence the extent of damages.

Do the existing structures provide any flood mitigation benefit?

Any mitigation benefit is likely to be minimal for the farm dams as it is presumed that they will be full with preceding rain before the flood peak producing rains. For a retarding basin to be of benefit it has to be "dry" at the start of the storm and have a low flow outlet to release the water gradually. As the structures were constructed as farm dams they do not have low flow outlets.

They could be designed and modified to act as retarding basins but this would require detailed geotechnical and hydrologic investigation.

The above does not apply to the Wards Hill Road structure which does have a low flow pipe and will presumably be "empty" prior to the start of the flood producing rains. All the other dams are (as far as we understand) used for some agricultural purpose and it would be difficult for Council to insist that they be modified or removed purely for floodplain management purposes.

There is the potential for the Wards Hill Road pseudo basin to be modified to provide greater flood mitigation benefit. This is discussed further in Section 5.1.4.

Should the existing farm dam structures be inspected or some way regulated?
Farm dams are unregulated unless they meet certain minimum sizes (these all do not). Council and DECC should determine whether an exception should be made in this case or if Council/DECC policies should be amended to include inspections of all farm dams.

RECOMMENDATIONS
Failure of No. 3 basin will cause the biggest impact. Discussions with the owner have indicated that this structure is not used for irrigation or any other significant purpose. It is proposed therefore that to eliminate the possibility of catastrophic failure and consequence damages and risk to life, as well as re-establishing the environmental flows, that the structure at No 3 basin be removed or significantly reduced.

DECC and Council should review whether these structures (farm dams) should remain as unregulated.

4.3 Channel Modifications

4.3.1 Discussion

Increasing the hydraulic capacity of the channel by:
- dredging deeper,
- widening,
- clearing of vegetation,
- removing hydraulic obstructions (bridges, fences) (refer Photograph 3),
- straightening of the creek,

will increase the percentage of flow within the main channel and so reduce flood levels. However there are a number of conflicting issues with such works that need to be addressed before these types of measures can be approved.

The following sections summarise the main issues.

4.3.2 Hydraulic Benefit

The magnitude of the reduction in flood levels is a function of the magnitude of the works undertaken with the following exceptions.

Vegetation clearing will have minimal benefit as the creek and overbank areas are not densely vegetated (refer Photographs 2 and 3). Removal of all the pedestrian bridges is also unlikely to produce a significant reduction in flood level as they are relatively minor structures (refer Photograph 3) causing little hydraulic restriction. They may even be washed away in floods. However there is also the risk that they increase the likelihood of blockage which would produce a significant hydraulic impact. Channel straightening will produce similar minor reductions because the current alignment of the channel is largely straight with no steep bends.

Potentially it is the widening and deepening that will produce the greatest reduction in flood level. However there are limits to the magnitude of the works. Deepening will fill in (either through bank collapse or sedimentation) if the batters are too steep or the grade of the channel causes erosion upstream (i.e. non-uniform grade). Thus the assumed maximum grade is from the invert of the culvert under Fraser Road (1.88 mAHD) to say -1 mAHD near Noble Road. Maintaining a level of -1 mAHD at Noble Road will require dredging and clearing through the mangroves downstream of Noble Road bridge. The Noble Road bridge would also have to be replaced (refer Photograph 1).

Widening is limited by the potential landtake issues as the creek is in private property with adjoining fences (refer Photograph 3).

4.3.3 Cost to Undertake Works

The main costs in undertaking the works are:
- excavation/clearing,
- disposal of material (unknown cost but say $90+ per m^3). This is of significant concern as the rubbish disposal sites will not accept wet fill and at present any material will have to be trucked at significant cost to an approved Sydney disposal site,
- re-establishment of channel banks,
- maintenance (indicative cost $5,000 per annum),
- Noble Road bridge replacement (indicative cost $150,000 depending on whether a bridge or culvert is adopted).

A listing of the indicative costs for Creek Rehabilitation Works are provided in Appendix B.

4.3.4 Benefits

The benefits provided by these works can be summarised as:
- reduction in risk to life,
- reduction in above floor and yard tangible damages,
- reduction in intangible damages (inconvenience, health),
- reduction (possible) in hazard on roads.

Figure 5 compares the existing design profiles with a 4 m wide dredged channel proposal for the 1% and 5% AEP flood events. The key points are:
- there are only 4 building floors inundated in the 1% AEP event. However two of these (10 and 14 Noble Road) are below the 1% AEP Brisbane Water Level (1.95 mAHD) and the channel works will not reduce inundation in a 1% AEP Brisbane Water event,
- the remaining two buildings inundated are first inundated in only a 10% AEP (35A Fraser Road) and 1% AEP (33 Fraser Road) event. Thus the annual average damages for these

two buildings is not high, consequently the reduction in tangible flood damages for these buildings as a result of implementing these works is small,

- there will be a reduction in risk to life and hazard on Noble Road and on the floodplain but this cannot be quantified. It should be noted that the Brisbane Water flood level exceeds the design flood levels (runoff determined) in the lower reaches and across Noble Road.

4.3.5 Environmental and Sustainability Issues

Dredging or widening a creek is generally not supported on environmental or sustainability grounds. The works will destroy the existing flora and create an “artificial” sized channel. Ongoing works will be required to maintain the invert level and the channel dimensions.

Of particular concern is the creation of a channel through the mangroves downstream of Noble Road. From a hydraulic perspective any works downstream of Noble Road will have no impact on the Flood Planning Level as this is based on the Brisbane Water level.

From an environmental perspective works downstream of Noble Road could only be supported if there is a significant hydraulic benefit to offset the loss of mangroves and habitat (albeit they will recolonise the affected area).

4.3.6 Maintenance

A major issue for Councils who undertake floodplain management measures is that in order for the works to be successful they generally require ongoing maintenance. In time any modified channel will require:

- maintenance of vegetation,
- erosion prevention,
- further excavation to remove infill sedimentation.

If these works are not undertaken the hydraulic advantage of the works will not be achieved and there may be some legal liability on Council if a landowner suffers increased damages as a result of Council not maintaining the works.

4.3.7 Need to Undertake some Works

In order to progress, a balance needs to be struck between the above issues. There are obvious benefits in undertaking some form of channel works. These include:

- some reduction in flood level, particularly to reduce the inconvenience in minor events that occur once or twice a year,
- the need to establish a defined stabilised creek channel that can be maintained,
- re-planting of some native and “flood friendly” vegetation to enhance the environmental qualities of the channel,

- lowering of the bed in the vicinity of the twin 900 mm partially buried culverts entering from Fraser Road south (refer Photograph 2) to ensure that the capacities of these culverts are not restricted,
- removal of the pedestrian bridges and replacement with low level causeways. This will reduce the risk of blockage and the potential for increased flood levels,
- replacement of the Noble Road bridge with a hydraulic more efficient structure that will be less prone to blockage. There is no point in providing a “raised” flood free bridge as the road on either side is inundated,
- re-designing the invert of the creek as a series of pools and riffle type structures will enhance the ecological habitat. It should also reduce the amount of sediment entering Hardys Bay. Possibly an easily maintained sediment trap should be formed near the Noble Road bridge to further minimise sediment entering the Bay.

4.4 Levees, Flood Gates and Pumps

Levees are built to exclude previously inundated areas of the floodplain from the creek up to a certain event. They are used in a number of locations in NSW particularly with towns on major river systems, e.g. Maitland-Hunter River, Nowra-Shoalhaven River, Lismore-Richmond River. They are also used on small river systems such as at Barralong Road on Erina Creek and at the intersection of Willoughby Road and Windsor Road on Terrigal Golf Course, upstream of Terrigal Lagoon. There is even a small “diversion” levee on Mudflat Creek at the corner of Fraser Road (adjacent to Photograph 17). Flood gates and/or pumps are used in conjunction with levees to eject the internal runoff within the leveed system or to prevent entry along pipe systems.

The major problem with levees is that access and amenities are affected. For this reason a levee system to protect all the buildings at Mudflat Creek is for practical purposes impossible. However diversion levees or similar may be possible and have been discussed further in Section 5.

4.5 Local Drainage Issues

Some residents have highlighted the issue of runoff ponding in yards or along Fraser Road. Whilst these issues are generally not considered or funded within this type of study it is important that they are identified to ensure they are not exacerbated or can possibly be attenuated with any proposed flood mitigation works.

4.6 Measures to Mitigate the Impact of Wave Runup

Wave runup is confined to the nearshore area and is highly dependent on factors such as the wave height, wave length, water depth and embayment slope. The action of these waves may cause inundation of property and foreshore erosion. Wave runup effects will generally only occur over a small percentage of the foreshore of Brisbane Water in a given event (in the prevailing wind direction). The effects will vary in time and space as a result of changing foreshore profiles, which may occur naturally (sedimentation, erosion, vegetation growth) or as a result of human activities (construction of seawalls, levees or similar). There is no record of significant wave runup activity at Hardys Bay.

Wave runup effects can produce flooding in the downstream part of the creek but is largely mitigated by the stands of mangroves. It is possible that removal of the mangroves may exacerbate the problem.

Wave runup and its implications should be investigated as part of the Brisbane Water Flood Study.

4.7 Flood Warning

An adequate flood warning system allows residents to move goods and vehicles above the reach of floodwaters and to evacuate their houses, if necessary. Such systems are extremely effective on large river systems where the time from the rain falling to the time of the flood peak (catchment response time) is several hours or preferably one or two days. On smaller catchments the catchment response time is measured in hours and on Mudflat Creek only 1 or 2 hours and for this reason a flood warning system is not possible.

The BOM provides forewarning of thunderstorms activity in the local area but is unable to locate where or when the severe rainfall will occur. On Narara Creek at Gavenlock Oval a siren has been installed which sounds an alarm once a given water level is reached. This has not proved highly effective to date and on Mudflat Creek is unlikely to have a beneficial effect.

Flood warning is therefore not a viable floodplain management measure for Mudflat Creek.

4.8 Evacuation Planning

There is no SES Flood Evacuation Plan for Mudflat Creek. In all past floods residents have taken their own initiative whether to stay or move. It is understood that the majority (if not all) stay.

The main problems with all flood evacuations are:
- they must be carried out quickly and efficiently,
- they are hazardous for both the rescuers and the evacuees,
- residents are generally reluctant to leave their homes, causing delays and placing more stress on the rescuers,
- evacuation routes may be cut some distance from their houses and people do not appreciate the dangers.

Fortunately there is abundant nearby high ground and flood free homes within the area which will mean that (assuming all people move safely) there is no ongoing risk to life from floodwaters. As the maximum depth of above floor inundation in the 1% AEP event (at the lowest house) is only 0.3m, residents could stand on furniture and lift goods to minimise the risk to life and damage to goods. In the PMF the maximum depth of above floor inundation is only 1.3m and thus it is possible that residents could remain inside their house on furniture, etc. It should be noted that all new houses will be built with floors a minimum of 0.5 m above the 1% AEP event and thus in the PMF will only have approximately 0.5 m depth of inundation. Standing on furniture is likely to be the most likely method of damage prevention as residents will have little warning time to evacuate. Even if they did it is unlikely that they would willingly leave their house, particularly as it would be raining heavily outside and possibly in darkness.

Residents (if they do evacuate or are unable to enter their homes during the event) would return once the creek levels fall. As the duration of flooding is short (say less than 3 hours), then residents can quickly return to their homes (assuming that their house has not experienced structural damage).

The need for evacuation from the area is therefore only likely to be for medical reasons, related or not to the flood hazard. The SES would need to evaluate this risk within any proposed Flood Evacuation Plan and incorporate sufficient management measures.

However given the isolated nature of the township it is likely that the SES will be unable to reach the area until after the event has occurred. They are also likely to be involved in other flood and storm related emergencies in the area.

4.9 Public Information and Raising Flood Awareness

The success of any flood damage prevention system and/or evacuation process depends on:

Flood Awareness: How aware is the community to the threat of flooding? Has it been adequately informed and educated?

Flood Preparedness: How prepared is the community to react to the threat? Do they (or the SES) have damage minimisation strategies (such as sand bags, raising possessions) which can be implemented?

Flood Evacuation: How prepared are the authorities and the residents to evacuate households to minimise damages and the potential risk to life? How will the evacuation be done, where will the evacuees be moved to?

A community with high flood awareness will suffer less damage and disruption during and after a flood because people are aware of the potential of the situation and listen to official warnings on the radio and television. In large catchments there is often a large, local, unofficial warning network which has developed over the years and residents know how to effectively respond to warnings by raising goods, moving cars, lifting carpets, etc. Photographs and other non-replaceable items are generally put in safe places. Often residents have developed storage facilities, buildings, etc., which are flood compatible. The level of trauma or anxiety may be reduced as people have "survived" previous floods and know how to handle both the immediate emergency and the post flood rehabilitation phase in a calm and efficient manner.

The level of flood awareness within a community is difficult to evaluate. It will vary over time and depends on a number of factors including:

- *Frequency and impact of previous floods.* A major flood causing a high degree of flood damage in relatively recent times (previous few years) will increase flood awareness. If no floods have occurred, or there have been a number of small floods which cause little damage or inconvenience, then the level of flood awareness may be low.

- *History of residence.* Families who have owned flood liable properties or lived in the area for a long time will have established a considerable depth of knowledge regarding flooding and a high level of flood awareness. A community which predominantly rents homes and stays for a short time will have a low level of flood awareness. It would appear that the majority of residents have lived in the area for several years and are familiar with flooding.

- *Whether an effective public awareness program has been implemented*. It is understood that no large scale awareness program has been implemented, however the SES and Council have made available booklets on how to deal with flooding.

For floodplain risk management to be effective it must become the responsibility of the whole community. It is difficult to accurately assess the benefits of an awareness program but it is generally considered that the benefits far outweigh the costs. The perceived value of the information and level of awareness, diminishes as the time since the last flood increases.

A major hurdle is often convincing residents that major floods will occur in the future.

It is important that a high level of awareness is maintained through implementation of a suitable Flood Awareness Program that Council has introduced in other parts of the LGA.

4.10 Development Control and Flood Planning Levels

The strategic assessment of flood risk can prevent development occurring in areas with a high hazard and/or with the potential to have significant impacts upon flood behaviour in other areas. It can also reduce the potential damage to new developments likely to be affected by flooding to acceptable levels. Development control planning includes both zoning and development controls.

The division of flood prone land into appropriate land use zones can be an effective and long term means of limiting danger to personal safety and flood damage to future developments. Zoning of flood prone land should be based on an objective assessment of land suitability and capability, flood risk, environmental and other factors. In many cases it is possible to develop flood prone lands without resulting in undue risk to life and property.

The following issues need to be addressed when considering flood related development control policies.

Ensure Adequate Access or Vertical Evacuation: This issue needs to be addressed to ensure safe evacuation to high ground is possible in times of flood. Due to the nature of the terrain this is likely to be a significant constraint. An alternative is to ensure that all new houses are built with some enclosed area at or above the PMF where the residents could remain "dry". Obviously for a two-storey building the upper floor is adequate. For a single storey loft access will be required.

Fill (or excavation) in the Floodplain: Filling of land for development can result in it no longer being flood liable. However, fill and excavation can have an affect on the flow patterns or even cause flood levels to rise. Filling for building pads should therefore be permitted as long as it does not affect local drainage issues. The cumulative effects of filling should be monitored (i.e. collected in a database) but are unlikely to present a major concern in the future. Any proposed significant filling on the floodplain must be analysed with regard to its potential impacts on flooding.

Building Materials: Some building materials are less susceptible to damage by floodwaters, or are easier to clean after a flood. By using such materials, flood damages can be minimised.

Structural Soundness when Inundated: Floodwaters can impact upon the structural soundness of buildings in a number of ways relating to flow velocities, depths and associated debris loads. These should all be considered in relation to certification of the soundness of structures for the local hydraulic conditions.

Fencing: Fences, whether solid or open, can impact upon flood behaviour by altering flow paths. This impact will depend upon the type of fence and its location relative to the flow path.

Public Assets: It is essential that all public assets which may be damaged by floodwaters are located to minimise (or hopefully eliminate) such damage. Council must ensure that adequate flood protection is provided for these assets.

Flood Planning Levels: The flood planning level (FPL) is used to define land subject to flood related development controls and is generally adopted as the minimum level to which floor levels in the flood affected areas must be built. The FPL includes a freeboard above the design flood level. It is common practice to set minimum floor levels for residential buildings as this reduces the frequency and extent of flood damage. Freeboards provide reasonable certainty that the reduced level of risk exposure selected (by deciding upon a particular event to provide flood protection for) is actually provided. It is common practice throughout NSW for Councils to adopt a FPL of the 1% AEP (100y ARI) event plus a 0.5 m freeboard. It may also be appropriate to stipulate a minimum floor level (say 300 mm) above natural surface to minimise future problems with local drainage issues, even if the land is above the FPL.

Rezoning Land: In some flood prone areas rezoning of land has been undertaken to eliminate further development and/or to promote redevelopment at a higher level. This measure is not appropriate for Mudflat Creek due to the nature of development in the township.

In summary, development control planning can reduce the effects of flooding on future development by minimising flood damages and managing risk. In some areas where the FPL or other criteria can only be achieved at considerable additional cost, there is community resistance to implementing these measures. However at Mudflat Creek these measures are unlikely to involve such resistance.

Climate Change: Current advice from world experts indicate that climate change will have adverse impacts upon sea level and rainfalls in NSW. Both of which may have significant influence on flood behaviour, depending upon the specific location under consideration.

At Mudflat Creek which is on the Brisbane Water estuary, climate change will potentially impact in three ways:

- an increase in sea level,
- an increase in peak rainfall volume and intensity,
- an increase in wave runup activity.

The impact of a sea level rise is likely to be the most significant impact. Also there is more certainty that sea levels will rise as a result of climate change (ice caps melting) than any increase in flood producing design rainfalls.

The latest Intergovernmental Panel on Climate Change (IPCC) information suggests sea level rises of between 0.18 m to 0.59 m by between 2090 and 2100 (estimates ignore ice flow melt). Taking into account ice flow melt and recent CSIRO modelling indicates a possible sea level rise of 0.18 m to 0.91 m by between 2090 and 2100.

It is prudent therefore to include some allowance for an increase in design flood levels due to a sea level climate change in setting floor levels and evacuation routes for any significant new development at Mudflat Creek. A suggested sea level climate change increase will be determined in the Brisbane Water Floodplain Risk Management Study.

The effect of a 10% increase in design rainfalls was simulated in the Flood Study (Reference 2) and this determined that flood levels would rise by up to 0.12m at Noble Road bridge but for the majority of the creek the increase is 0.05m or less. As this increase is relatively small it can be safely accommodated within the “normal” freeboard of 0.5 m.

The effects of climate change on wind wave activity along the foreshore are unknown as yet and should be addressed as part of a study for Brisbane Water.

4.11 House Raising

House raising has been widely used throughout NSW to eliminate inundation from habitable floors. However it has limited application as it is not suitable for all building types. Also, it is more common in areas where there is a greater depth and more frequency of inundation than at Mudflat Creek and raising the buildings allows creation of an underfloor garage or non-habitable room area.

House raising is suitable for most non-brick single storey buildings on piers and is particularly relevant to those situated in low hazard areas on the floodplain. The benefit of house raising is that it eliminates inundation to the height of the floor and consequently reduces the flood damages. At Mudflat Creek house raising (to say the 1% AEP plus 0.5 m freeboard) would probably mean prevention of inundation to no greater than 0.5 m in the PMF event.

Details of the buildings inundated in floods up to the 1% AEP are listed in Table 4.

Table 4: Description of Buildings Inundated in the 1% AEP

House	Event First Inundated (AEP)	Floor Level (mAHD)	Suitable for House Raising	Photograph
2 Noble Road	2%	1.73	Property re-developed in 2007	
10 Noble Road	20%	1.64	No - 2 storey	
14 Noble Road	20%	1.76	No - slab on ground	
33 Fraser Road	1%	3.52	No - brick	
35A Fraser Road	10%	2.63	No - brick	

Of the five buildings inundated only one (2 Noble Road) was suitable for house raising and this has now been re developed in 2007.

4.12 Voluntary Purchase

Voluntary purchase involves the acquisition of flood affected properties (particularly those frequently inundated in high hazard areas) and demolition of the house to remove it from the floodplain. Generally the land is returned to open space however in many cases there may be an opportunity to build a new house at a higher level.

This measure is mainly implemented over the long term in high hazardous areas as a means of removing isolated or remaining buildings. It can also restore the hydraulic capacity of the floodplain.

Many local communities do not accept voluntary house purchase as it would have a significant impact on their way of life. Among their concerns are:

- it can be difficult to establish a market value that is acceptable to both the State Valuation Office and the resident,
- in many cases residents may not wish to move for a reasonable purchase price,
- removal of properties may impose stress on the social fabric of the area,
- it may be difficult to find alternative equivalent priced housing in the nearby area with similar aesthetic values or features.

The adoption of a voluntary purchase scheme is unlikely to be embraced by the majority of affected property owners and the associated social and economic costs would not justify the benefits.

5. COMPARISON OF FLOOD MODIFICATION MEASURES

5.1 Overview

During the course of the study an initial matrix was developed to rank the possible flood modification measures. Subsequently this was refined at floodplain management committee meetings and in discussions with the technical committee. The following sections and an updated matrix (Table ii) provides a brief summary of each of the measures that have been considered. The measures have been sub divided into those undertaken upstream (Section 5.2) and downstream (Section 5.3) of Fraser Road.

Figures 6a and b provide a diagrammatic representation of the measures considered.

5.2 Summary of Measures Considered Upstream of Fraser Road

5.2.1 Do Nothing

Whilst this measure will provide no benefit it will also provide no disbenefit and has no capital or maintenance cost. It could be argued that this measure “allows nature to take its course”. Upstream of Fraser Road there is no overriding reasons for any measures to be undertaken as flooding does not cause a significant problem.

5.2.2 Channelisation

Upstream of the Fraser Road bridge the channel could be widened on the northern side (too steep on the southern side) to increase its capacity. This could also be combined with construction of a floodway (lower level of bank) on the northern side. The objective of these works would be to confine the flood flows to the main channel and if combined with upgrading of the culvert under Fraser Road would minimise overflow across Fraser Road (refer Photographs 12 and 13).

The main issues with this are the cost, say $50,000 plus landtake costs on the northern side and private footbridge replacement excluding any upgrading of the Fraser Road culverts. Also, any upgrading of the Fraser Road culverts need to be of sufficient capacity to prevent floodwaters escaping the channel upstream and crossing Fraser Road at the corner. It is unlikely that the culverts can be upgraded to that extent and for this reason other measures have been pursued.

As the buildings upstream of Fraser Road are on high ground any reduction in flood level provides no tangible reduction in flood damages to the existing buildings. However by reducing flood levels these works would reduce the frequency of overtopping of Fraser Road (refer Section 5.3.11).

5.2.3 Levee

As an alternative or in conjunction with channelisation, a levee could be constructed on the northern bank. This would probably have to be placed adjacent to the creek and would involve providing access to private land and reconstruction of the private footbridges. A small levee could limit overtopping across Fraser Road in a small event, however in a larger flood it would be overtopped. Constructing a high levee would be costly, involve significant landtake and there are issues of public safety if it fails or when it is overtopped. A levee may cost $50,000 with additional costs for the footbridge replacement and reduction of access issues. Whilst it will provide a hydraulic benefit in reducing flows across Fraser Road these cannot be quantified in terms of a reduction in above floor damage as these have not occurred in the past and no detailed assessment of when it would occur has been undertaken (above floor inundation has only been considered from flood levels along the main channel and not as a result of overland flow).

The main drawbacks of this measure are the aesthetic, access and landtake issues as the levee will have to cut across several properties. These drawbacks make this measure unlikely to be accepted by the community.

5.2.4 Enlarge Fraser Road Culvert

This measure would provide a benefit if it is assumed that blockage will not occur (for design the existing 1950 mm diameter pipe is assumed to be blocked). The relatively small capacity of the existing culvert acts as a "choke point" and thus raises flood levels upstream, possibly increasing the likelihood of overland flows crossing Fraser Road. Photographs 12 to 14, showing flows over Fraser Road were taken prior to the upgrading of the 1950 mm culvert. Thus in a similar sized event today, there should be less overtopping (unless blockage is a factor). A blockage reduction device has been considered in Section 5.3.7.

For design it is generally assumed that the culverts will be blocked by debris. Thus, whilst in reality flood levels may be reduced upstream, the Flood Planning Level will not change. A major benefit of upgrading the culvert is the possible reduction in flow across Fraser Road. The major cost with installing the culverts is the roadworks and possible services re-alignment. An indicative cost is $100,000. Downstream of Fraser Road the channel will also have to be upgraded to accommodate the increased flow.

5.2.5 Wards Hill Road Retarding Basin

Retarding basins upstream of the escarpment provide both a peak flow attenuation and a water quality/ sedimentation benefit. Preliminary investigation indicates that modifying the existing basins (farm dams) upstream of Wards Hill Road is problematic as they are on private property, have no outlet structures, are constructed of unknown materials and the owners generally require them to be full of water for irrigation purposes. These have been investigated in Section 4.2.4.

The most viable basin that could be utilised to mitigate peak flows downstream is the Wards Hill Road basin that exits with an 1800 mm culvert under the road. The height storage details based on Council's ALS data are provided in Table 5.

Table 5: Wards Hill Road Retarding Basin Properties

Storage Volume (m^3)	RL (mAHD)	Depth below Road Crest (m)	Comment
0	95	3	invert of creek and culvert
100	96	2	
1200	97	1	
3800	98	0	approximate road crest
9000	99	1 m above road	above road crest

The following four cases were evaluated using the hydrologic model with the results shown in Table 6:

1. No Basin (i.e prior to construction of Wards Hill Road),
2. Basin as it exists in 2007,
3. Basin with a 1 m high wall along the eastern side of Wards Hill Road,
4. Basin with a 1200 mm outlet pipe replacing the 1800 mm outlet pipe (constructed by including a "baffle" at the inlet),

Table 6: Results of Wards Hill Road Retarding Basin Cases

AEP	Outflow at Wards Hill Rd (m^3/s)	Outflow at Fraser Rd (m^3/s)	Water Level in Basin (mAHD)
Case 1	**Base - No Basin**		
1%	17.6	19.6	n/a
2%	15.4	17.1	n/a
5%	13.2	14.7	n/a
10%	11.1	12.2	n/a
Case 2	**Basin (as exists in 2007)**		
1%	17.5	18.7	98.1
2%	15.3	16.2	98.1
5%	12.9	13.6	98.0
10%	9.5	11.1	98.0
Case 3	**Basin with 1 m high wall to 99 mAHD**		
1%	17.0	16.9	99.0
2%	11.8	13.8	98.9
5%	10.6	12.4	98.4
10%	9.5	11.1	98.0
Case 4	**Basin with 1200 mm Outlet Pipe**		
1%	17.6	18.9	98.1
2%	15.4	16.4	98.1
5%	13.2	13.8	98.1
10%	11.1	11.5	98.1

The results in Table 6 indicate:

- the existing basin (Case 2) provides a 14% reduction in peak flow in the 10% AEP event at Wards Hill Road and a 9% reduction at Fraser Road. In the 1% AEP event the reduction is only 5% at Fraser Road,
- raising the basin wall by 1 m (Case 3 - by constructing a concrete panel wall on the upstream side) provides a 10% reduction in peak flow compared to Case 2 (existing conditions) in the 1% AEP event at Fraser Road but nil benefit in the 10% AEP event (as under existing conditions Wards Hill Road is not overtopped),
- reducing the outlet capacity to a 1200 mm pipe (Case 4) produces no significant benefit in all events analysed compared to Case 2.

In conclusion, re designing the basin outlet characteristics could be undertaken to reduced flood levels at Fraser Road. Apart from the cost implications, the main concerns with this measure are the need to obtain approval from the Roads and Traffic Authority (RTA) to undertake such works and the potential liability issues for Council should the structure fail or not work as designed (blockage of the inlet). The liability issues are of significant importance given the failure of the Pacific Highway road embankment in June 2007 at Piles Creek and the loss of life.

Council should further investigate this matter by obtaining advice from the RTA and Council's legal advisors before proceeding further. This advice should weigh up the potential reduction in flood levels with the increase legal liability for Council.

5.3 Summary of Measures Considered Downstream of Fraser Road

5.3.1 Do Nothing

For upstream of Fraser Road this measure may be acceptable as there are minimal flood problems or creek related issues. However downstream of Fraser Road there is a need for some form of works as summarised in Section 4.3.7.

5.3.2 Pipe All Flows from Fraser Road to Hardys Bay

The main concern with this option, apart from the cost, is whether all runoff can actually enter the pipe taking into account the likelihood of blockage and the need for a very large inlet. Unless this can be assumed the system will not function as designed. Measures can be incorporated into the design to cater for these two issues, however experience has shown that it is unlikely that they will be 100% successful. There are also groundwater recharge and "environmental flow" issues that are encompassed by the term "Water Sensitive Urban Design" or WSUD. Clearly piping the flows is contrary to WSUD principles and cannot therefore be supported. An indicative cost for this option is ($3,000/m length for a 230 m length) $690,000 (excluding costs for bridges, retaining structures, etc.). Another suggestion is to rock line or even concrete line the creek. Concrete lining is not acceptable from a WSUD viewpoint (some lined creeks in Sydney are now being reverted back to a more "natural" system).

5.3.3 Provide Siltation Control and Monitoring

It is apparent from the half-buried twin 1050 mm pipes on the southern flow path that ongoing siltation is occurring. Many residents are of the opinion that this has increased significantly in say the last 50 years due to ongoing land clearing in the upper catchment. It has been reported that 50+ years ago "a boat could be rowed up the creek under the present Noble Road bridge". This claim is disputed by others. Another claim is that this has contributed to the increase in density of mangroves downstream of Noble Road, again this theory is not accepted by everyone.

Whilst the accuracy of the above claims cannot be verified it is undisputable that sedimentation has occurred in the past causing problems for the creek system (partially blocking the 1050 mm pipes). However it is unknown if the rate is now diminishing, as the landscape of the upper catchment is more stable or if after the next flood the present sedimentation is "washed out" to the bay leaving a "cleared" creek system. It should be remembered that the cycle of erosion and sedimentation is a natural phenomena and is the reason that floodplains are formed in the first place.

In order to establish the implications of the ongoing sedimentation it is proposed to undertake a regular monitoring program combined with construction of at least one siltation control structure. Ongoing monitoring would include say an annual inspection and provision of a photographic record. The cost of this would be $2,000/annum. This program would be amended as the needs arise. It would be preferable if the inspection can be undertaken by a local resident group as this would ensure that the "local" issues are addressed.

A siltation control structure would be constructed as part of any creek rehabilitation works and has not be costed separately.

As part of this study a grain size analysis and related assessment was undertaken (refer Appendix A).

The aim of this study was twofold. Firstly to determine the quality of the sediment and whether it could be disposed as landfill. The study concluded that according to current guidelines it is classified as **solid waste**. However the preliminary results indicate the presence of potential acid sulphate soils and an acid sulphate soil management plan is required to ensure satisfactory treatment before disposal.

The second aim was to determine whether the tests undertaken could provide any insight into the rate of sedimentation over the last 50+ years. The study concluded that the tests undertaken do not provide any insight. While further tests are suggested there are none that will provide conclusive evidence. The most worthwhile test would be to undertake historical searches (photographs, anecdotal evidence, etc.). To some extent this has already been done by the local community and no conclusive evidence (apart from anecdotal) has been found.

5.3.4 Channel Works to Noble Road Bridge and Downstream

One of the most obvious mitigation measures is to widen and deepen (to a certain extent) the existing channel from Fraser Road to Hardys Bay. A detailed design of such works was completed in 2001 which comprised:

- replacing the 1950 mm pipe under Fraser Road with twin 2400 mm x 2400 mm RCBC's,
- for approximately 200 m downstream of Fraser Road constructing a 3 m base width with 1:1 batters. The channel invert graded at 1.3% slope from 1.7 mAHD at Fraser Road to -1.5 mAHD upstream of Noble Road,
- removal of the existing Noble Road bridge and replacement with three 3300 mm x 2100 mm RCBC's. The box culverts could be replaced with a bridge structure as this would reduce the risk of blockage,
- immediately upstream of Noble Road the channel base width was 10 m and this extended for some 100 m into the mangrove area downstream of the Noble Road bridge,
- provision of an additional two 1050 mm pipes in parallel to the existing twin 1050 mm pipes along the southern secondary flow path from Fraser Road.

The design did not detail the reduction in flood levels that would occur if the above works were undertaken. This present study has analysed these works in two parts. Firstly as works to immediately downstream (say 20 m downstream) of Noble Road bridge and secondly by extending those works further into Hardys Bay (say 100 m or more as envisaged in the 2001 design). The reason for this division is that works extending to 100 m downstream of Noble Road bridge will involve a significant destruction of mangroves through the estuarine flats, also, as this region is tidal, it is likely that infilling of the channel (and thus on going dredging requirements) will be more rapid than upstream.

The hydraulic modelling undertaken to determine the benefits (reduction in flood level) of these works assumed that there was no blockage at the Fraser Road and Noble Road structures (for design these were assumed to be blocked). If this nil blockage approach was not undertaken the hydraulic benefits of the upgraded structures could not be accounted for. If these works are undertaken by Council the effect of blockage on Flood Planning Levels would have to be reviewed to take account of the larger culverts.

If channel works are to be undertaken it is presumed that this would include upgrading of both the Fraser Road and Noble Road structures. The works need to extend downstream of Noble Road to ensure an efficient transition into the new structure but also to allow for a sediment control basin/structure. It would be logical to include this downstream of the bridge, rather than upstream, as the access for maintenance is easier downstream. A nominal distance of 20 m downstream has therefore been assumed.

The proposed works as identified in the 2001 Plans were input to the hydraulic model and the results obtained for the full range of design events. Figure 5 indicates the change in peak height profile for the 5% and 1% AEP events for the full extent of the works (nominally 100 m+ downstream) and to 20 m downstream of Noble Road.

The results can be summarised as follows:

- the channel works to 20 m downstream of Noble Road lowers flood levels by an average of approximately 0.3 m downstream of Fraser Road and 0.6 m upstream. The large reduction upstream is due to the increased culvert capacity under Fraser Road,
- the channel works to 100 m+ downstream of Noble Road lowers flood levels by an additional 0.5 m immediately upstream of Noble Road but the reduction tapers off to nil at chainage 220 m,
- under existing conditions (no blockage) there are 3 and 4 building floors inundated in the 5% and 1% AEP events respectively. The channel works to 20 m downstream of Noble Road lowers levels so that no floors are inundated in the 5% AEP event and only 3 in the 1% AEP event. The extension of the works to 100 m+ downstream of Noble Road has no impact on the number of floors inundated in either event but does reduce the depth of inundation in the 1% AEP event by up to 0.2 m at the buildings,
- it should be noted that in the 1% AEP event, the dominant flooding mechanism in the lower reaches is from Brisbane Water, thus channel works downstream of approximately chainage 220 m will only provide a benefit in a rainfall induced flood and not a Brisbane Water induced flood (i.e the works will not reduce the Flood Planning Level in the lower reaches).

An indicative cost for the works to 20 m downstream of Noble Road is $1.1 million (including Noble Road bridge replacement) with an additional $0.35 million to undertake the works to 100 m+ downstream of Noble Road. The benefit cost ratio is 0.14 and 0.02 respectively. It should be noted the assumed benefits (reduction in annual average damages) is indicative as no account has been taken of Brisbane Water flooding or the fact that “blockage” of culverts has not been taken into account.

The reason for the low benefit cost ratio is that few houses are inundated and those that are experience inundation infrequently. Also the cost to undertake the works are significant, although part of the costs provides additional intangible flood benefits (reduction in hazard) and non flood related benefits (replacement of ageing bridge at Noble Road, enhancement of environmental quality of the creek).

The main issues with this measure are the possible environmental impacts and the likely ongoing maintenance costs to ensure that the excavated channel does not fill in.

5.3.5 Realign Channel Downstream of Fraser Road

The existing alignment is within drainage easements of varying width, except for No's 55 and 37 Fraser Road where there is no easement. The alignment follows a straight line between the two roads and divides the rear yards of all the Fraser Road properties. A suggestion is to realign the channel so as to maximise the useable yard space by re aligning the creek to the south. The major issue with this concept is the environmental and legal aspects of "relocation of a watercourse".

Apart from the above advantage, it would:

- bring the channel closer to the exit of the twin 1050 mm pipes on the southern secondary flow path,
- allow greater flexibility for designing a more environmentally sustainable channel than exists at present,
- reduce the need for residents to "cross" the creek and thus construct bridges,
- possibly reduce the flood hazard by ensuring a greater distance from the creek to the houses,
- increase the distances between the houses and the creek (erosion of the bank will have less impact on the foundations of buildings),
- enable a vegetation buffer to be planted on either bank,
- enable footbridge removal and replacement with low level causeways as well as possible fence modifications. This would enhance the hydraulic capacity of the creek.

5.3.6 Undertake Regular Creek Maintenance

This could be undertaken for the existing creek or for any creek upgrade. These works would provide limited hydraulic benefit but will reduce the likelihood of blockage and enhance the environmental qualities of the creek. In particular it would ensure that the exit of the twin 1050 mm pipes on the southern secondary flow path remain free of sediment. The annual cost of these works may be $5,000 per annum. In order for this measure to be successful it obviously must be carried out on a regular basis and Council must commit funds on an annual basis. Should Council fail to undertake the works there may be some liability on Council if residents have increased flood damages as a result.

5.3.7 Reduce the Likelihood of Blockage of the Culvert/Bridges

As noted previously the flood analysis for establishing Flood Planning Levels assumes 100% blockage of the Fraser Road and Noble Road structures. Whilst for Flood Planning Level purposes it is not possible to assume nil blockage, in reality any structure that reduces the likelihood of blockage will provide some benefit during an actual event. Bollards or steel cages have been used in other parts of the LGA for this purpose. These structures may cost up to $30,000 depending upon their complexity.

5.3.8 Establish or Widen Drainage Easements

Whilst this measure provides no direct hydraulic benefit, the key outcome of establishing drainage easements on all properties will be that Council will be in a better position to ensure works that may decrease hydraulic conveyance are minimised (fences, bridges, landscaping works).

The cost to establish drainage easements cannot be determined at this stage.

5.3.9 Control Sheet Flow across Fraser Road at Secondary Flow Path

The north-south alignment of Fraser Road is crossed by upstream runoff during heavy rainfall events. At the northern end the runoff is combined with overflows from the main creek. Of particular concern is the sheet flow along the secondary flow path across Fraser Road. There are minor drainage pipes under the road but once these are at capacity or blocked by debris runoff must cross the road. This represents a minor hazard to vehicular traffic due to the shallow depths but represents an inconvenience to local residents as the runoff travels down driveways causing minor erosion. Unfortunately there is no cost effective and environmental acceptable means of eliminating this problem.

The problem arises as overland flow travels down the relatively steep slopes east of Fraser Road and after overtopping the road becomes concentrated along driveways, etc. Local residents have modified the overland flow paths by constructing driveways, landscaping, creating mounds and fencing along the road. All these works have significantly altered the pattern of flow and will have reduced the overland flow into some properties but increased it into others. It is also noted that some overland flow paths are restricted by fencing perpendicular to the flow.

The most cost effective solution is some form of upgrade of the overland flow collection system which should divert some runoff along Fraser Road and into Mudflat Creek. Adjustments to the road crossfall and vertical alignment will also assist. However it is unlikely that all driveways will be protected. For these driveways it may be easier to design them as overland flow paths that safely take the runoff away from buildings and ultimately into the creek.

Constructing pits and pipes under the road would assist and should be combined with any roadworks. The main issue with this approach is that it would be difficult to capture the overland flow east of Fraser Road into drainage pits. It is also preferable to define easements so that the drainage route can be maintained clear of unauthorised material.

As the extent of the problem and measures required to mitigate it cannot be accurately estimated at this time it is proposed that a drainage study/detailed design be undertaken to determine the most appropriate works required to address the problem. This study should include/consider:

- detailed survey,
- community consultation,
- upgrade of the overland flow collection system,
- road re-alignment (vertical, horizontal and cross fall).

5.3.10 Upgrade Access along Stanley Street

Stanley Street acts as the main flow path to take overland flow from upstream into Hardys Bay. Residents must either travel along Fraser Road and cross this unnamed creek upstream of Stanley Street or travel along Stanley Street to Noble Road. The main drawback of the latter is the hazard to vehicular and/or pedestrian traffic on Stanley Street during a flood.

Possible amelioration measures include:

- enlarging, cleaning out and maintaining the drainage ditch within the road reserve - estimated cost $10,000,
- constructing a culvert within the road reserve - estimated cost $100,000.

The latter option provides the most effective solution if an adequate inlet to the culvert can be provided which will not block. However this measure requires significant cost and provides limited reduction in hazard and damages as another access route along Fraser Road is available during a flood. Though this route will also be affected by floodwaters.

5.3.11 Overland Flooding along Fraser Road North

This issue was addressed in the Flood Study (Reference 1) and the key points are:

- 37, 45 and 47 Fraser Road have experienced flooding of their yards and possibly floor levels in the past (refer Photographs 12 and 13, taken in April or July 1988),
- since 1988 the culvert under Fraser Road has been upgraded and there has been changes to Fraser Road and construction of an earthen and concrete levee near 37 Fraser Road,
- flooding occurs as a result of overtopping of Mudflat Creek east of Fraser Road (in events greater than a 20% AEP event) combined with runoff from the heavily vegetated steep slopes on the northern side of Fraser Road.

Figure 20 from the Flood Study summarises the main flow paths. On account of the extent of flooding and inconvenience caused it is recommended that some mitigation measure be undertaken.

Possible solutions to this problem are:

1. **Prevent or reduce overtopping of Fraser Road from Mudflat Creek.** This can be achieved through either constructing a levee, enlarging the channel and/or upgrading the culvert under Fraser Road (refer Section 5.2). It is unlikely that the levee or channel upgrading will be accepted by the community.

2. **Divert runoff into Mudflat Creek along Fraser Road (north-south alignment).** This can be achieved by regrading Fraser Road, upgrading the drainage swale and/or installing a pipe system. These works will all assist in preventing floodwaters heading westwards

along Fraser Road in minor events but will have less benefit in large events due to the amount of overtopping flow. There are a number of measures available including:

- enlarge the drainage swales on either side of the road,
- enlarge the culverts under the driveways,
- form a mound on the western side linking up with the existing mound at the bend,
- installing pipes can be considered but the flat grades and problems with ensuring there are sufficient inlets suggest that an "open system" is preferable.

The cost of these works will vary depending upon what is undertaken.

3. **Provide overland flow collection device along Fraser Road.** This measure will assist in redirecting runoff along defined flow paths in minor events. However, in large events it will be largely ineffective due to the significant volume of floodwaters. It is known that the residents do not support kerb and guttering. The cost of these works is unknown.

4. **Modify east-west alignment of Fraser Road.** There are a number of possible measures that could be undertaken. These include altering the vertical and horizontal alignment of the road to create a larger drainage swale and/or containing more runoff within the paved section. Unfortunately the road alignment is constrained by a steep slope on the northern side and property boundaries on the south. Survey and preliminary design needs to be undertaken to investigate the optimal solution. This may require altering private driveways and/or establishing drainage easements. There is a drainage easement in 59 Fraser Road but this has little capacity due to the flat grades. It is an open drain and must be regularly maintained to be effective.

   The provision of another easement could be investigated as part of any drainage study/detailed design. Containing the runoff within the road reserve does present access problems during a flood event.

5. **Voluntary purchase a property and create a drainage reserve.** This measure is rather extreme but has to be considered as it would significantly reduce the problem.

CONCLUSIONS

It is possible that a combination of the above measures will be required. Whilst these measures will reduce the inconvenience and hazard of flooding, the tangible benefit cannot be determined as no houses experience above floor inundation due to this form of inundation. A local drainage study/detailed design would need to be undertaken to evaluate the necessary environmental, hydraulic, social and economic considerations.

6. ACKNOWLEDGEMENTS

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- Gosford City Council,
- Department of Environment and Climate Change,
- Floodplain Management Committee,
- residents of Mudflat Creek.

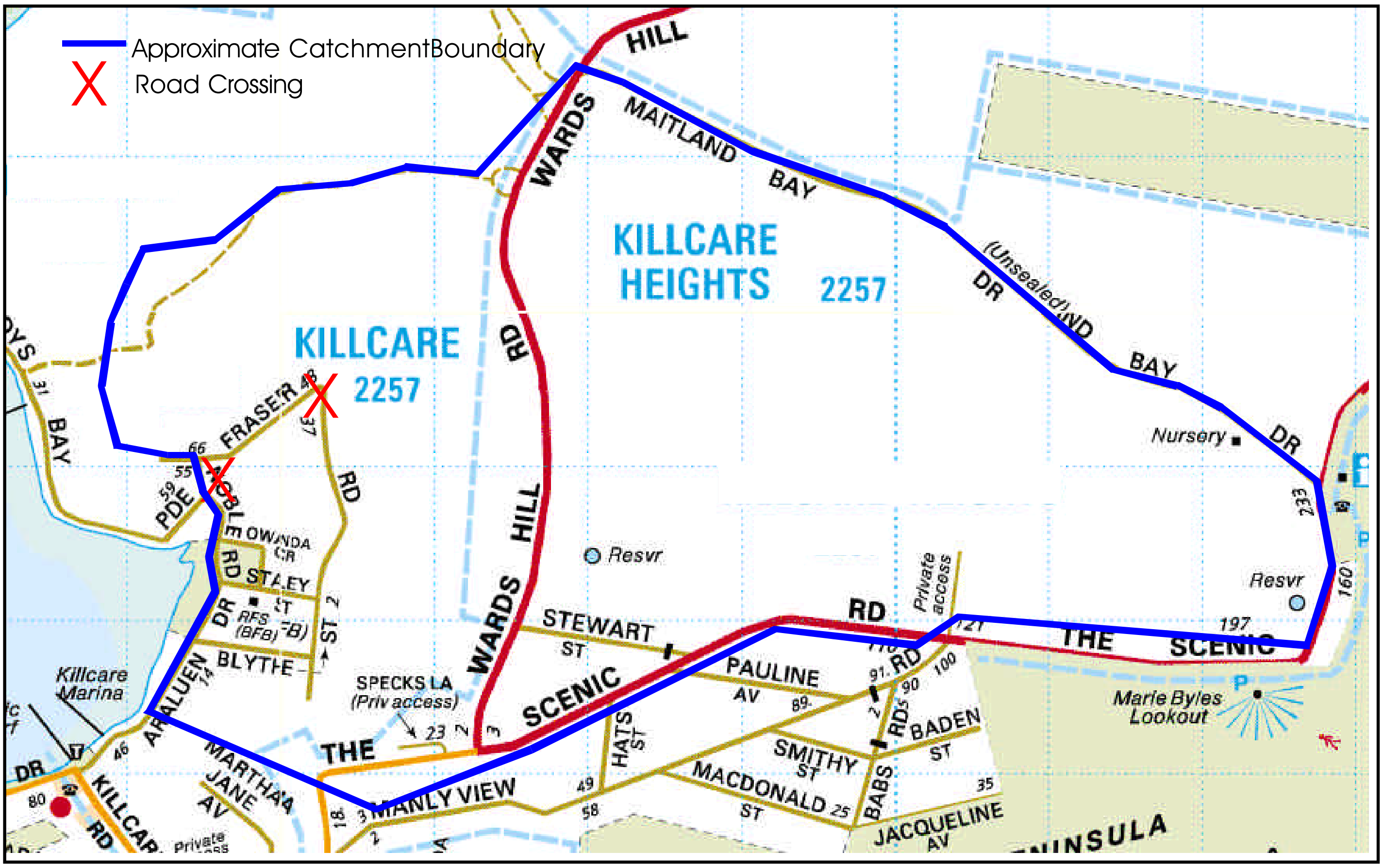
7. REFERENCES

1. **Floodplain Development Manual**
NSW Government, April 2005.

2. Gosford City Council
Mudflat Creek Flood Study
Webb, McKeown & Associates, November 2006.

FIGURE 1

CATCHMENT MAP AND BASIN LOCATIONS



1970's Aerial Photography showing location of basins upstream of Wards Hill R d.

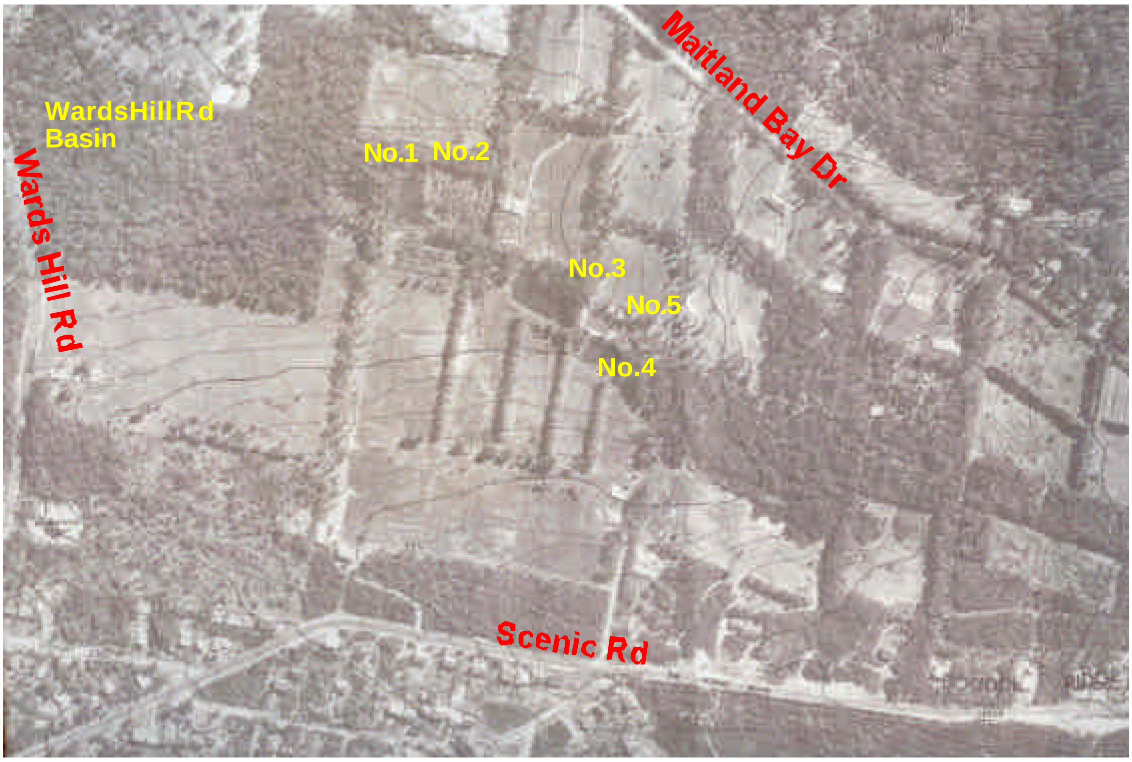


FIGURE 2

SURVEY DATA
CREEK DEFINITION

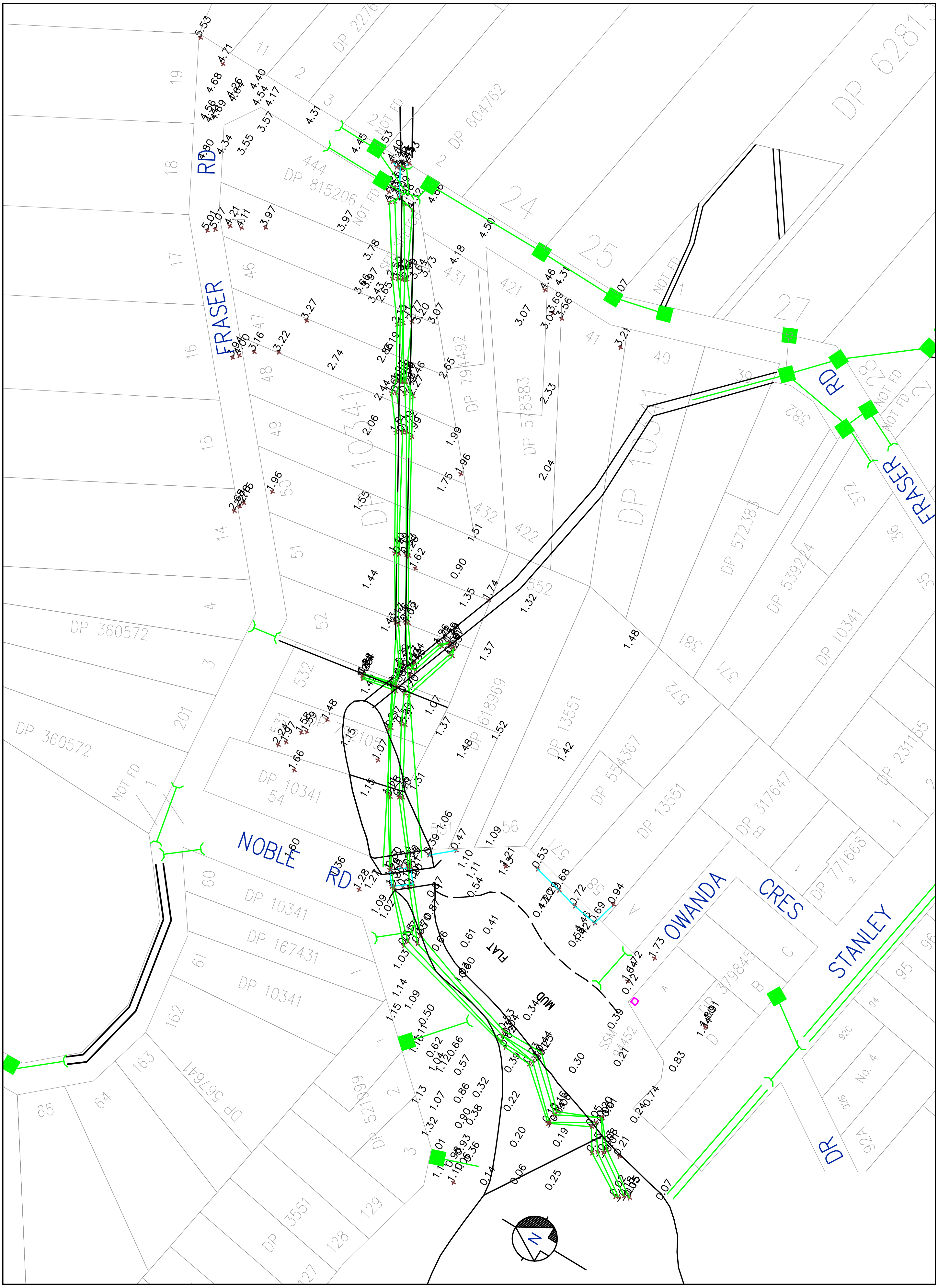
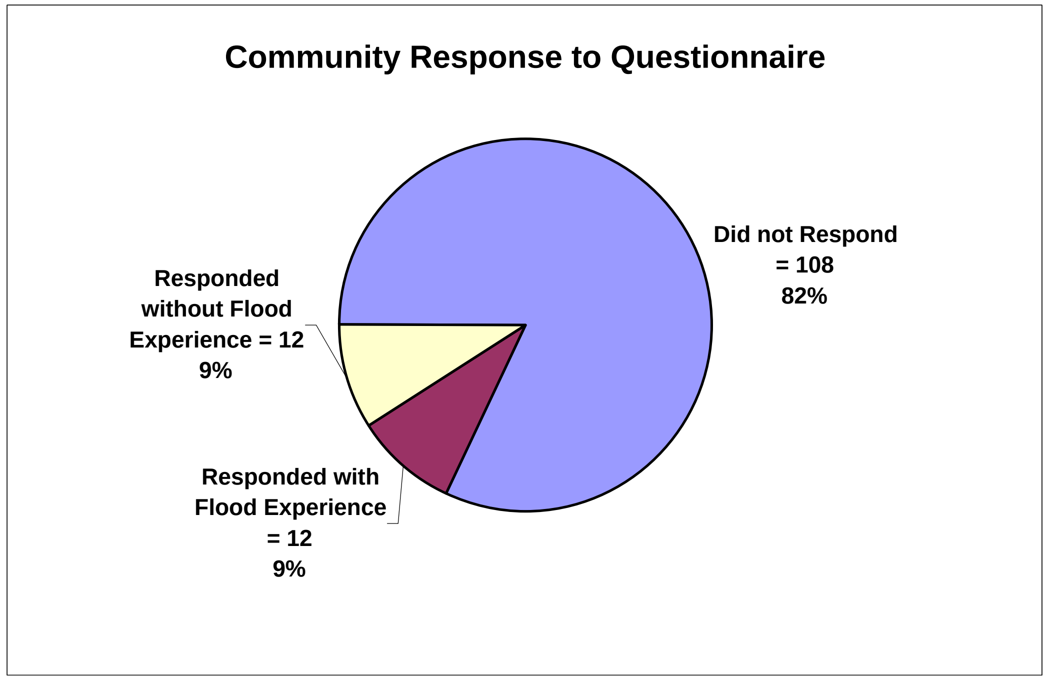
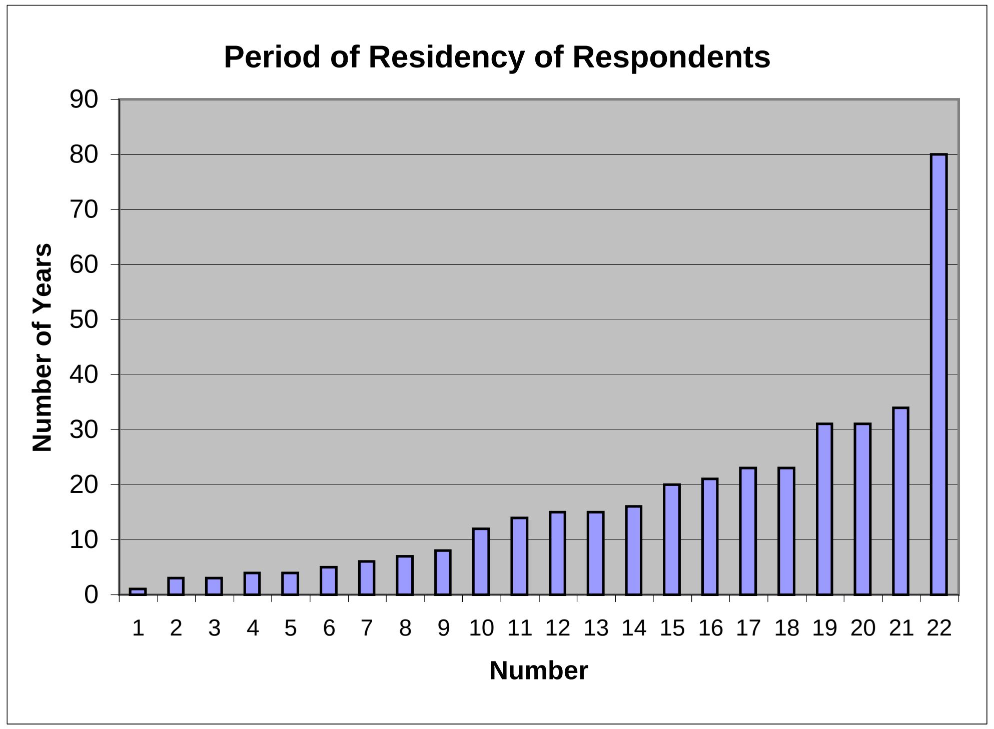
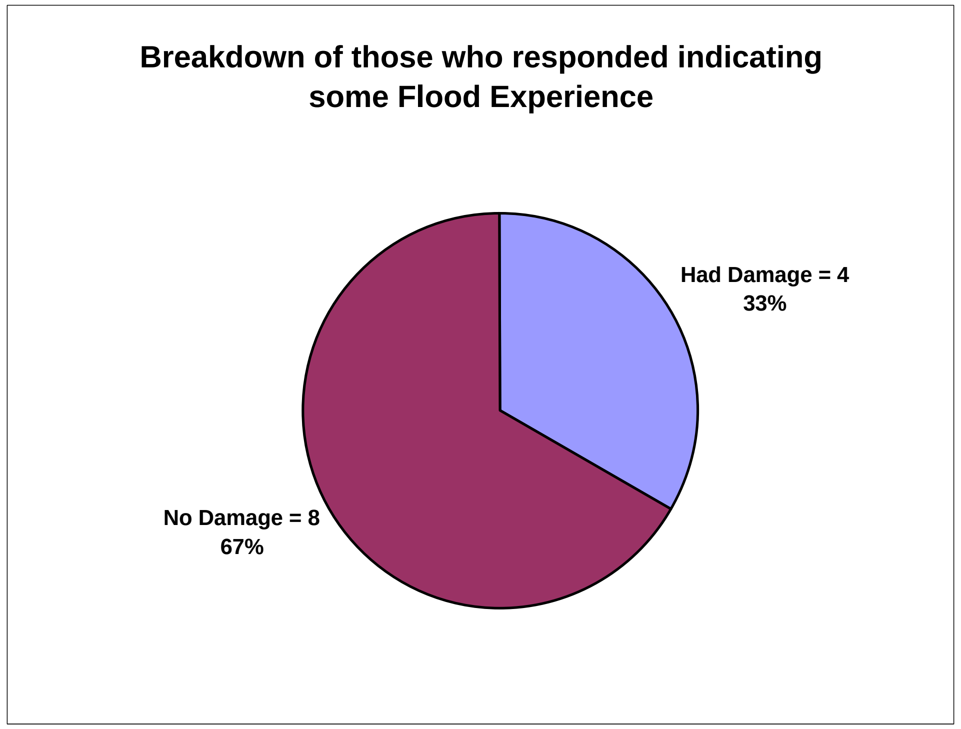
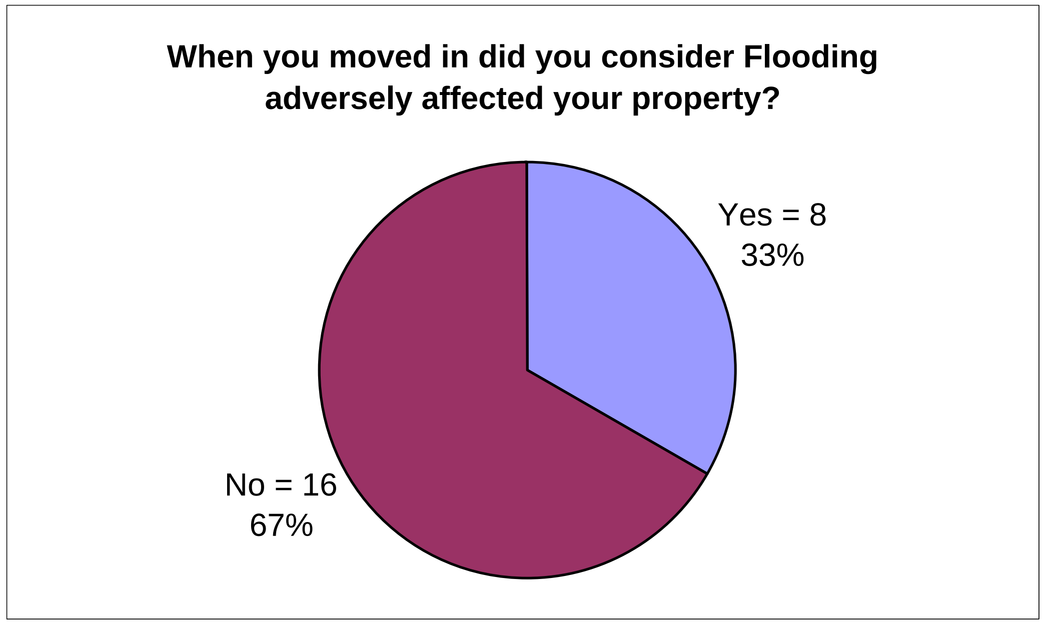


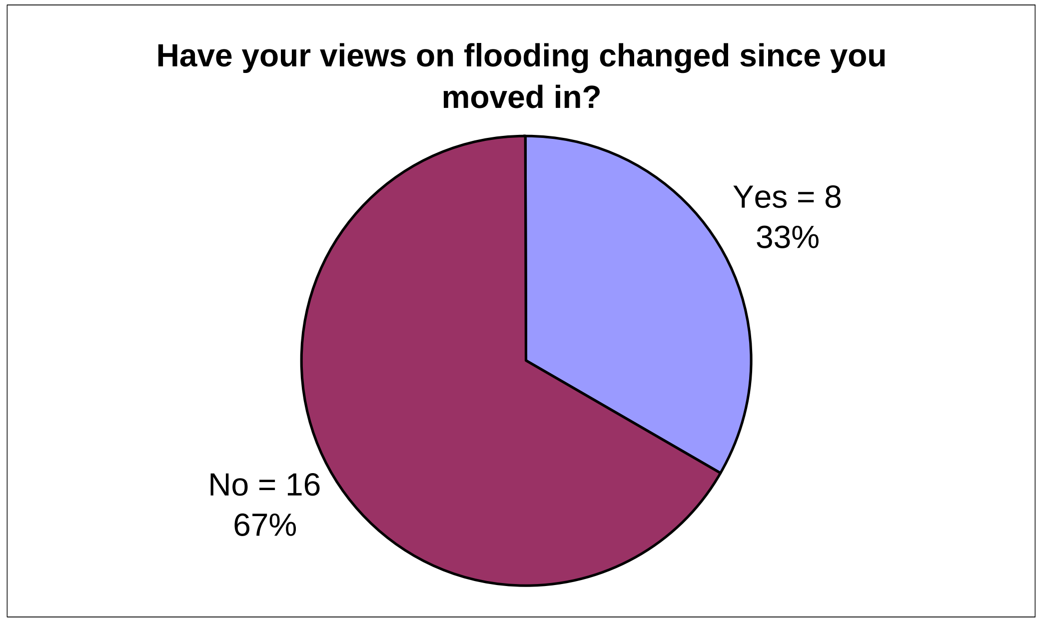
FIGURE 3
ANALYSIS OF QUESTIONNAIRE RESULTS

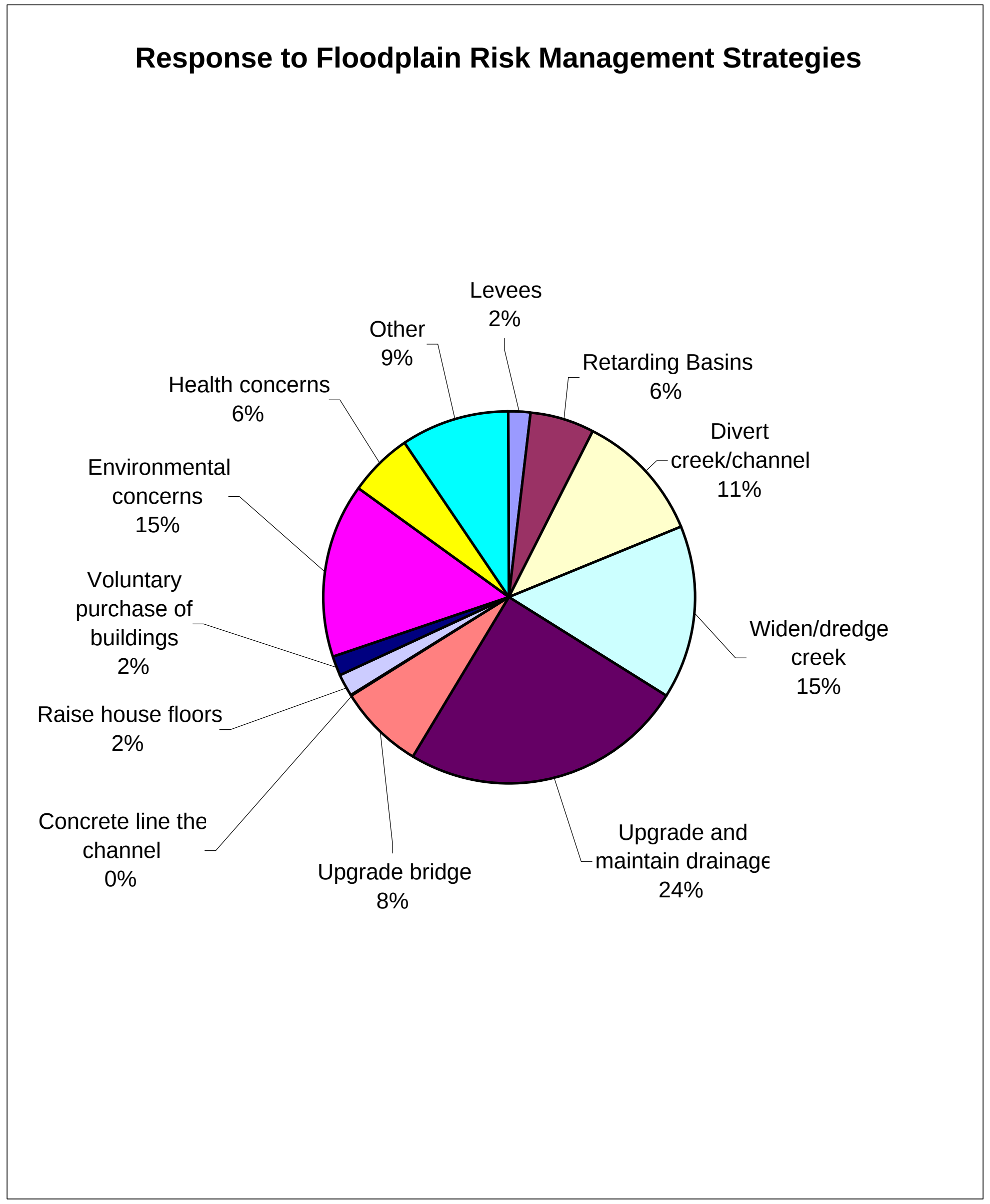












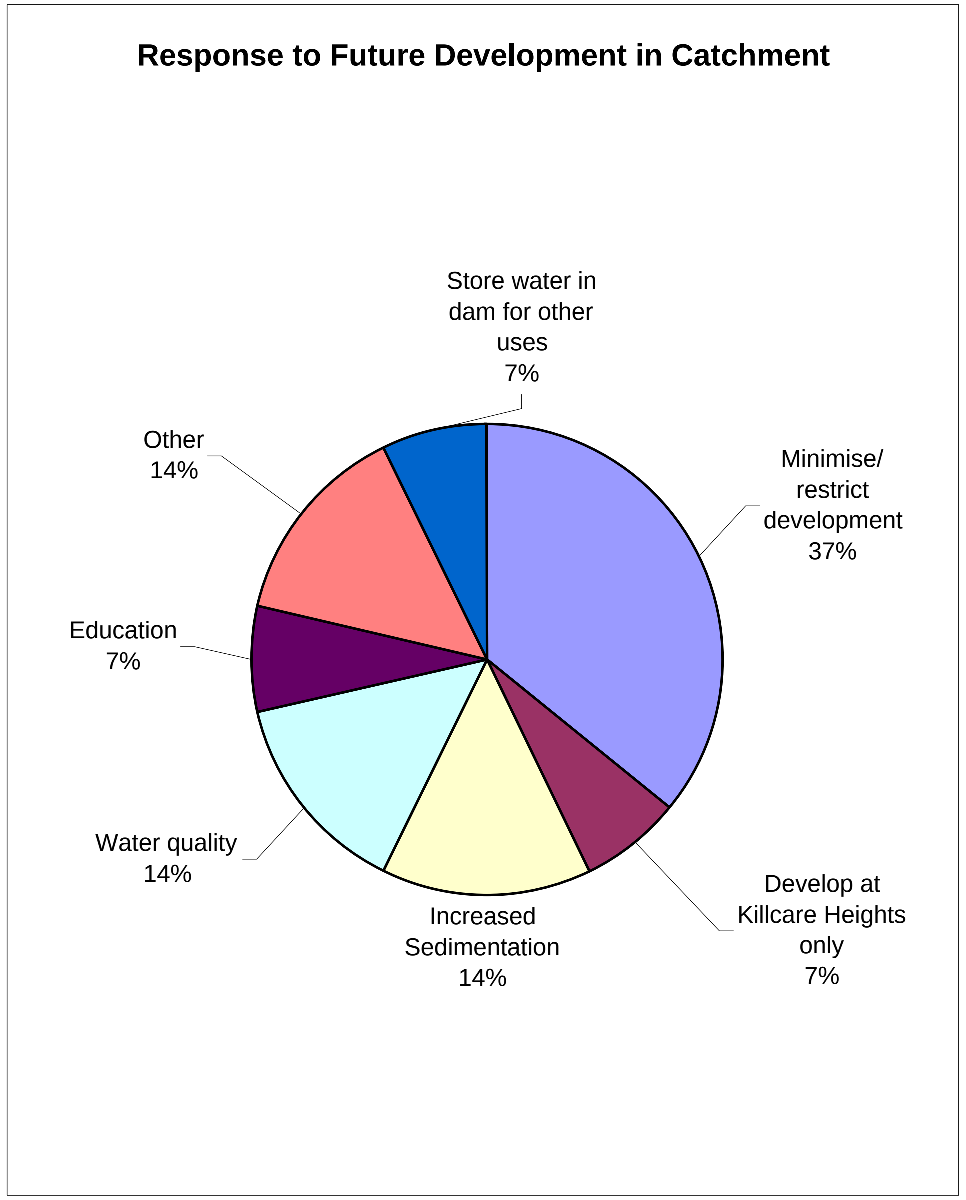


FIGURE 4

POSSIBLE GENERAL FLOODPLAIN MANAGEMENT MEASURES

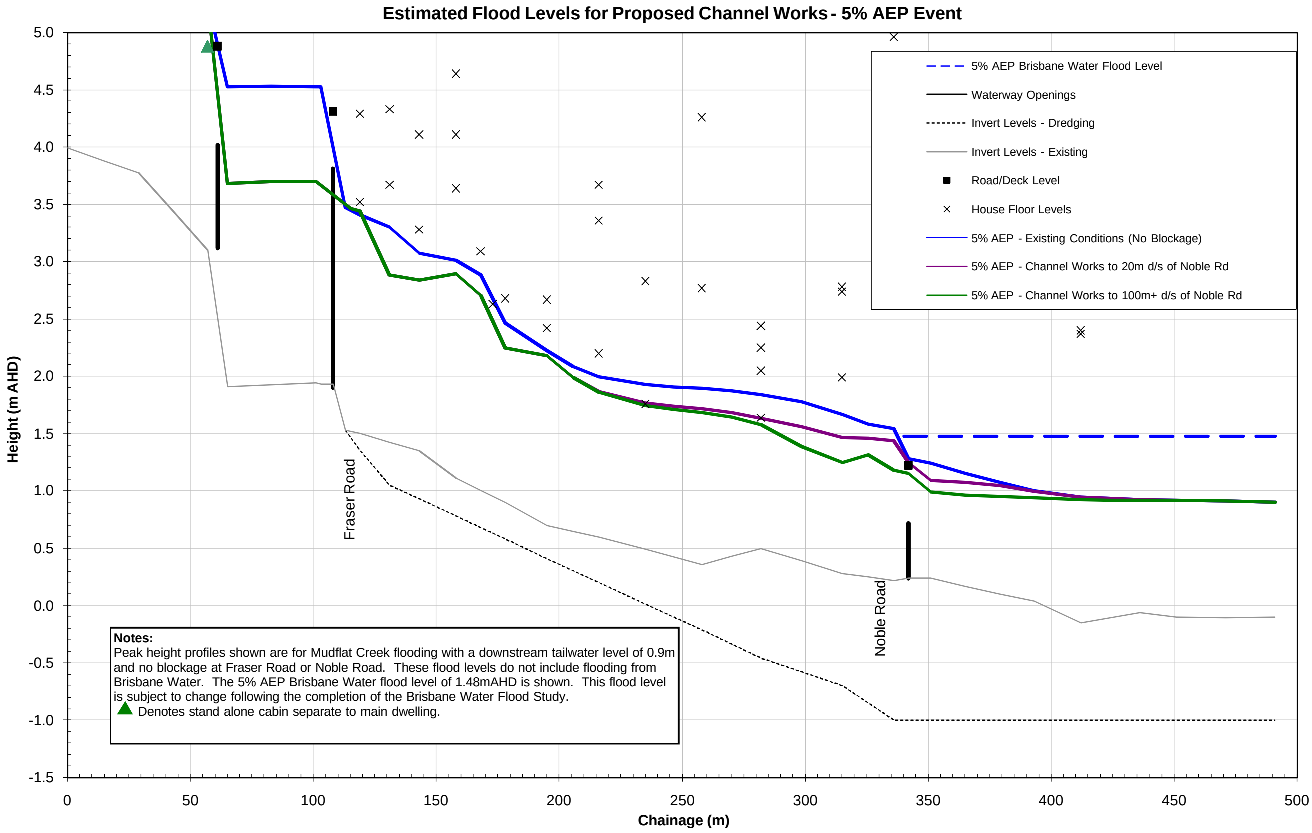
Section In Report	Description	Symbol
4.2.	Dams/Retarding Basin	In upper catchment
4.2.3	On Site Detention	For all new developments
4.3	Channel Modifications - dredge, widen, clear vegetation, remove obstructions, straighten	(light blue line)
4.4	Levees, Flood Gates, Pumps	Not shown
4.5	Local Drainage Issues	(red dot)
4.6	Wave Runup	(blue wave symbol)
4.7	Flood Warning	Not shown
4.8	Evacuation Planning	For all developments
4.9	Public Information	For all developments
4.10	Development Controls	For all developments
4.11	House Raising	No suitable houses
4.12	Voluntary Purchase	No house proposed

FIGURE 5

COMPARISON OF PEAK HEIGHT PROFILES

Note: The peak height profiles assume NO BLOCKAGE at Fraser Road and Noble Road

For Flood Planning Level purposes these structures are assumed to be 100% BLOCKED.



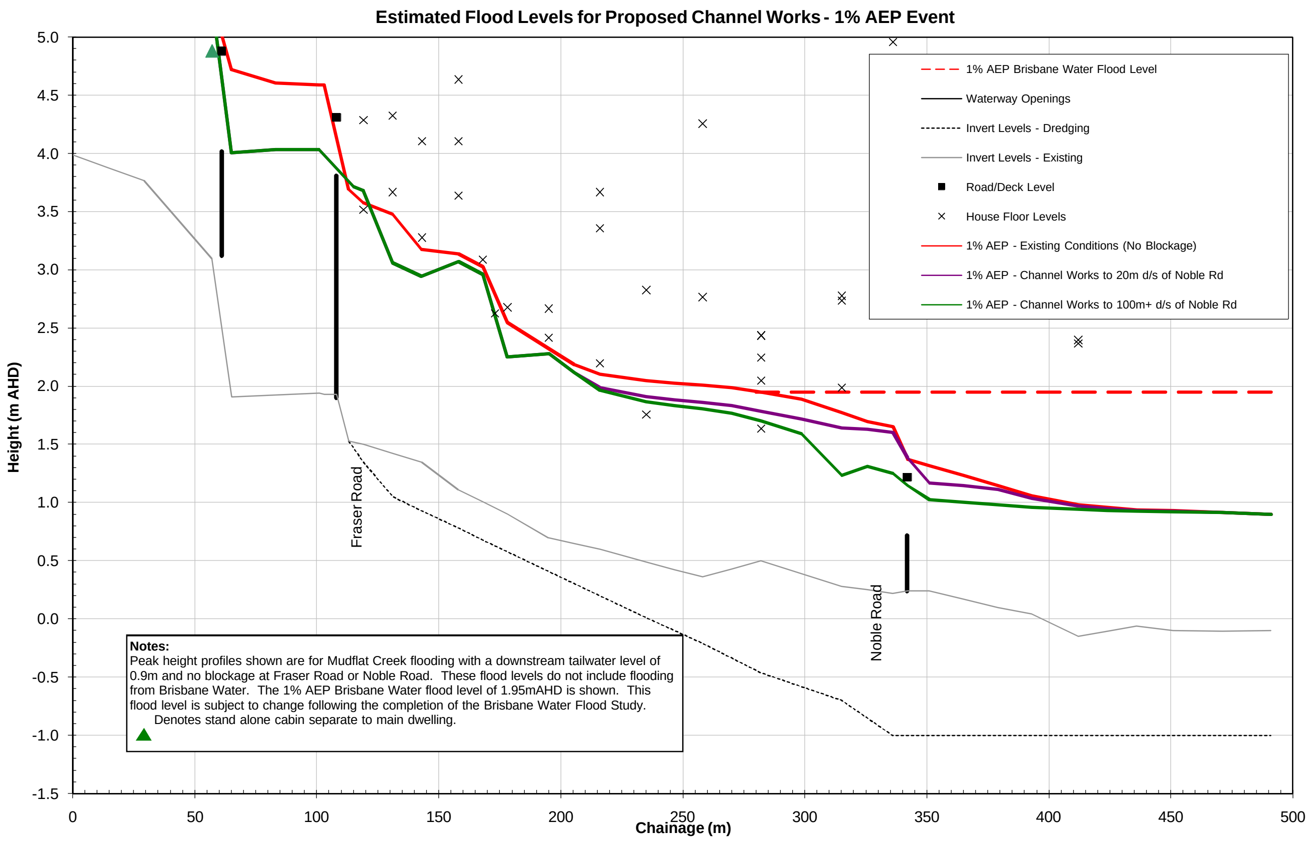


FIGURE 6
POSSIBLE FLOOD MODIFICATION MEASURES
Upstream of Fraser Road
Section In Report | Description | Symbol
5.2.1 Do Nothing Not shown
5.2.2 Channelisation
5.2.3 Levee
5.2.4 Enlarge Fraser Road Culvert
5.2.5 Wards Hill Retarding Basin Not shown
FRASER ROAD
FRASER ROAD
NOBLE
ROAD
OWANDA
CRESCENT
STANLEY STREET
HARDYS BAY
Downstream of Fraser Road
Section In Report | Description | Symbol
5.3.1 Do Nothing Not Shown
5.3.2 Pipe Flows
5.3.3 Provide Siltation Control & Monitoring
5.3.4 Channel Works Not Shown
5.3.5 Realign Channel
5.3.6 Creek Maintenance Not Shown
5.3.7 Blockage Prevention
5.3.8 Enlarge Easements
5.3.9 Sheet Flow Across Fraser Road along Secondary Flowpath
5.3.10 Upgrade Access along Stanley Road
5.3.11 Overland Flooding along Fraser Rd North Refer to Figure 7
N
0 25 50
m

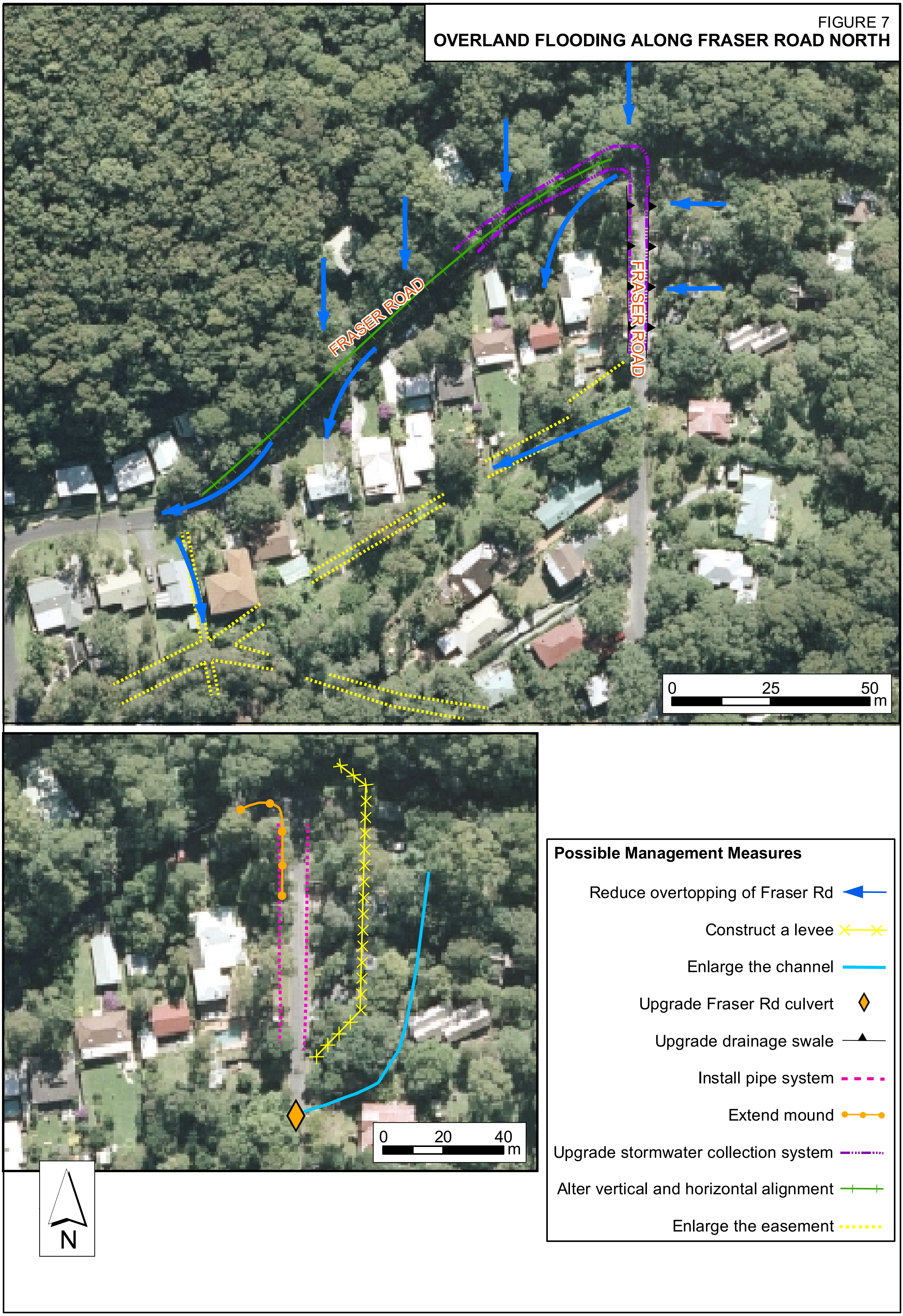
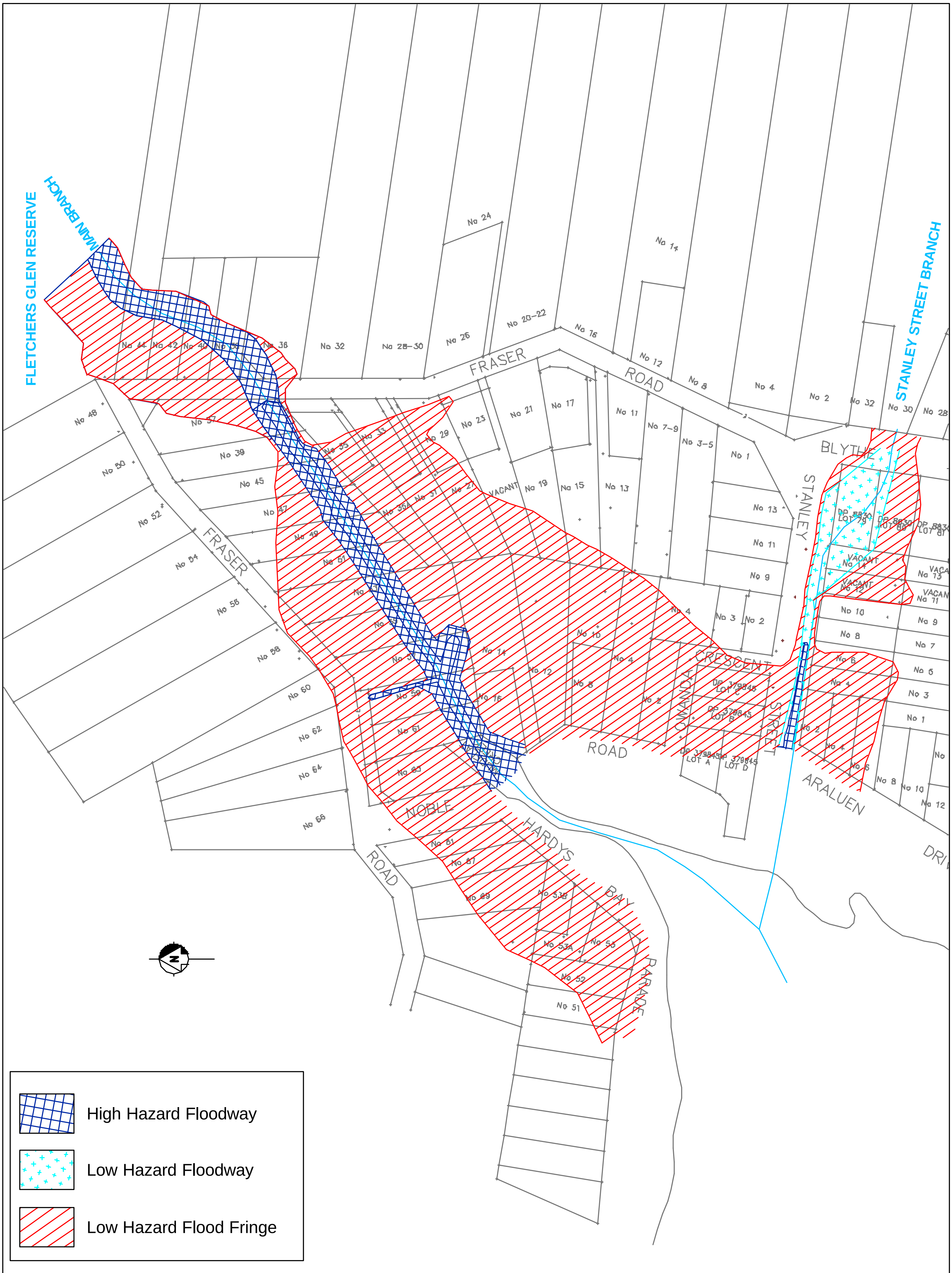


FIGURE 7
OVERLAND FLOODING ALONG FRASER ROAD NORTH

FIGURE 8

UPDATED HYDRAULIC AND HAZARD CATEGORISATION - 1% AEP DESIGN CONDITIONS



Note: Flood extent based on available survey.

APPENDIX A: GRAIN SIZE AND RELATED ANALYSIS

Aargus
AUSTRALIA

ACN 063 579 313
Environmental Services - Remediation - Geotechnical Engineering - Drilling

5 November 2007
Our Ref: E1965

Mr Richard Dewar
Webb, Mckeown and Associates
Level 2, 160 Clarence St
Sydney, NSW 2000
By Facsimile: 02 9262 6208 pp 1 of 3

Dear Richard,

Re: Soil Classification
Mudflat Creek, Killcare NSW

Aargus Pty Ltd was appointed by Mr Richard Dewar of Webb, McKeown and Associates Pty Ltd to conduct a soil classification of for the site located at Mudflat creek, Killcare, NSW, which runs parallel to Fraser Rd and will now be referred to as 'the site'

To assess the waste classification of materials to be disposed of off-site, the NSW EPA refers to the *NSW EPA* (1999) *Environmental Guidelines: Assessment, Classification and Management of Liquid and Non-Liquid Wastes.* To assess the suitability of materials to be used on other sites the NSW EPA refers to the NEPM Health Investigation Levels (1999) *Guidelines on Investigation Levels for Soil and Groundwater.*

Aargus staff visited the site on 16 October 2007. At the time of the site visit the site is a creek which runs parallel to Fraser Rd and through the middle of a number of residential properties which are single or double storey brick, fibro or wood houses.

Four samples of the stockpile were analysed for Heavy metals, Polycyclic Aromatic Hydrocarbons (PAH), Polychlorinated Biphenyls (PCB) and Organo-Chlorine Pesticides (OCP). Following the laboratory analysis and with reference to NSW EPA guidelines the soil is classified as **solid waste**. Further classification was not undertaken because of the presence of acid sulphate soils on site which must be disposed of as **solid waste** in accordance with treatments outlined in the acid sulphate soil management plan (ASSMP). Following analysis of the samples and with reference to NEHF A guidelines the soils may be found suitable for use at 'Standard' residential sites with garden accessible soil (home-grown produce contributing less than 10% of vegetable and fruit intake; no poultry). This includes the less sensitive land areas of recreational areas, high rise apartments and commercial sites. In this analysis this material is identified as containing acid sulphate soils and must be treated according to the ASSMP prior to any re-use. Soils may then be classed as suitable according to the NEPM health investigation guidelines.

As part of this soil classification, Aargus undertook a walkover of the site and took into consideration the following points where applicable:

- Description and quality of the building structure & materials;
- Current operations;
- Waste Management Practices & trade waste;
- Above ground storage tanks;
- Underground Storage Tanks;
- Odours;
- Site vegetation & sealed surfaces;
- Historical operations (if known);
- Former raw materials & transportation (if known);
- Surface water;
- Groundwater (if known); and
- Site Surrounding and their operations.

From inspection of the above details, information was gathered with regards to the property.

The underlying material at the site was FILL, TOPSOIL, Brown, med-grained and moist which was underlain by NATURAL, CLAYEY SAND, brown/grey, medium grained and moist. The soils were noted to contain brown to dark grey estuarine muds.

No USTs or ASTs were visible on-site. No staining or odours were visible at the time of the inspection. There was no evidence of localised oil or chemical spills on any sealed or unsealed areas and this issue does not warrant any concern. Vegetation of the surrounding properties was generally healthy. Visible fibro fragments were not observed at the site. The site was bordered by residential properties.

The site was previously the location of a number of citrus orchards. The creek flows down from the mountain to the northeast and flows across the plateau through the houses into Hardys Bay. The proposed development consists the deepening of a creek by 1m and the widening of the creek by 4m in order to increase hydraulic conveyance and hence possibly increase flood protection in times of heavy rainfall.

Samples were analysed for heavy metals (Ar, Cd, Cr, Pb, Ni, Zn), Polycyclic Aromatic Hydrocarbons (PAH), Polychlorinated Biphenyls (PCB) and Organo-Chlorine Pesticides (OCP).

Full laboratory information, spiked samples and duplicates are available upon request. A summary of the laboratory analyses is provided with NSW non-liquid waste classification and NEPM health investigation criteria in Table 1 below.

Table 1: Summary of laboratory results showing total and mean concentrations of analytes and guideline values

Analyte Tested	PQL	S1	S2	S3	S4	CT1 Inert	CT2 Solid	CT3 Industrial	NEHF A
Arsenic (As)	1	3	**13**	3	2	10	100	400	100
Cadmium (Cd)	0.1	<0.1	0.1	<0.1	<0.1	2	20	80	20
Chromium (Cr)	1	12	**21**	6	6	10	100	400	100
Lead (Pb)	2	**15**	**19**	6	7	10	100	400	300
Nickel (Ni)	1	5	**21**	3	1	4	40	160	600
Zinc (Zn)	5	22	48	32	12	nsl	nsl	nsl	7000
Total PAH	8	<8	<8	<8	<8	200*	200*	800*	20
Total PCB	3	<3	<3	<3	<3	2*	<50*	<50*	10
Aldrin + Dieldrin	0.1	<0.1	<0.1	<0.1	<0.1	nsl	nsl	nsl	10
Chlordane	0.1	<0.1	<0.1	<0.1	<0.1	nsl	nsl	nsl	50
DDT + DDD + DDE	0.15	<0.15	<0.15	<0.15	<0.15	nsl	nsl	nsl	200
Heptachlor	0.05	<0.05	<0.05	<0.05	<0.05	nsl	nsl	nsl	10

Notes:
- All data in mg/kg unless otherwise stated
- S refers to Sample.
- nsl: No Set Limit
- concentration in **bold** exceed criteria limits
- CT1 CT2 and CT3 refer to total concentration (inert, solid and industrial) for non-liquid waste classification (*NSW EPA – Environmental Guidelines: Assessment, Classification & Management of Liquid & Non-liquid Waste, 1999*)
- *- Refers to total concentration SCC1, SCC2 and SCC3 from the above non-liquid waste classification.

The above results show the soil is classified according to the NSW EPA guidelines as **solid waste**. Further classification was not undertaken because of the presence of acid sulphate soils on site which must be disposed of as **solid waste** in accordance with treatments outlined in the acid sulphate soil management plan (ASSMP). Following analysis of the samples and with reference to NEHF A guidelines the soils may be found suitable for use at 'Standard' residential sites with garden accessible soil upon treatment as per ASSMP guidelines. Soils can also be reused at commercial, industrial and recreational sites.

If any further areas of environmental concern are uncovered during the excavation process, this office should be notified for further assessment.

We would be pleased to provide further information on any aspects of this report.

For and behalf of
Aargus Pty Ltd

Ben Buckley

Ben Buckley
Environmental Scientist

Reviewed By

Nick Kariotoglou
Managing Director

Aargus

BRINK & ASSOCIATES A.B.N. 75 050 212 710
Part of the Aargus Group of Companies
Geotechnical, Geological, Hydrogeological, Environmental Services

Central Coast: 1/13 Clare Mace Crescent Tumbi Umbi P (02) 4389 2300 F (02) 4389 1600 PO Box 40 Ourimbah NSW 2258
Sydney: 5/12 Tarlington Place Smithfield P (02) 9609 3800 F (02) 9604 6427 PO Box 6871 Wetherill Park NSW 2164

07068-A ML:ML

15th November 2007

Webb, McKeown and Associates Pty Ltd
Level 2, 160 Clarence Street
SYDNEY NSW 2000
Email: dewar@webbmackeown.com.au

ATTENTION: Mr. Richard Dewar

Dear Sir,

Floodplain Risk Management Study – Mudflat Creek, Killcare Creek

Factual Report - Grain Size Analysis

As requested and as part of the Acid Sulphate Soils testing to be undertaken by Aargus Australia, a grain size analysis had been carried out by the NATA accredited laboratory of Brink & Associates. A total of four samples had been supplied by Aargus Australia. The testing carried out was particle size distribution in accordance with test method AS1289.3.6.1.

The samples tested are summarised in the following Table 1:

Table 1 – Samples Tested

Sample Location	Sample Depth (m)	Material (Visual Assessment)
BH1	1.0	Silty Clay, dark grey
BH2	1.0	Silty Clay, dark grey-brown
BH3	1.0	Silty Clayey Sand, grey-brown
BH4	1.0	Silty Clayey Sand, grey-brown

The results of the laboratory testing are presented in the attached test report.

The results of testing indicate the following:

- The material sampled from BH1 was predominantly silty clay, with only 31% of sand size particles varying from fine to medium grained.
- The material sampled from BH2 was predominantly silty clay, with only 35% of sand size particles varying from fine to medium grained.
- The material sampled from BH3 was predominantly silty clayey sand, with 14% of silt and clay size particles. The sand size particles are generally fine to medium grained.
- The material sampled from BH4 was predominantly silty clayey sand, with 16% of silt and clay size particles. The sand size particles are generally fine to medium grained.

Should further analysis be required to determine the classification and the particle distribution of fine particles (silts and clays), hydrometer testing of the samples are to be carried out together with Plasticity Index and Liquid Limit.

Please do not hesitate to contact the undersigned if you require any further information.

For and on behalf of
Brink & Associates

Mike Leung, BE (Civil) MEnv EngSc MIEAust
Senior Geotechnical Engineer

Reviewed by

Ralph Erni, B.Sc. Eng. (Civil) MIEAust CPEng NPER3
National Engineering Manager

Encl. Particle Size Distribution Test Report (1 page)
Grading Analysis Plots for BH1 to BH4 (4 charts)

Brink Holdings Pty Ltd ABN 75050212710 trading as

BRINK & Associates

Geotechnical, Geological, Environmental Consultants

PARTICLE SIZE DISTRIBUTION TEST REPORT

Client	Webb, McKeown & Associates Pty Ltd	Job Number	07068 - A
Project	Flood Plain Risk Management Study	Date	6/11/2007
Location	Mud Flat Creek, Killcare Creek	Page	1 of 1

TEST METHOD AS1289 3.6.1 ☐

		MT1	MT2	MT3	MT4
Sample Number		MT1	MT2	MT3	MT4
Date Sampled		19/10/2007	19/10/2007	19/10/2007	19/10/2007
Location					
Borehole		BH1	BH2	BH3	BH4
Depth	(m)	1.0	1.0	1.0	1.0
% Passing AS Sieve Size	75.0 (mm)	-	-	-	-
	53.0 (mm)	-	-	-	-
	37.5 (mm)	-	-	-	-
	26.5 (mm)	-	-	-	-
	19.0 (mm)	-	-	-	-
	13.2 (mm)	-	-	-	-
	9.50 (mm)	-	-	-	-
	6.70 (mm)	-	-	-	-
	4.75 (mm)	100	-	100	100
	2.36 (mm)	99	100	99	99
	1.18 (mm)	98	97	98	96
	0.600 (mm)	97	93	96	89
	0.425 (mm)	94	89	90	80
	0.300 (mm)	88	83	69	59
	0.150 (mm)	76	72	25	26
	0.075 (mm)	69	65	14	16

Notes:

MT1 Silty Clay, Dark Grey

MT2 Silty Clay, Dark Grey Brown

MT3 Silty Clayey Sand, Grey Brown

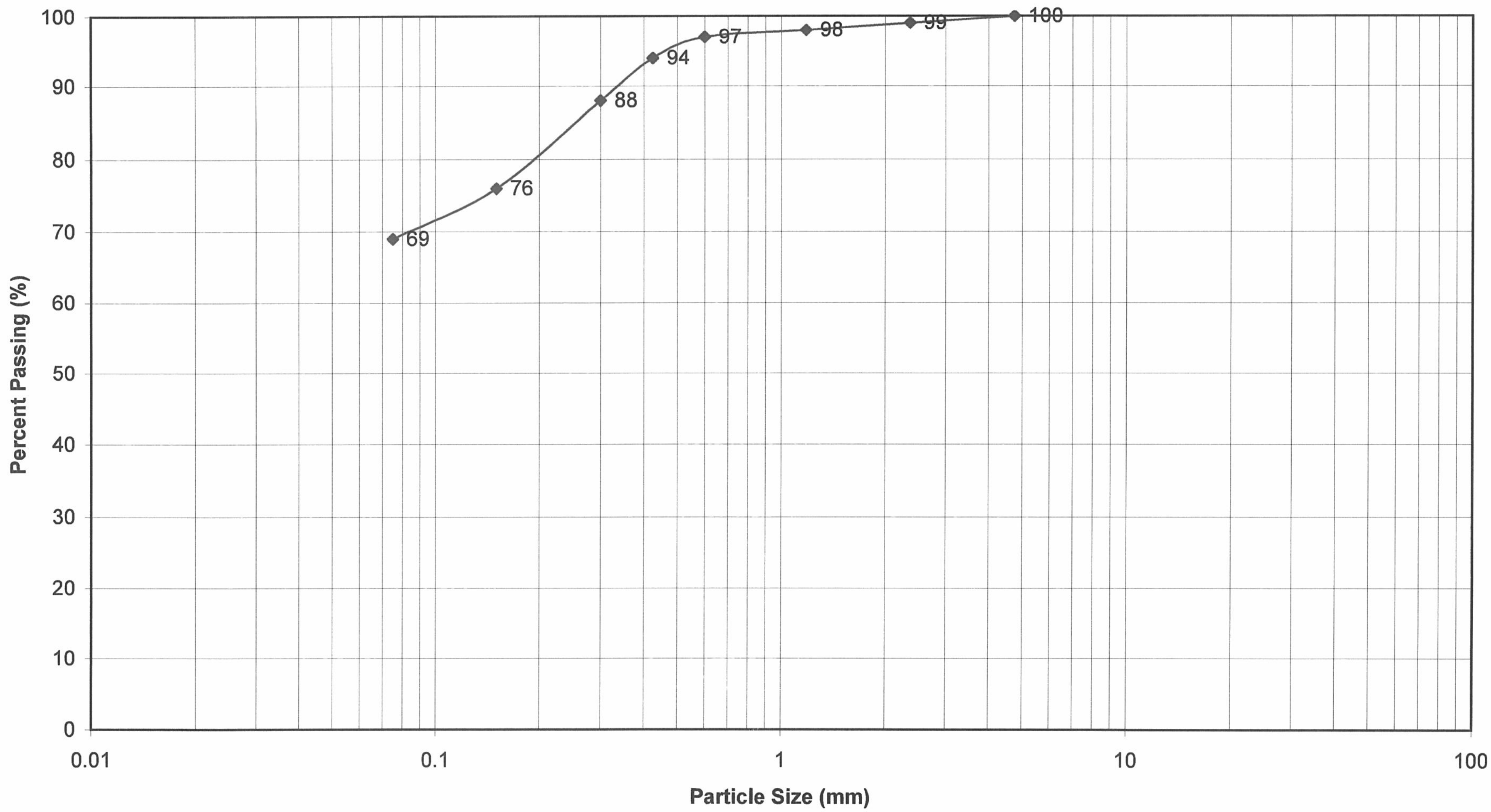
MT4 Silty Clayey Sand, Grey Brown

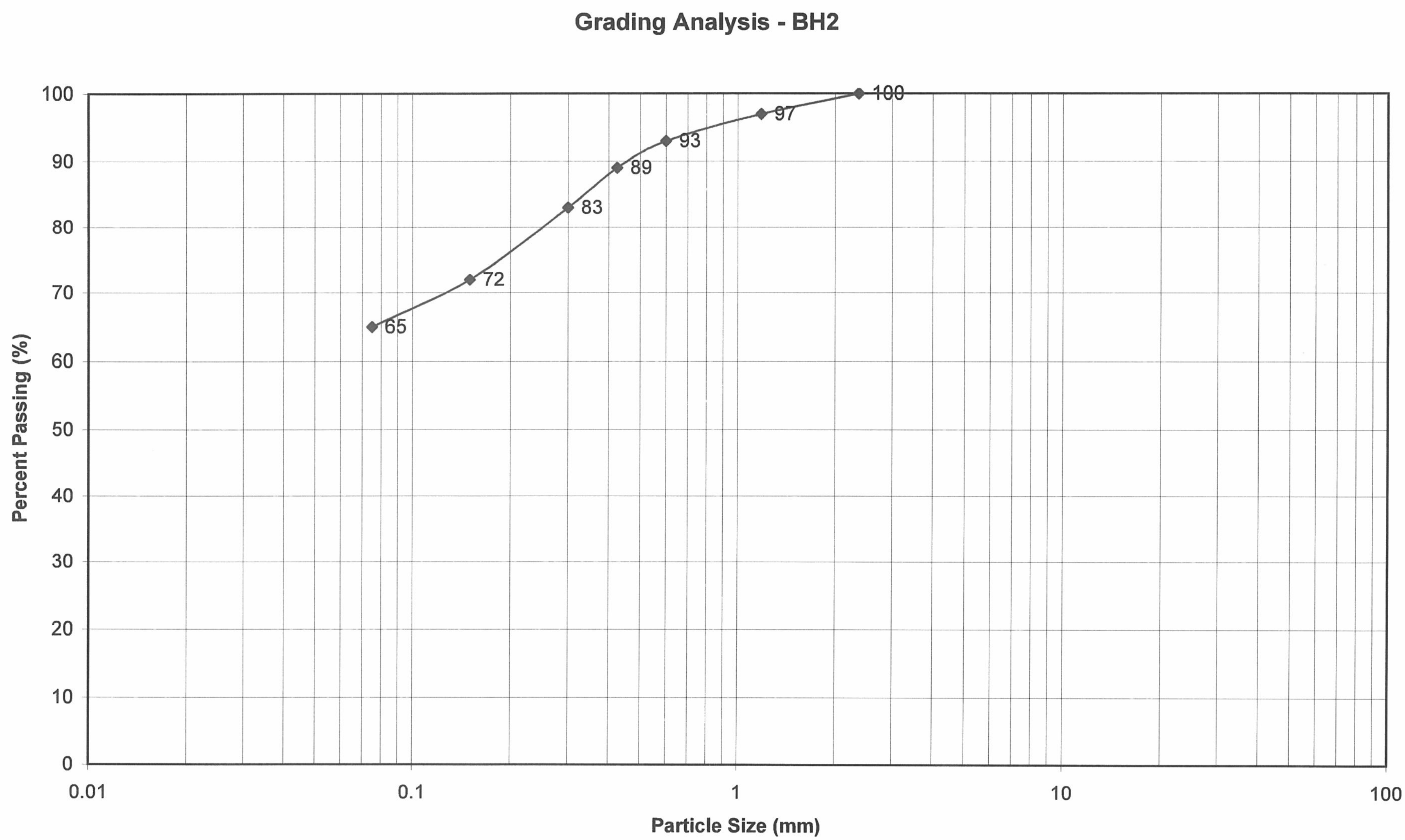
NATA

Approved Signatory

Date 7/11/2007

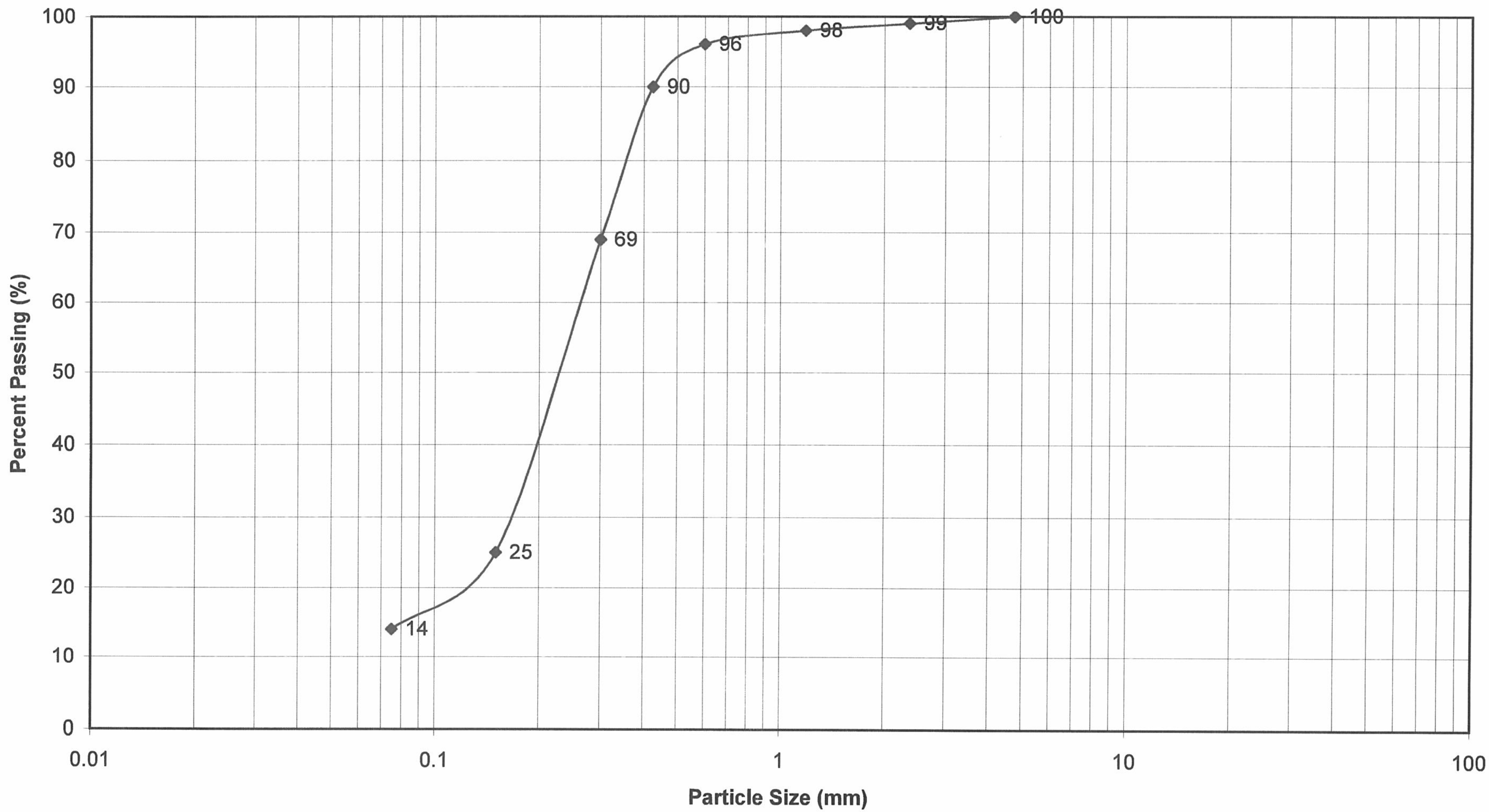
Grading Analysis - BH1



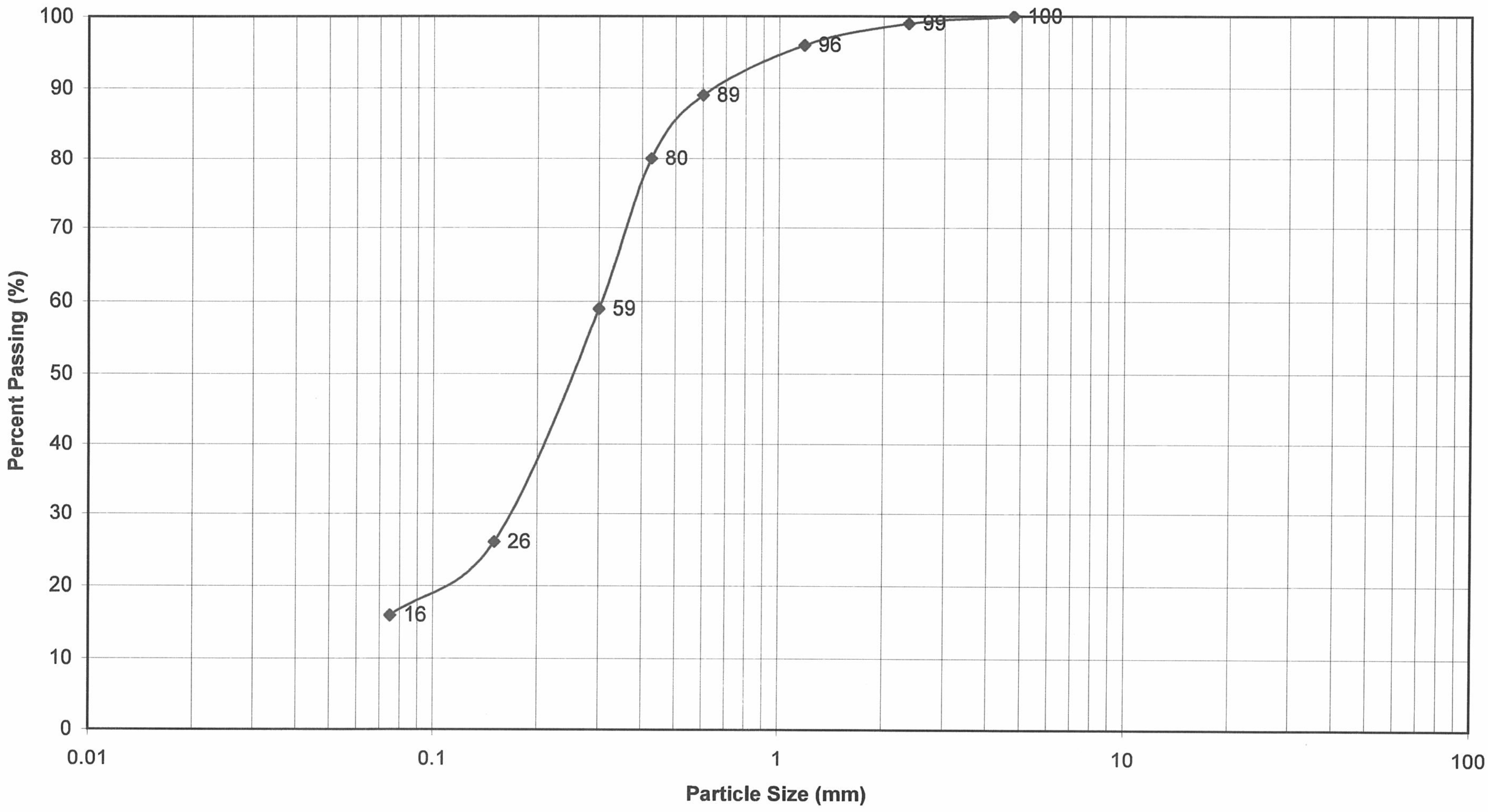


Grading Analysis - BH2
100
90
80
70
60
50
40
30
20
10
0
Percent Passing (%)
0.01
0.1
1
10
100
Particle Size (mm)
100
97
93
89
83
72
65

Grading Analysis - BH3



Grading Analysis - BH4



Aargus
AUSTRALIA

ACN 063 579 313
Environmental Services - Remediation - Geotechnical Engineering - Refill Centres

23rd January 2008
Our Ref: E1965

Mr Richard Dewar
Webb, McKeown and Associates
Level 2, 160 Clarence St
Sydney, NSW 2000
By Facsimile: 02 9262 6208 pp 1 of 4

Dear Richard,

Re: Summary of Testing at Mudflat Creek Killcare, NSW

Aargus Pty Ltd was appointed by Mr Richard Dewar of Webb, McKeown and Associates to conduct a series of tests at Mudflat Creek, Killcare NSW ("the site"). The tests included chemical analysis of soils for classification purposes, grain size analysis and acid sulphate testing. The results showed the soils were classified according to the NSW EPA guidelines as solid waste and confirmed the presence of acid sulphate soils. The tests were undertaken to also evaluate if the following questions have been answered:

1. What rate or amount of sedimentation has occurred in the last 50 years?
2. Has sedimentation slowed down and stabilised?
3. Is sedimentation greater over the last 50 years than the previous 50 years?
4. Will the current rate of sedimentation have an effect on the management of works if they occur?

At the present time preliminary testing, visual and anecdotal evidence from interviews with residents have shown that the creek has been filled due to sedimentation. Evidence of silty clays and acid sulphate soils were found on either side of the creek suggesting that the creek was historically wider. The sedimentation has grown to the extent where no creek area exists in some areas and grassland occurs. No determination can be made from current information as to how fast the creek has been filling. Sedimentation would have occurred before during and after house construction in the area and provides concerns with respect to the following:

Aargus Pty Ltd
Telephone: 1300 137 038
Facsimile: 1300 136 038
Website: www.aargus.net

NSW: PO Box 398 Drummoyne NSW 2047
QLD: PO Box 1340 Fortitude Valley QLD 4006
VIC: PO Box 2333 Hawthorn VIC 3122
SA: PO Box 3143 Rundle Mall SA 5000

- Flood plain management (sedimentation refilling into dredged areas)
- Erosion controls at the source
- Stability and settlement of existing land uses (only a concern for developments and planning requirements for council).

The tests conducted to date by Aargus do not provide sufficient information to determine the extent (amount) or rate of sedimentation that has occurred in the last 50 years. They cannot provide any information in determining if the siltation process has slowed down and stabilised, or determining if it has become greater in the time period examined. The reason for this is because information determined from the tests was qualitative not quantitative thus cannot be correlated to the above questions 1, 2, 3 and 4 that have been asked. Qualitative results provide us with answers that there is sedimentation occurring. Quantitative analysis would determine how much sedimentation is occurring and over what timespan. Whilst we may be able to determine the locations of sedimentation that has occurred in further tests, we would not be able to determine in what timeframe it has occurred so quantitative analysis is only hypothetical based upon further modelling scenarios.

The results of the soil type, being silty clays, in connection with acid sulphate soils showed that sedimentation did exist outside the creek bed area. Natural soils (non creek or former creek areas) around the area contain medium to heavy clays and sands. The tests performed with grain size analysis and acid sulphate soil testing also provide information that sedimentation has occurred. These tests show us that the type of soil that is present differs between deposition (sediment) soils and natural soils. Deposition soils are resident to most creek and river systems and contain silty clays and are mixed in with organic matter. They are usually finer grained and come from other areas where they have been washed down from, i.e. sediments. The soil types containing acid sulphate soils are also prevalent in creek beds and former waterways. Natural clays however have a larger grain size and are not found as creek bedding material. This information may help in identifying areas where sediments may have initially come from however the information does not provide great value as it does not provide quantities of deposition/sedimentation. Chemical sampling of sediment soils, natural soils and upgradient soils could also be undertaken and linked to the chemical characteristics of each soil type. This also provides limited beneficial information as it will only indicate where not how much sedimentation has occurred.

Further testing can be performed in order to confirm the following:

- To determine the extent (amount) of historical sedimentation occurring in the area. This will only provide where sedimentation has occurred and not how much is occurring over what period.

- To determine the current rate of sedimentation occurring in normal and high level (storm events) flows. This information is very useful to see if sedimentation basins are needed to prevent future dredging issues.
- Historical searches to determine the amount of urban development occurring in that area over the last 50 years to determine if sedimentation is becoming greater from increased stormwater runoff. This can be conducted by looking at aerial photos, cadastral records, photos, anecdotal evidence and library records. It is our understanding that limited information may be available. Council housing records can however be linked to dates of buildings and some useful data may be attained.
- Determining the creek bed stability and the stream bed erosion rate in order to determine possible sources of sediments and where they will be deposited downstream.
- Conduct trenching works to delineate the extent of silty clays to natural clays. This involves digging a few trenches across the creek bed in different areas and then carrying out further acid sulphate and grain size review to determine where former creek locations were and how much has filled in.
- Conduct compaction tests to confirm the stability of current soils and if they are considered suitable for load bearing soils for developments (on and off sedimentation areas). This is only of value for council planning purposes.

However there is a difficulty in understanding the movement of river sediments as it is usually a random event. Another problem is that most sedimentation is caused from storm events and sampling is difficult during these events along with the fact every storm is different and data cannot be easily connected. Specifically this means that the sampling depends on rainfall and large waiting times could be problematic. Also because Mudflat Creek leads directly into Hardy's Bay, tidal flows may have an impact which adds another possible source of sedimentation.

Obtaining further valuable data about what has happened in the last 50 years seems limited. However further interpretation of information may provide valuable information into the extent of sedimentation. A highly detailed modelling plan could also be prepared and extensive sampling may also be conducted to further bolster future plans.

Options for further testing and their value are:

1. Conduct trenching to determine the location of sediments compared to natural clays. This would provide information on the extent of sedimentation. Trenching is considered of minimal value as the knowledge of where sediments were and where they are now will only provide qualitative information. It does not indicate how quick sediments were deposited and what rate they are depositing.

2. Conduct Historical searches to determine the before and after aerial locations of former land bodies. This can be conducted by looking at aerial photos, cadastral records, photos, anecdotal evidence and library records. By linking this with council and house built dates, information can be attained cheaply on general changes that have occurred over the last 50-80 years.
3. Conduct density tests to determine stability issues for founding material for the planning and development issue. This is of limited use for the present study but it is recommended that council adopt a planning process that encompasses stability testing for future developments within sedimentation areas.
4. Conduct turbidity sampling in stormwater events to determine the potential for current sedimentation to occur (semi modelling). This is time dependant and an appropriate rainfall event may not occur for 5 years.
5. Conduct further Acid Sulphate Soil testing. This is of limited use for the study but it is recommended that council adopt a planning process that encompasses PASS/ASS testing for future developments that may be causing damage to the environment by releasing acids to the waterways or by managing acids eating away reinforcements/metal in foundations.

In summary, the acid sulphate soils testing, grain size analysis and chemical soil class were the preliminary tests undertaken. These tests do not provide enough information to determine the patterns of sedimentation happening over the last 50 years. However these tests do provide a basis for similar testing that could be undertaken across a broader systematic area to determine the extent of the sedimentation present.

Preliminary costing for the above items 1-5 would be in the vicinity of $15,000 + GST. To conduct detailed numerical modelling would be in the vicinity of $25,000. Only item 2 is likely to provide any further conclusive insight into the pattern of sedimentation over the last 50 years and is obviously dependant on what information can be found.

If mitigation works are to go ahead an Environmental Management Plan is required along with an Acid Sulphate Soil Management Plan for the dredging works. The Acid Sulphate Management Plan can be conducted for a cost of $2,500 + GST.

If you have any questions please don't hesitate to contact us.

For and behalf of
Aargus Pty Ltd

Ben Buckley

Ben Buckley
Environmental Scientist

Reviewed By

Nick Kariotoglou
Managing Director

APPENDIX B: INDICATIVE COSTS FOR CREEK REHABILITATION WORKS

Table B1: Indicative Costs for Creek Rehabilitation Works

	Quantity	Unit	Rate (2007)	Cost
Fraser Road to upstream of Noble Road:				
Site Costs (incl erosion &traffic control)	1	item	$22,000	$22,000
Excavation	1350	m^3	$39	$51,975
Remove Spoil	1430	m^3	$17	$23,595
Tip fees	1430	m^3	$99	$141,570
Rocklining	600	m^2	$99	$59,400
Backfill	120	m^3	$17	$1,980
Rockbars	8	each	$5,500	$44,000
Landscaping	1600	m^2	$11	$17,600
Excavate pavement	200	m^3	$55	$11,000
Remove Fraser Road pipe	10	m	$220	$2,200
Supply culvert	12.6	m	$2,750	$34,650
Prepare subgrade	100	m^2	$22	$2,200
Lay culvert	12.6	m	$528	$6,653
Headwalls	2	each	$16,500	$33,000
Backfill	126	m^3	$66	$8,316
Pavement	100	m^3	$55	$5,500
Bitumen Seal	50	m^3	$22	$1,100
Traffic furniture	1	item	$5,500	$5,500
Sub-total				**$472,239**
Project Management & Contingencies			30%	$141,672
TOTAL				**$613,910**
Upstream of Noble Road to 20 m beyond:				
Site Costs (incl erosion & traffic control)	1	item	$22,000	$22,000
Excavation	840	m^3	$39	$32,340
Remove Spoil	1240	m^3	$17	$20,460
Tip fees	1240	m^3	$99	$122,760
Rocklining		m^2	$99	$0
Backfill		m^3	$17	$0
Rockbars		each	$4,400	$0
Landscaping		m^2	$11	$0
Excavate pavement	400	m^3	$55	$22,000
Remove Noble Road bridge	10	m	$550	$5,500
Supply culvert	10	m	$4,917	$49,170
Prepare subgrade	200	m^2	$44	$8,800
Lay culvert	10	m	$825	$8,250
Headwalls	2	each	$22,000	$44,000
Backfill	100	m^3	$66	$6,600
Pavement	100	m^3	$55	$5,500
Bitumen seal	50	m^3	$22	$1,100
Traffic furniture	1	item	$5,500	$5,500
Kerb	40	m	$88	$3,520
Footpath	60	m^2	$66	$3,960
Sub-total				**$361,460**
Project Management & Contingencies			30%	$108,438
TOTAL				**$469,898**
Upstream of Noble Road to 100 m beyond:				
Site Costs (incl erosion & traffic control)	1	item	$22,000	$22,000
Excavation	2600	m^3	$39	$100,100
Remove Spoil	3000	m^3	$17	$49,500
Tip fees	3000	m^3	$99	$297,000

	Quantity	Unit	Rate (2007)	Cost
Rocklining		m^2	$99	$0
Backfill		m^3	$17	$0
Rockbars		each	$4,400	$0
Landscaping		m^2	$11	$0
Excavate pavement	400	m^3	$55	$22,000
Remove Noble Road bridge	10	m	$550	$5,500
Supply culvert	10	m	$4,917	$49,170
Prepare subgrade	200	m^2	$44	$8,800
Lay culvert	10	m	$825	$8,250
Headwalls	2	each	$22,000	$44,000
Backfill	100	m^3	$66	$6,600
Pavement	100	m^3	$55	$5,500
Bitumen seal	50	m^3	$22	$1,100
Traffic furniture	1	item	$5,500	$5,500
Kerb	40	m	$88	$3,520
Footpath	60	m^2	$66	$3,960
Sub-total				**$632,500**
Project Management & Contingencies			30%	$189,750
TOTAL				**$822,250**