SINCLAIR KNIGHT MERZ

SKM

Northern Territory Government

Rapid Creek Floodplain Risk Management Discussion Paper

DISCUSSION PAPER

- Final
- 17 December 2013

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Sinclair Knight Merz
Level 2, 25 Parap Road
PO Box 2145
Parap NT 0820
Australia
Tel: +61 8 8982 4800
Fax: +61 8 8982 4840
www.globalskm.com

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Executive Summary

Rapid Creek in the northern suburbs of Darwin has a history of flooding. The most recent major flood occurred in February 2011 with the formation of Cyclone Carlos. A number of houses were inundated in the suburb of Millner and arterial roads were cut by the floodwaters.

A flood study was undertaken in 2012 and involved hydrologic modelling, hydraulic modelling and floodplain mapping. Design floods considered were the 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP floods together with the Probable Maximum Flood. The floodplain mapping identified the extent and depths of flooding and also high hazard areas where generally depths exceed two metres or depth × velocity exceeds one metre ×metre per second.

The 2012 flood study shows an increase in the potential for flooding compared to a previous study carried out in a1999. The increase is a result of analysis with 10 years of additional rainfall and streamflow data, more up to date computer modelling methods and their application to a larger part of the floodplain and possibly as a result of increased catchment development over the last 10 years.

A flood damages study was subsequently carried out and the potential average annual damage was estimated to be $480,000 to $610,000 and the net present value of all future damages to be $11 million to $14 million.

The current study investigates options for flood mitigation. Mitigation options include:

- flood modification options, which seek to reduce the frequency and extent of floodwaters at locations where there is potential risk to people and/or property
- Response modification options, which seek to amend the community’s response to rising floodwaters so as to minimise the potential risk to people and/or property
- Property modification options, which seek to modify the built form within the floodplain so as to minimise the potential risk to people and/or property

Flood modification options considered include flood control weirs and detention basins, modification to the channel with a view to carrying more floodwaters in the Creek and less in the floodplain, and levees to prevent floodwaters from getting to the areas where the most damage and largest risk exist.

Response modification options include flood warning, raising community awareness of how to more safely respond to floods and how to best manage flood recovery.

Property modification options include house raising, voluntary house purchases, flood proofing properties, and modifying construction techniques to reduce the vulnerability of buildings when they are invaded by floodwaters. Other measures include specifying minimum floor levels for future construction on the floodplain and planning controls which modify the composition of floodplain occupancy.

Recommendations include a mix of measures selected from the three types of modification options. Specific recommendations include:

- Rapid Creek is maintained in a manner that reduces the build-up of resistance to flows that can occur as a result of siltation of hydraulic structures and accumulation of rubbish and debris over time
- Programmes are put in place to raise flood awareness, disseminating flood information through various media. Residents would be encouraged to adopt personal flood action plans. This would include informing floodplain residents how best to prepare for floods, including how to respond in a safe manner and so as to minimise the time and cost taken for recovery
- An improved flood warning system based on rainfall be implemented to give residents as much advance warning as possible, including warning based on likely severe weather over the Darwin northern suburbs
- Ongoing consultations are held with Defence and Darwin International Airport with a view to mitigating any adverse impacts of future catchment development in their areas and planning measures be used to ensure development or re-development in other parts of the catchment is not of a type and extent that would worsen flooding
- The existing flood control weir at the rear of the Airport Resort be maintained to ensure its ongoing ability to mitigate flood peaks from the upper catchment and to minimise its risk of failure during a major flood
- Options are examined with a view to re-developing the floodplain in the areas most at risk (the suburb of Millner) through planning and zoning changes. These would be structured so as to take effect over a longer period of time and be driven by market forces, but would result in a reduction in overall risk to life and property to Rapid Creek flooding
- Upgrade of the McMillans Road and Trower Road crossings of Rapid Creek. These crossings should be of a high standard as they carry major arterials linking the inner suburbs to the northern suburbs, including to the Darwin Public and Private Hospitals

It is envisaged that the implementation of these measures will take place over varying time frames and with varying levels of ongoing commitment. These depend on their acceptability when stakeholder and community consultation takes place, priorities and funds available.

It is also recommended that further work is carried out to shore up the studies that have been carried out to date. This further work includes obtaining floor levels of properties in the floodplain, carrying out extensive stakeholder and floodplain resident consultations. Floor levels will facilitate re-running the damages assessment and firming up the relationship between benefits and costs as well as informing emergency responses.

Consultations will provide guidance on the acceptability of the various mitigation strategies proposed.

1. Introduction

1.1. Background and Project Objectives

There have been a number of studies into flooding along Rapid Creek since the establishment of the Darwin Northern suburbs. In the late 1990s, a study by Connell Wagner produced floodplain mapping of the area between Trower Road and McMillans Road for the Department of Lands and Planning. A number of properties were identified as being at risk. A major flood occurred in February 2011 during the formation of Cyclone Carlos over Darwin. A number of properties were inundated and floodwater was understood to have entered houses in the suburb of Millner.

The Department of Natural Resources Environment, The Arts and Sports (now Department of Land Resource Management) commissioned an update of the previous study at the end of February 2012.

The resulting flood study consisted of the following:

- Updated hydrology study using the URBS model
- Updated hydraulic study using the TUFLOW model
- Floodplain mapping from the Flood Control Weir (1,500 m upstream of McMillans Road) to the sea

This was followed by a preliminary examination of mitigation options and a flood damages study was carried out, commencing in February 2013.

The current commission commenced in August 2013 and is for a more thorough examination of flood mitigation measures.

The objectives of the current study are:

- Determine the most likely feasible mitigation options or combinations of mitigation options
- Recommend the most cost-effective mitigation strategy

1.2. Flood Risk

1.2.1. What is the risk?

The floodplain community of Rapid Creek, particularly in the Millner area, experiences flooding that allows little time to respond. In a major storm, Rapid Creek can inundate Rapid Creek Road and areas in suburban Millner within 1.0 to 1.5 hours of the onset of heavy rainfall. A number of residents, whose properties mainly front Rapid Creek Road, experience difficulties evacuating to higher ground due to the restricted time to react and the early loss of access to Rapid Creek Road.

It is estimated that 67 houses are located on allotments that are wholly or partially below the 1% AEP (Q100) flood level. Of these, it is estimated that 28 have rooms constructed at or near ground level so there is a risk of personal safety and property damage.

The damage bill caused by the 2011 Cyclone Carlos event was estimated at $6 million [SKM 2013 d]. A number of properties along Rapid Creek Road also experience potential flooding from Storm Surge.

1.2.2. Flood risk management

Managing risks from floods may involve altering the chance of flooding affecting a community and/or reducing the impacts of flooding by reducing the community's vulnerability and exposure to flooding.

The methods that are effective in reducing flood risk are very location specific. There is no one-size-fits-all solution and a variety of measures are generally necessary to reduce risk.

For Rapid Creek, the community requires risk mitigation measures that can be managed locally, because emergency services and other support are shared across Greater Darwin during floods.

There are three specific types of flood risks that need to be addressed in the management study [Refer NSW Government 2005]:

- the management of flood damage and personal danger to the existing community and properties at risk (the existing risk) to an acceptable level;
- the management of flood damage and personal danger in areas yet to be developed (the future risk) to an acceptable level; and
- the management of personal danger associated with the continuing or residual risk which exists because :
  - management measures can be overwhelmed. This can occur as a result of a larger flood than adopted in the design of mitigation strategies, or a larger flood occurring as a result of future development
  - not all areas are protected by management measures, e.g., outside a levee

> *"Effective flood risk management can enable a community to become more resilient to floods by:*
>
> - *Planning and preparing for floods*
> - *Responding to, and recovering from floods*
>
> *Effective flood risk management requires:*
>
> - *a coordinated, multidisciplinary approach*
> - *across all levels of Government and between agencies with different responsibilities*
> - *the support of non-government organisations, a range of industry professionals and the active engagement of the community" [McLuckie, 2013]*

1.2.3. Rapid Creek Floodplain Risk Profile

Section 2.6 discusses the risk profile. Although some of the risks may be acceptable to the community, some risks are likely to be only tolerable to unacceptable to the community particularly:

- The depth of flooding in the lower parts of Millner, and

- the risks associated with the McMillans Road crossing (Kimmorley Bridge)

1.2.4. Climate change/Storm surge

Appendix F provides a discussion on climate change and storm surge flooding of Rapid Creek. It concludes that many of the low-lying properties likely to be affected by flooding of Rapid Creek as a result of intense rainfall in its catchment are also in the secondary storm surge zone.

The sea level forms a downstream boundary condition to the TUFLOW model and the impact of climate change was taken into account in the flood study by assuming a sea level rise of 0.8 m by year 2100. This rise affects Rapid Creek downstream of Trower Rd but has little effect upstream of Trower Road.

1.3. Rapid Creek Catchment

1.3.1. Description

Rapid Creek rises in the Marrara Swamp at the eastern end of Darwin Airport, and flows for 9.8 km discharging into the sea (Beagle Gulf) at the southern end of Casuarina Beach (Refer Figure 2). The Rapid Creek catchment covers an area of 28 sq. km and includes parts of the suburbs of Karama, Malak, Anula, Moil, Jingili, Wagaman, Alawa, Casuarina, Wanguri, Nakara and Brinkin, Millner and Rapid Creek.

Figure 1. Minor flooding of the Red Footbridge

In these built up areas of the catchment, runoff enters the Creek via underground piped drainage systems as well as unlined and lined open drains. Large parts of the catchment to the south of McMillans Road are still undeveloped.

The Marrara Swamp is drained by two separate drainage lines, on the north western and south western sides of the Swamp. Where the two drainage lines re-join to form Rapid Creek, a Flood Control Weir exists which attenuates the peak discharge and delays the floodwaters. The Flood Control Weir was constructed in 1985.

Road crossings of Rapid Creek can be found at Henry Wrigley Drive, McMillans Road (where the crossing is known as Kimmorley Bridge), and Trower Road.

A stream gauging station has operated continuously at Rapid Creek since the 1960s. It is located at the upper end of the Freshwater Gardens.

Progressive catchment areas are as follows:

- Flood Control Weir 13.7 sq. km
- Henry Wrigley Drive 15.1 sq. km

- McMillans Road 18.7 sq. km
- Gauging station 18.9 sq. km
- Trower Road 21.3 sq. km
- Sea outfall 27.8 sq. km

Figure 2. Rapid Creek Catchment Area

1.3.2. Brief Flooding history

Stream gauging station records show that floods have occurred in Rapid Creek from time to time since the 1960s. No doubt many floods have occurred before that but no archives investigations nor have paleo-flood investigations been carried out for the current studies.

Major floods occurred in December 1974 (associated with Cyclone Tracy), 1977, 1991 and 2011 (associated with Cyclone Carlos.)

The arterial roads Trower Road and McMillans Road are major routes north and east out of the inner suburbs and some of the northern suburbs. Floods cut McMillans Road at the Kimmorley Bridge almost every year.

Trower Road is known to have been overtopped near the intersection with Rapid Creek Road (i.e., the western approach to the Bridge.) during the 1974 and 2011 floods. Rapid Creek Road was overtopped at more than one location between McMillans Road and Trower Road in 2011 and was likely to have been similarly overtopped during other major floods.

Flooding in and around low-lying houses in Millner occurred in 2011 and is likely to have occurred in 1974 and possibly on other occasions.

1.3.3. Present and Future development

History of development

Rapid Creek catchment has been progressively developed along with the City of Darwin.

At the time of Cyclone Tracy in 1974, the inner northern suburbs of Rapid Creek and Millner were well established. Alawa was constructed in the late 1960s, Jingili in the early 1970s and Moil was also constructed before Cyclone Tracy arrived in December 1974. The original Casuarina Shopping Centre was constructed in 1973 but has had major upgrades since then. The suburbs of Wagaman and Nakara were constructed just before December 1974 (Cyclone Tracy.) Anula and Malak were under construction when Cyclone Tracy struck.

After suffering severe damage from Cyclone Tracy, an intensive re-building programme re-established the existing northern suburbs and completed those under construction at the time of that Cyclone's occurrence.

Further development took place in the 1970s with Brinkin and Karama being developed by 1980. The suburbs of North Lakes and Marrara were also constructed in the 1970s and into the 1980s.

Therefore:

- The lower Rapid Creek catchment was substantially developed by the time of the first of the major floods on record (December 1974 – Cyclone Tracy)
- By the time of the 1977 flood, the pre-cyclone suburbs were substantially rebuilt and suburbs fringing the upper catchment (Malak, Karama, North Lakes and Marrara) were well underway
- At the time of the 1991 flood, all the current residential suburbs were well established

Current extent of development

More recent development has seen construction taking place in the Batten Road area in the form of schools, churches and clubs/meeting places. The sporting facilities in Marrara have also expanded. The terminal facilities, and car parking areas of Darwin International Airport have grown considerably and new buildings have been constructed in the General Aviation and Cargo areas.

There has already been an impact on floods from airport development because:

- *56% of the lease area has already been developed*
- *it is located immediately above Millner, with little opportunity to attenuate any spikes in runoff from paved, sealed and roofed areas*

Future development

Future development is likely to include further expansion of Darwin International Airport Business Park, further developments in the eastern areas adjacent Amy Johnson Avenue and in-fill development in existing suburbs.

Individual developments in these areas cannot be shown to have a significant impact on flooding in the northern suburbs. However, if all of these developments were to happen then there could be some impact. Further investigation is recommended to determine measures to manage any impacts of future developments in the catchment area, particularly for areas downstream of the Flood Control Weir.

1.4. NT Planning Process

1.4.1. Legislation

The NT Planning Scheme imposes controls on development in areas affected by both riverine flooding and storm surge flooding

The Planning Act provides for planning and control of the use and development of NT land. The Act establishes the NT Planning Scheme and provides for a development control and approval process.

Section 6.14 of the Planning Scheme provides for the control of development that is impacted by a Defined Flood Event (DFE). It also sets controls on areas impacted by Storm Surge. Specifically it includes:

- Flood level defined as the 1% AEP event (from Water Act)
- DFE being the 1% AEP
- DFA (Defined Flood Area) being that inundated by the DFE
- Development requirement for a minimum habitable floor level of 1% AEP level (either flood or storm surge) + 300mm
- Avoidance of filling within the DFA
- Definition of the Primary (PSSA) and Secondary Storm Surge Areas (SSSA) as the 1% AEP and 0.1% AEP storm surges, respectively
- Development within the PSSA is limited to open space; recreation; non-essential public facilities; and short stay tourism
- Development within the SSSA is limited to PSSA uses plus industrial and commercial. Other uses should be avoided

*"Flood proofing by using piers or split level/ two **storey** construction with garages, workshops, wet areas and recreation rooms at the lower level is preferred.*

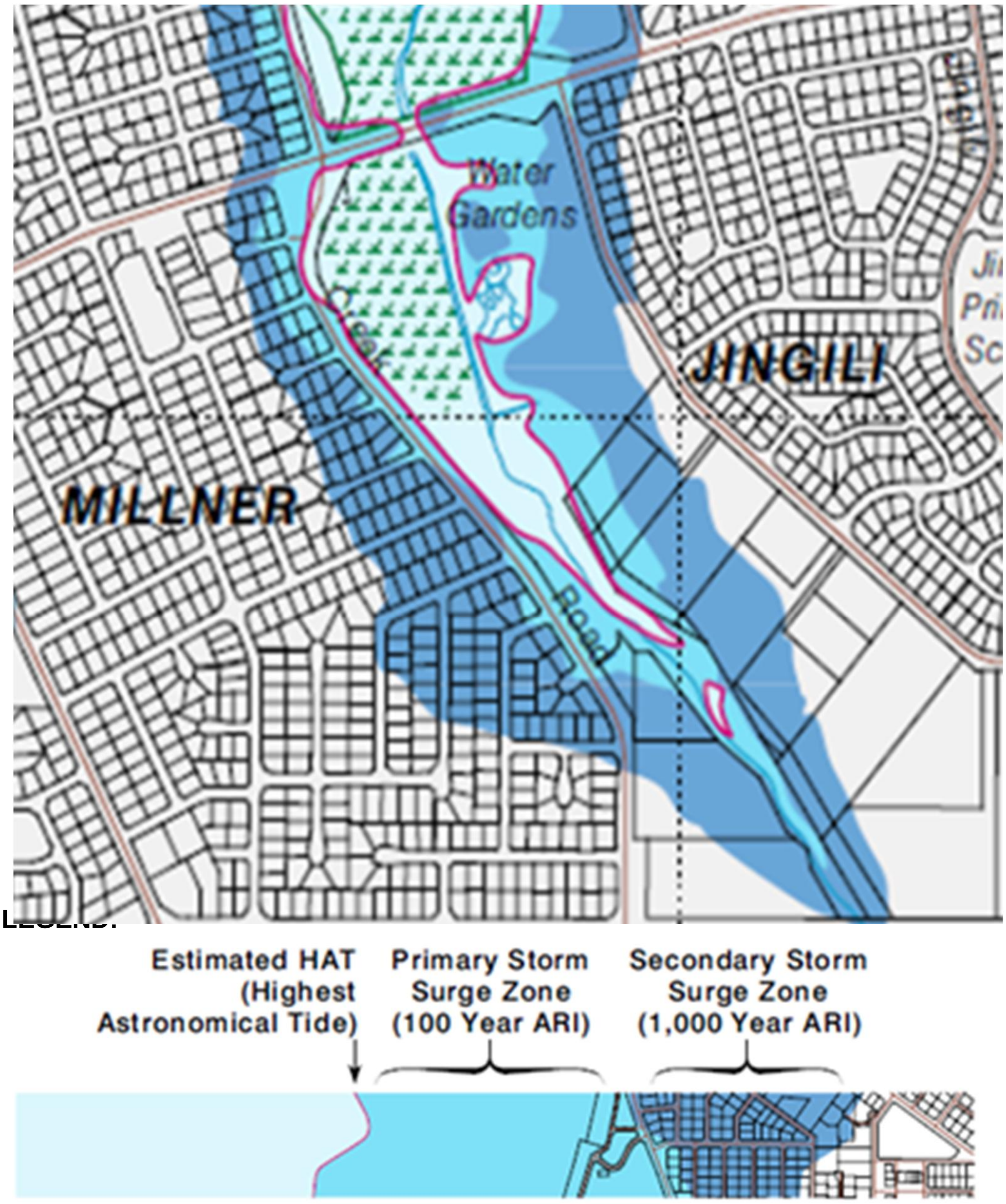
Partial flood proofing could be achieved through the use of construction materials and/ or methods which will either:

- *(a) exclude floodwater up to the DFE from a building; or*
- *(b) resist deterioration during inundation events up to the DFE, thereby limiting flood damage costs."*

[NT Planning Scheme Section 6.14]

The clauses of Section 6.14 are accompanied by the notes in the text box above.

Flood mapping was published by the NT Government for Rapid Creek in 1999 (Connell Wagner). This mapping was used in the NT Department of Lands, Planning and the Environment (DLPE) publication “Rapid Creek Planning Concepts and Land Use Objectives, 2000:” Storm surge mapping and awareness information has been published by NT Emergency Service (see Figure 3).



- **Figure 3 Storm Surge Map (Extract NTES)**

Information on flood affectation of properties can be provided in the "Record of Administrative Interests and Information" certificate from the Land Register. This allows interested parties to understand potential flood impacts on the "Search Certificate".

However, the Record of Administrative Interests and Information is not part of the Land Register and is not guaranteed by the Northern Territory of Australia, and the NT Government accepts no Liability for any omission, misstatement or inaccuracy contained. In practice, it cannot be guaranteed that a search will show flood liable land in the Millner (or any other) area.

Section 6.14 facilitates re-development in the floodplain with planning consent, utilising certain land uses and appropriate materials and forms of construction. Utilising this as a mitigation strategy is discussed further in Section 4.4.

1.4.2. Zonings

The majority of the residential zoning within the Rapid Creek floodplain (defined by the Probable Maximum Flood, PMF) is Residential SD (refer to Figure 4 for an extract of the Darwin Zoning Map) and covers mainly the Millner and Jingili suburbs. There is also a Special Development SD11 zoning that covers land on both sides of the Creek immediately downstream of McMillans Road. This provides for the non-urban nature of this land and allows larger properties that must include at least 1,000 m^2 of land above the 1% AEP flood level.

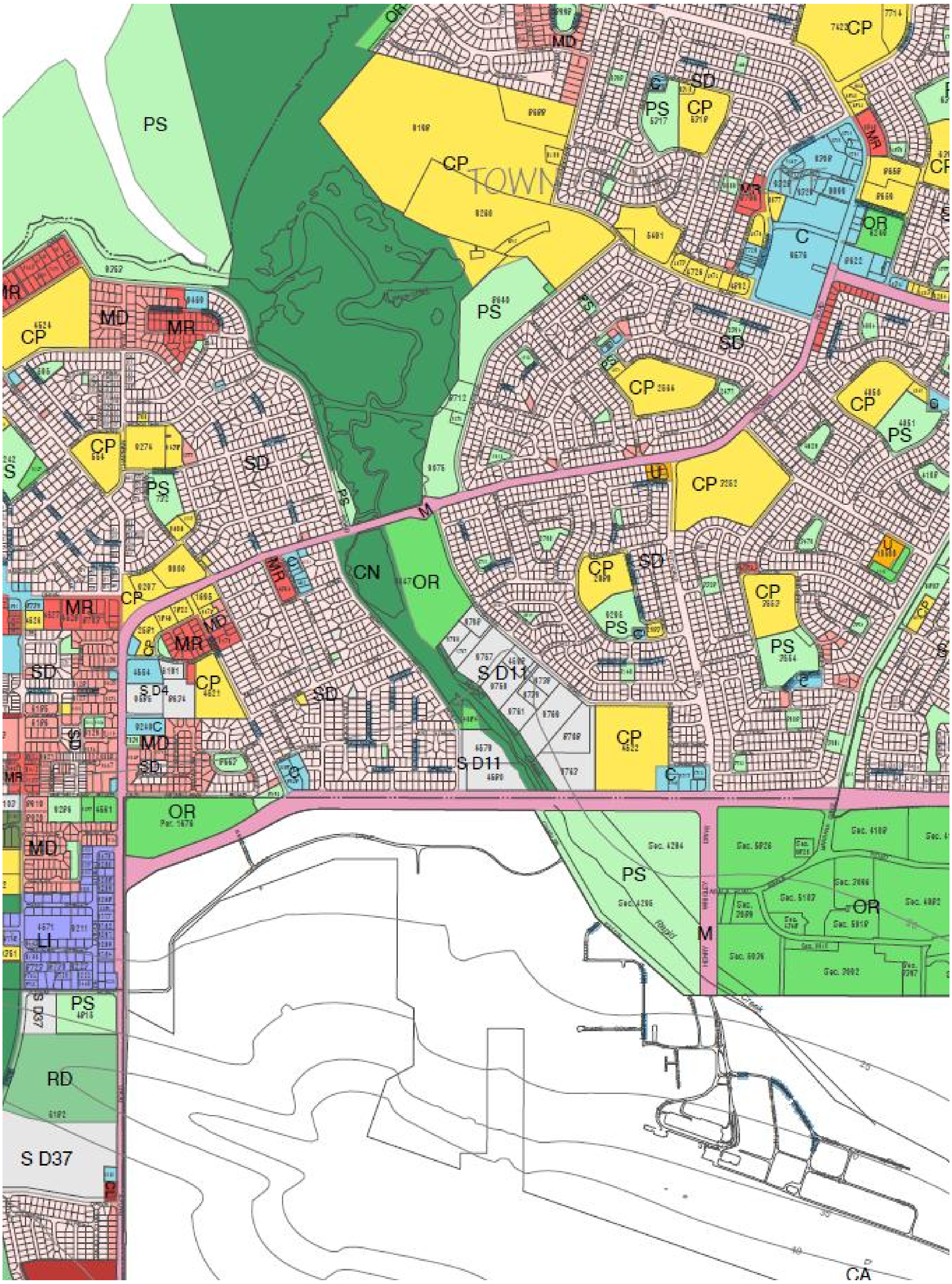
The majority of the upper catchment includes no planning controls (CA) which is Defence and Airport property and Recreation and Conservation lands.

1.4.3. Building Regulations

Part 10 of the NT *Building Regulations*, under the *Building Act* state the regulations surrounding buildings in flood prone areas. Key aspects include:

- flood level for a flood prone area is the flood level for a 1% AEP (Q100) flood level
- height of the lowest floor level, or lowest part of the floor level, of a habitable room shall be not less than 300 mm above the flood level for the flood prone area
- structural design of the building shall be adequate to withstand flooding and for this purpose special consideration shall be given to the:
  - site, size and shape of the building;
  - effect of buoyancy on the sub-structure of the building; and
  - stresses that the depth and velocity of water and the impact of water borne debris may have on the structure

In the NT, Local Governments cannot develop their own building or planning requirements to control the construction of buildings in flood prone areas.



■ **Figure 4. Zoning Map (Extract)**

2. Flood Study

This Section briefly discusses the results of the recent flood studies carried out for Rapid Creek.

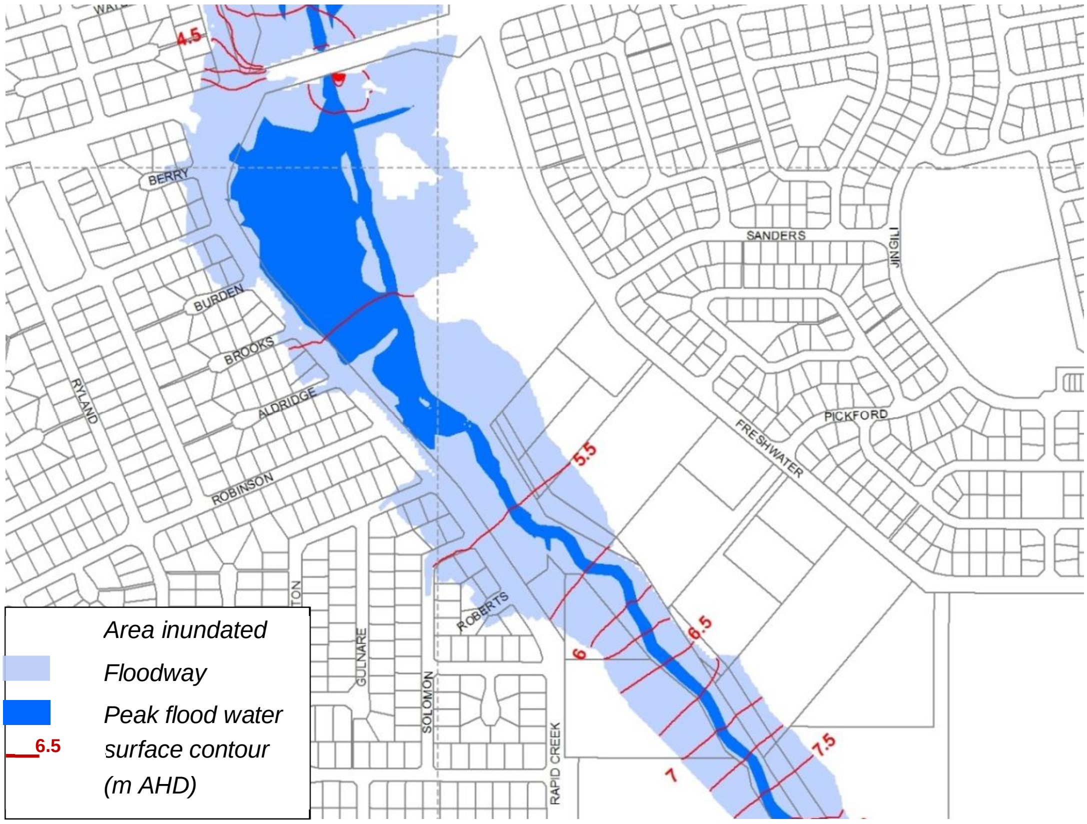
2.1. Description of Flooding

2.1.1. Extent of flooding

Floods in Rapid Creek result in filling of the Marrara Swamp, with overflow to areas behind the existing Flood Control Weir. Downstream of the Flood Control Weir, the floodwaters proceed under the Henry Wrigley Drive Bridge and, in sufficiently large storms, over the right bank approach to the Bridge.

Floodwaters frequently overtop the Kimmorley Bridge at McMillans Road and, to some extent, back up into drains entering the Creek from the Darwin International Airport land and undeveloped low lying land between Henry Wrigley Drive and McMillans Road.

Downstream of McMillans Road, the floodwaters begin to spread. In the area above the Red Footbridge, this is limited by the steep slope of the Creek. North of the Red Footbridge, the floodwaters spread wider and fill up the area behind the Trower Road Bridge. In moderate to major floods, say 10% AEP (Q10) or larger, Rapid Creek Road is flooded and floodwaters threaten low-lying properties in the Millner area. (Figure 5.)



▪ **Figure 5. Q10 floodplain map for Millner area**

A 1% AEP (Q100) flood (Figure 6) will spread into the entire lower part of Millner. Floodwaters will flow over Trower Road at the Rapid Creek Road intersection and will spread to properties near the northern side of that intersection (in the suburb of Rapid Creek). On the right (eastern) bank, the lower parts of properties in the Freshwater Farms area are inundated. Water will flow over Trower Road on the eastern approach to the Trower Road Bridge between the Bridge and Freshwater Road.

Downstream of Trower Road the slope of the creek is very flat and floodwaters spread in a wide corridor between Lakeside Drive and Rapid Creek Road. Floodwaters are expected to be high in the University tributary that drains parts of Casuarina, Wanguri and Nakara.

For larger floods, inundation is more extensive up to the Probable Maximum Flood (PMF), which is the flood that would result from the Probable Maximum Rainfall. The Probable Maximum Rainfall is an estimate of the largest storm that could occur if all the worst possible meteorological conditions occurred at the same time. The Probable Maximum Rainfall is significantly larger than any recorded storm over the Rapid Creek Catchment and produces a PMF with a calculated peak flow seven times the 1% AEP (Q100) peak flow.

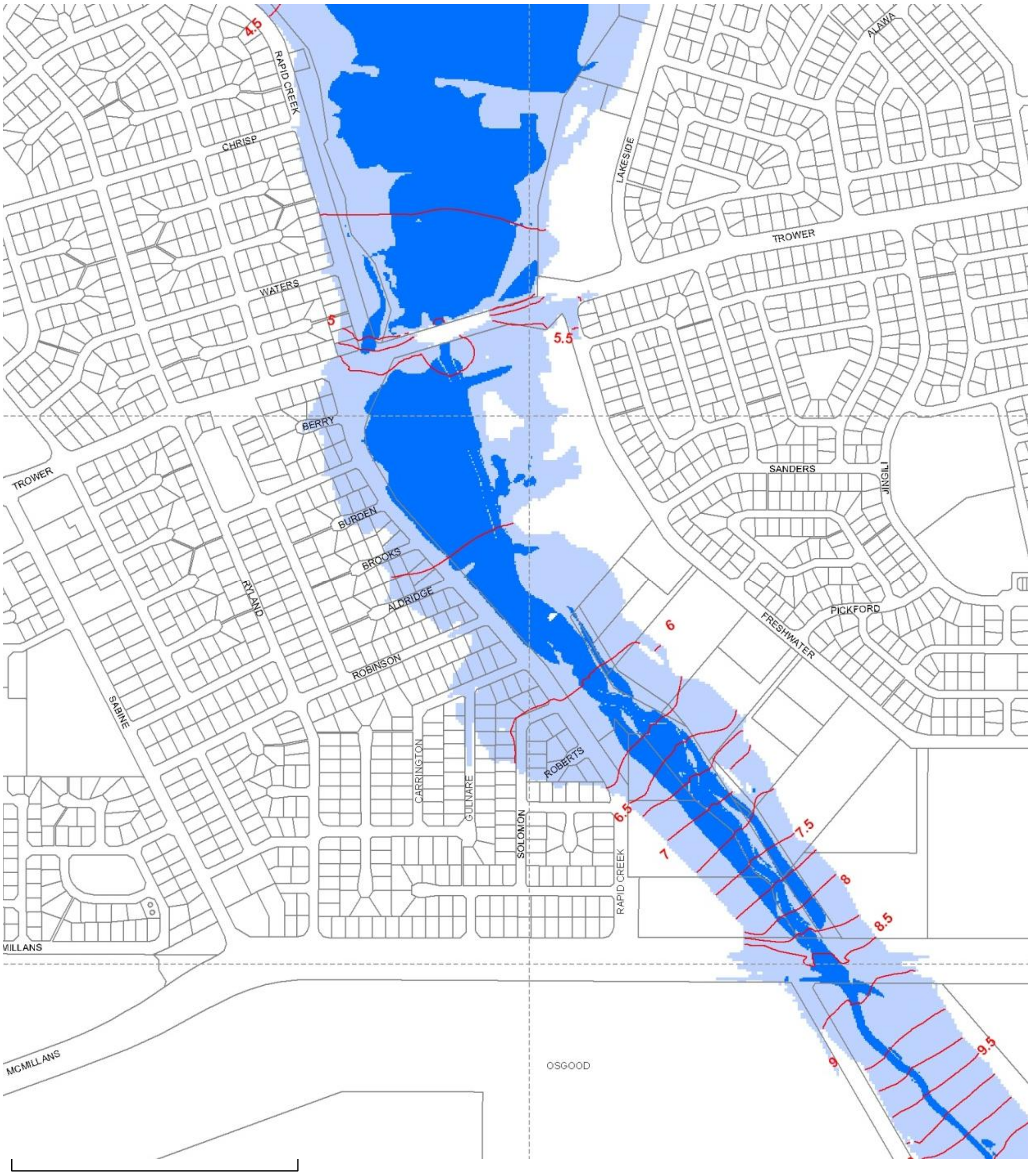
Figure 7 shows the PMF and inundation extends:

- well into the streets of Millner,
- into the suburb of Rapid Creek between Rapid Creek Road and Oliver Street, and properties fronting Rapid Creek Road north of Oliver Street,
- into Jingili between Sanders Street and Trower Road and extending as far as Varney Cr, as well as much more extensive inundation of the properties in the Freshwater Farms area
- into Alawa for properties fronting Lakeside Drive.

Note that in some low lying residential areas of Millner, the calculated Probable Maximum Flood (PMF) occurs with high hazard conditions (depth more than 2.0 m or depth m) × velocity (m/sec) more than 1.0) This means significant risk to people and property in these areas should such a flood occur.

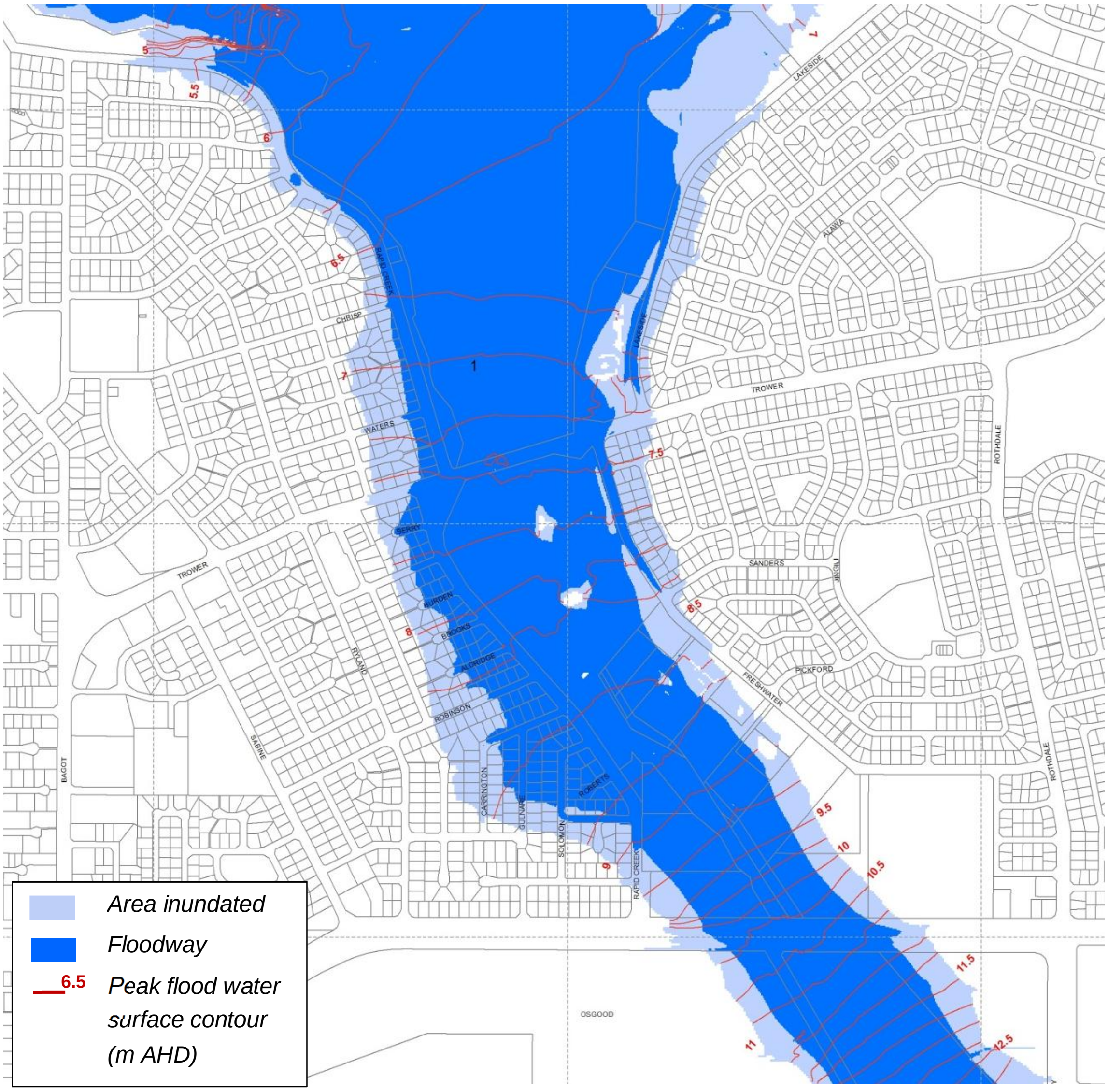
The defined flood event for protection of property when economical to do so is typically 1% AEP (Q100). This is the case under the NT Planning Scheme (as discussed in Section 1.4.1).

The occurrence of a PMF can be considered extremely rare and it is only likely to be economic to protect against a PMF in exceptional circumstances, such as large populations in developed areas downstream of major dams. Floodplain mapping for the PMF will normally only be taken into account in Disaster Planning by Emergency Services.



- **Figure 6. Q100 flood plain map for Millner area**

In the suburb of Millner, 48 residential allotments lie wholly within and 19 allotments partially within the calculated 1% AEP (Q100) floodplain



- **Figure 7. PMF flood extent**

Table 1 shows the numbers of properties encompassed by the calculated extent of inundation for Q100 (1% AEP) flood.

- **Table 1. Extent of inundation into residential areas during 1% AEP (Q100)**

Location	Number of properties within the extent of inundation of the 1% AEP (Q100) flood	
	Wholly	Partially
Millner	48	19
Rapid Creek	1	3
Jingili	0	6 (Freshwater Farms area)

Note that the inundation shown over an allotment on the floodplain maps is not necessarily associated with inundation above floor level of any building on the property, nor of inundation on the property itself for the following reasons:

- No floor level survey has yet been undertaken for buildings in the floodplain
- Yards and accesses into individual properties may have been built up above the general ground level
- Solid fences, mounds/garden beds and outbuildings may impede the passage of floodwaters

2.1.2. Timing and duration of flooding

Timing

Rapid Creek is a small catchment and during a major storm, the time between the onset of heavy rain and flooding in the suburb of Millner is short.

However the Flood Control Weir introduces a delay to floodwaters. The stream gauging station is located at the upper end of Millner where flooding of residential land commences. For the design storms considered[1], typical flood waves arriving at the gauging station are two-peaked. The first peak represents a spike of runoff from the urban areas contributing downstream of the Flood Control Weir and a second peak comes from the upper catchment, delayed by the gauging station.

For the design storms considered, the calculated first peak occurs at around 1 to 1.5 hours after the onset of heavy rain and the second peak from 1.5 to 4.5 hours depending on the size of the storm being considered. The first peak is higher for the critical storms.

Duration

For the purposes of discussion it is assumed that flooding over Rapid Creek road commences at a 10%AEP (Q10) flood at the gauging station. The estimated Q10 peak flow is 88 cubic metres per second (m^3/sec).

The length of time that larger floods exceed 88 m^3/sec is therefore an estimate of the duration of flooding. For short duration storms and smaller floods the duration of inundation indicated is of the order of 0.5 hour. For longer duration and larger storms the effect of the ‘second peak’ kicks in and the duration of inundation may be up to 4.0 hours.

Rapid Creek rises quickly and a major flood can peak within 1 to 1.5 hours of the start of heavy rain

For real storms (as opposed to design storms) the rainfalls are often multi-peaked and the flood pattern more complex. Applying the same method of calculation suggests a duration of inundation of 5.5 hours in the flood of 16 February 2011 (See also Section 2.2)

[1] Design floods considered were the 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP (or Q10, Q20, Q50, Q100, Q200 and Q500)

2.2. Historical Floods

As discussed in Section 1.3.2, there have been a number of floods since stream gauging station records began in the 1960s. From analysis carried out in the Flood Study Report [SKM 2013 b], the five highest ranked floods at the Rapid Creek Gauging Station have been as shown in Table 2.

Table 2. Highest recorded Rapid Creek floods

Rank of flood	Date	Peak flow (m^3/sec)	Associated with
1	16 February 2011	157	Cyclone Carlos
2	5 January 1991	108	N/A
3	3 January 1997	100	Cyclone Rachel
4	25 December 1974	118	Cyclone Tracy
5	16 March 1977	104	N/A

NOTE: Slightly different results are found for the five highest ranked floods that would have occurred (according to the analysis) if the Flood Control Weir had existed at the time record collection commenced.

The water level reached in a 10% AEP (Q10) flood is approximately where overflow commences on the left bank of Rapid Creek and starts to overtop Rapid Creek Road near Solomon Street. A 5% AEP (Q20) flood is where floodwaters will start to threaten low-lying homes in Millner and a 5% AEP (Q20) flood and larger floods can be considered “major floods”.

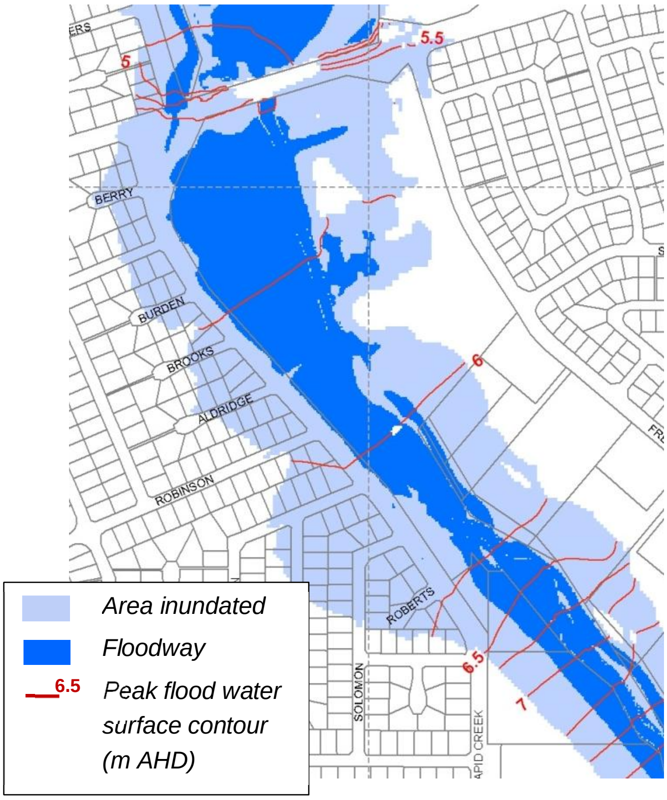


Figure 8. Extent of inundation in Millner during Cyclone Carlos

The flood that occurred during Cyclone Carlos on 16 February 2011 is estimated to be a Q140 (0.7% AEP.) Flood levels were noted and surveyed soon after that flood and used to calibrate the hydraulic model (Appendix H).

The estimated extent of inundation in Millner for the flood of February 2011 is shown in Figure 8. Table 3 lists the numbers of properties within the estimated area inundated.

Table 3. Extent of inundation into Millner during Cyclone Carlos

Location	Number of properties within the extent of inundation of the Cyclone Carlos flood	
	Wholly	Partially
Millner	54	17

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2.3. Design Floods

The hydrology component of the Flood Study estimated hydrographs (graphs of how flow varies with time during the passing of a floodwave) for a number of "design floods".

These design floods are based on the response of the Rapid Creek catchment to "design storms", (see Section 2.1.2) which is calculated using Australian Rainfall and Runoff (1991), the key reference text for Australian Hydrology. Also calculated was a hydrograph for the Probable Maximum Flood (PMF).

In the calculations, losses from the rainfall that occurs during each design storm are adjusted in a consistent manner, such that the peak flow from each design storm corresponds to the peak flow calculated independently from flood frequency analysis [SKM 2013 a].

The resulting design flood hydrographs calculated from each of these storms were used in the hydraulic analysis and the floodplain mapping.

Appendix G gives further information on the results of the hydrology study.

The floodway areas are generally confined to the Creek channel for smaller floods. For the 1% AEP and larger events, McMillans Rd, Rapid Creek Road / Trower Road intersection, and other localised areas of Rapid Creek Road act as a floodway.

2.4. Hydraulic Classification

The Flood Study included hydraulic model runs to define the floodway as those areas where a significant volume of water flows during floods.

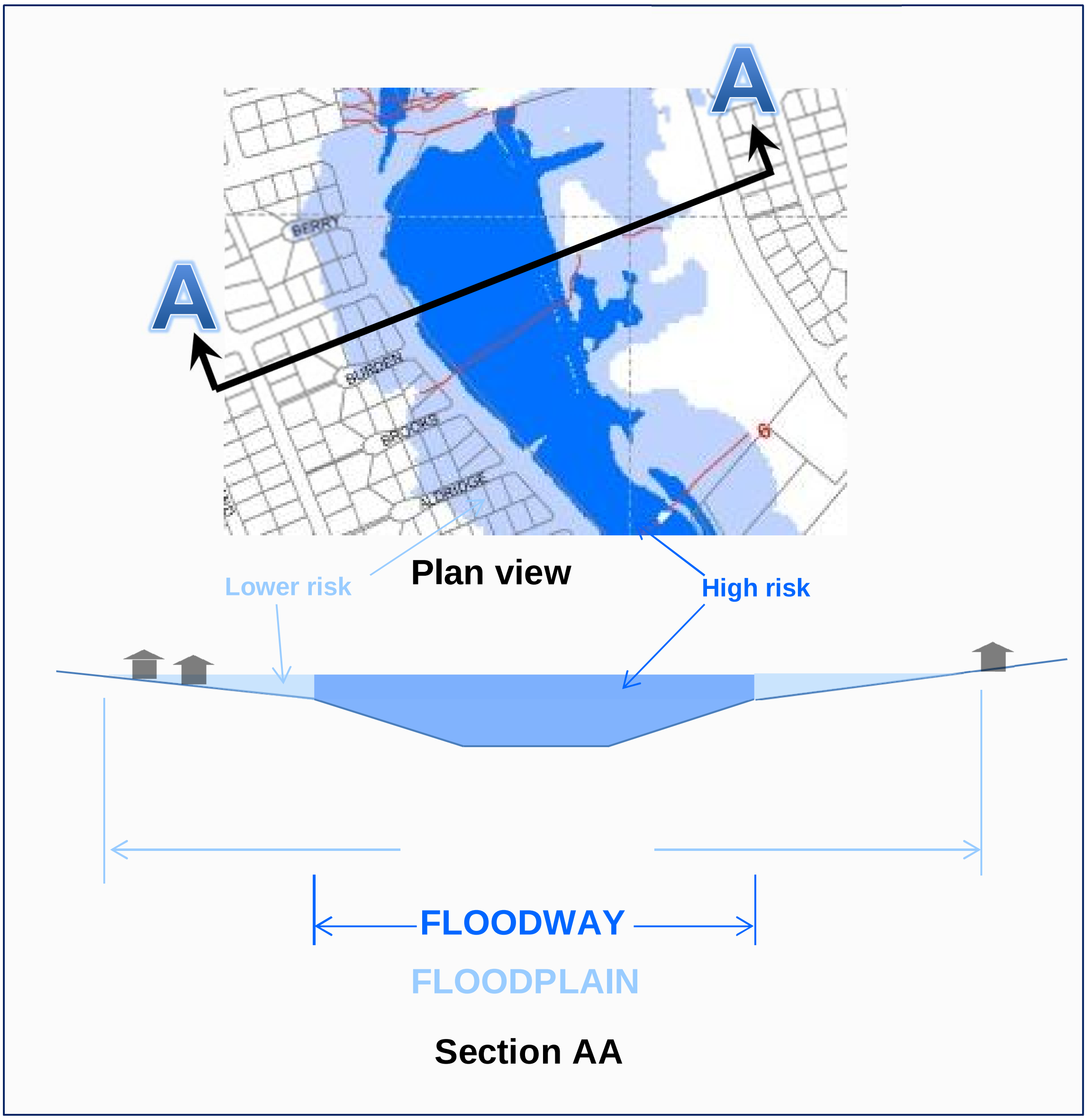
The floodway was defined for each design storm event using depth and velocity results from the TUFLOW model. The floodway was defined as areas where flood depth is greater than 2m or the velocity-depth product (V x D) is greater than 1.0

2.5. Flood Hazard Classification

Floodplain managers distinguish between the floodway (the area of greatest risk) and the remainder of the floodplain.

The floodway is defined as "those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are the areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood level." [NSW Government, 2005]

Figure 9 shows typical floodplain and floodway areas. For this study, floodway has been calculated as areas with a depth greater than 2.0 m or depth (m) × flow velocity (m/sec) > 1.0 as described in 2.4 above.

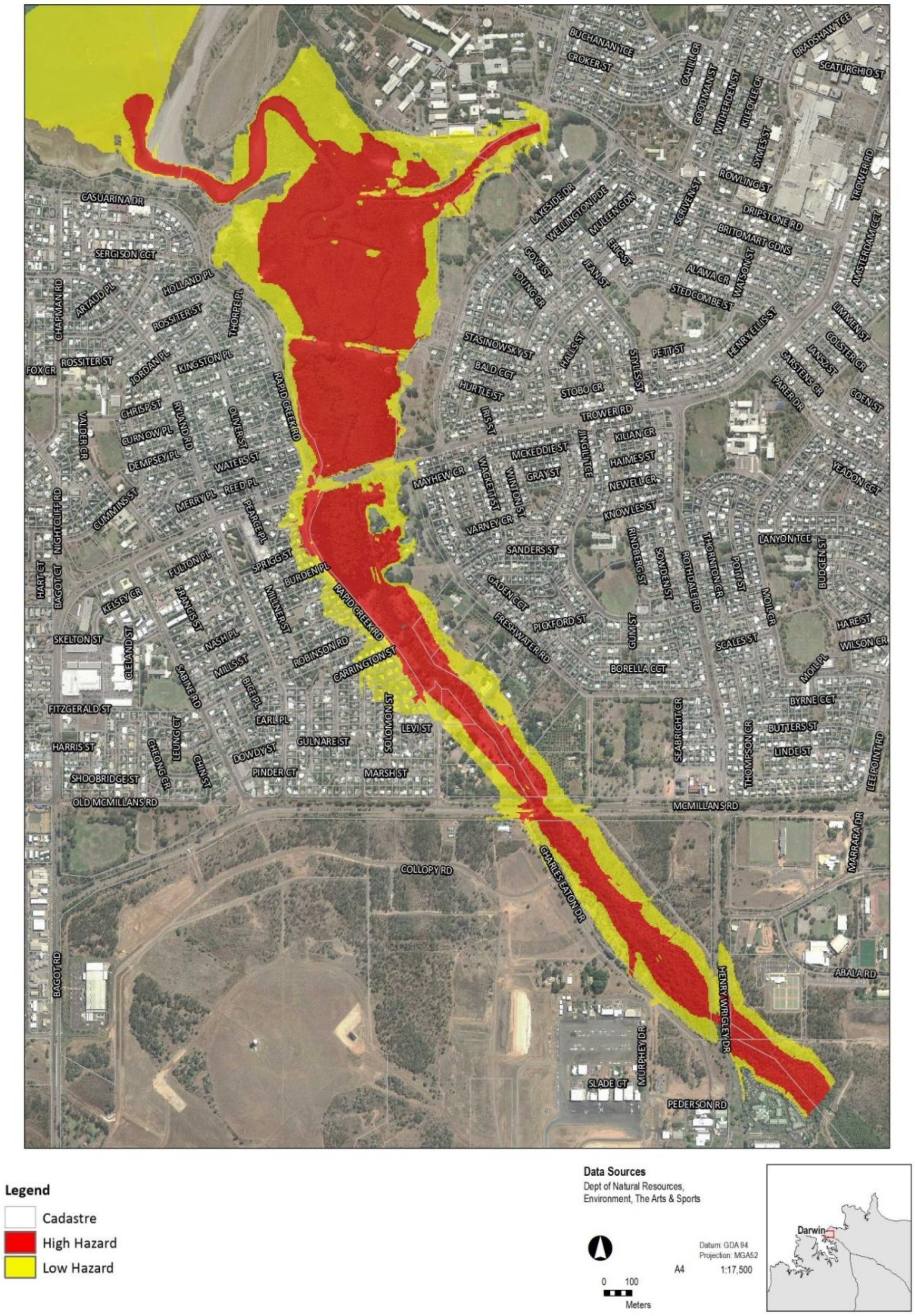


■ **Figure 9. High risk and lower risk flood areas**

Referring to the NSW Floodplain Development Manual [NSW Government, 2005], the 1% AEP (Q100) event was adopted and the hazard categories can be described as:

- **High hazard** – possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings.
- **Low hazard** – should it be necessary, truck could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The high and low hazard areas across the flood plain are shown (Figure 10).



- **Figure 10. 1% AEP event provisional hazard**

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2.6. Flood risk assessment

There are four key risk categories relevant for the area:

- Road Access
- Residential Personal Safety
- Residential Property Buildings
- Critical infrastructure

Table 4 [after McLuckie 2013] identifies a suggested risk framework used for assessing the risk profile in each category.

- **Table 4. Risk Profile – Key considerations for Options**

Risk	Description	Hazard Area	
		Floodway (to Q100 limit)	Flood Fringe (Q100 to PMF limit)
Road access	Loss of emergency access via roads during and after flood for both residents and emergency services	Tolerable generally Unacceptable for vulnerable population	Acceptable
Residential personal safety	People at risk during flooding due to inundation of habitable areas and emergency response actions	Tolerable to unacceptable depending on population vulnerability, depth of above flood flooding and ease of egress	Acceptable
Residential Property Buildings	Damage to residential buildings and associated development	Tolerable	Acceptable
Critical Infrastructure	Damage and disruption to essential infrastructure e.g. roads, bridges, power, telecommunications	Tolerable	Acceptable

NOTES:

Acceptable means population can live with this risk without feeling necessity to reduce risk any further

Tolerable means society can live with this risk but believe that as much as reasonably practical should be done to reduce risks further

Unacceptable means individuals and society will not accept these risks and measures must be put in place to bring them down to at least tolerable level

Applying the framework to Rapid Creek:

Road access: Parts of McMillans Road, Rapid Creek Road, and Trower Road are in the floodway (and therefore are areas of high hazard) during the 1% AEP (Q100) flood event.

Personal safety: No houses are located within the 1% AEP (Q100) floodway of Rapid Creek. As noted above, however, 67 residential allotments are located (wholly or partially) within the 1% AEP (Q100) floodplain. However there are some vulnerable residents in the Millner area, there are some locations where egress is only to Rapid Creek Road (which is at a lower level than many of the flood-affected houses) and depths of flooding are up to 0.8 m.

Residential buildings: No houses are located within the 1% AEP (Q100) floodway

Critical infrastructure: McMillans Rd bridge immunity is likely to be considered unacceptably low by the community.

Overall, much of the risk associated with flooding of Rapid Creek may be acceptable to the community. However, some of the risks are likely to be tolerable to unacceptable to the community particularly:

- The depth of flooding in the lower parts of Millner, and
- the risks associated with the McMillans Road crossing (Kimmorley Bridge)

3. Potential Flood Damages Assessment

3.1. Property profiles

Properties at Millner (and elsewhere in the northern suburbs) are typically a mixture of:

- Ground level (slab on ground) houses constructed by the Housing Commission. Some are still in the ownership of the Government as public housing but many have been purchased by occupants. Many of those purchased have had various improvements/renovations adding to the value of potential damage during floods
- Elevated houses constructed by the NT Government before and after Cyclone Tracy. These are now typically in private ownership and many have had extensive improvements/renovations
- Many of the elevated houses have been built-in under and will contain claddings and furnishings, stored goods and materials that will contribute to the value of flood damage when floods are above (and at or near) the bottom floor level
- Newer houses constructed after an existing house's demolition. These are typically ground level houses but some newer two storey or elevated houses may have been constructed

3.2. Properties at risk

The 1% AEP (Q100) floodplain map (see Figure 6) shows the low-lying areas in Millner where inundation can be expected. There are 48 wholly and 19 partially inundated residential allotments within the blue shaded area but this does not indicate which houses will actually experience floodwaters above their floor levels.

No floor levels have yet been surveyed for this study.

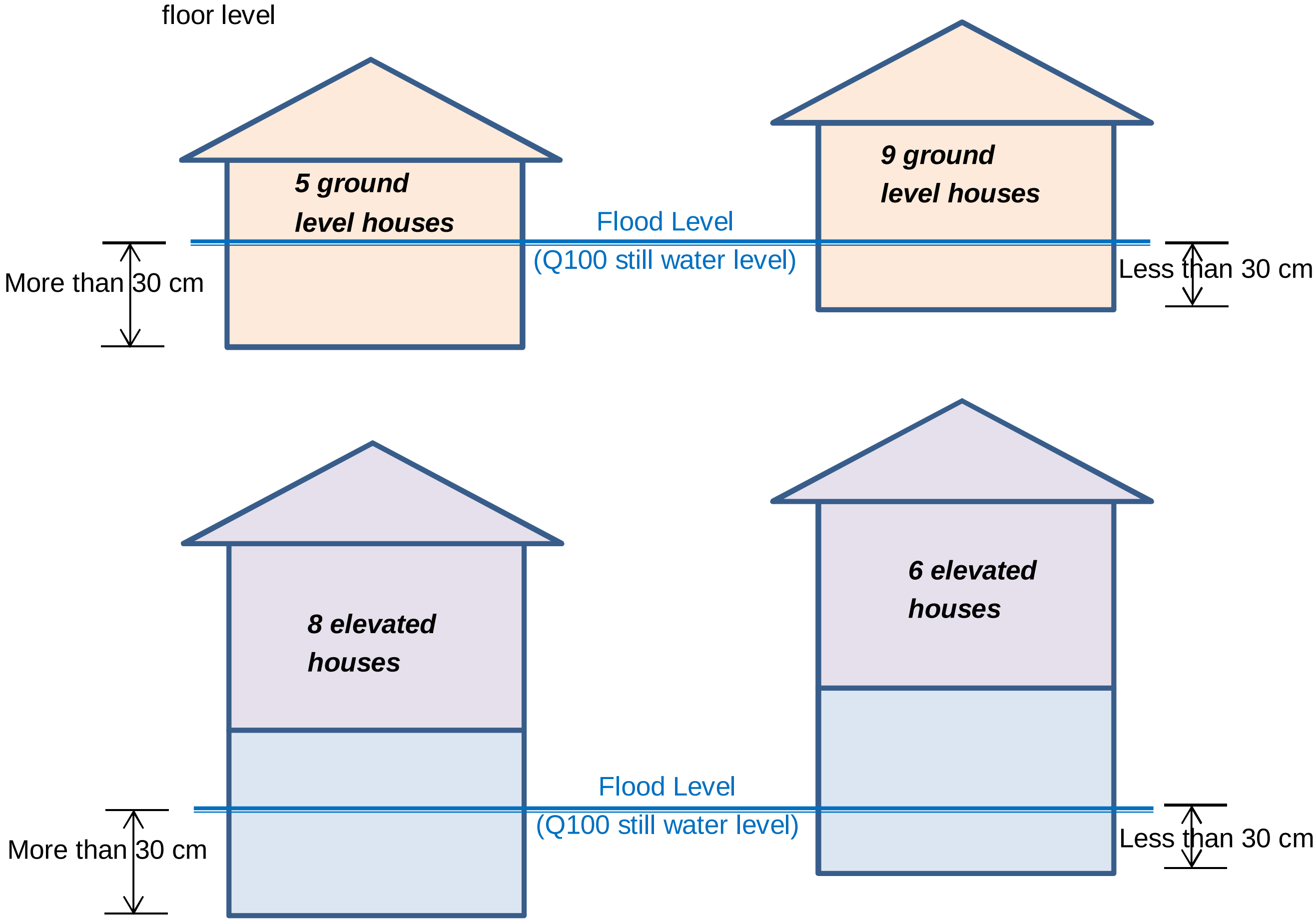
From the floodplain mapping and an inspection of the affected streets of Millner on 19 September 2013, the following was estimated in relation to the 1% AEP (Q100) flood event (Figure 11):

- 5 ground level houses where the flood level would be 30 cm or more above floor level
- A further 9 ground level houses where the flood level would be at or above floor level but less than 30 cm above floor level
- 8 elevated houses which have been built-in under and the flood level would be 30 cm or more above bottom floor level
- A further 6 elevated houses which had been built-in under and the flood level would be at or above bottom floor level but less than 30 cm above bottom floor level

Although the above indicates 28 properties where 1% AEP (Q100) water level would be at or above floor level, it is important to remember that additional properties are included in the potential damage calculations because:

- The above is based on calculated still water levels but active floodwaters can rise above still water levels

- Damage can occur in houses as a result of water near floor level because of seepage up through porous building materials
- Damage can occur to outbuildings and materials stored in them, in yards and to vehicles, trailers, caravans, boats and the like sitting in yards or driveways at a lower level than house floor level

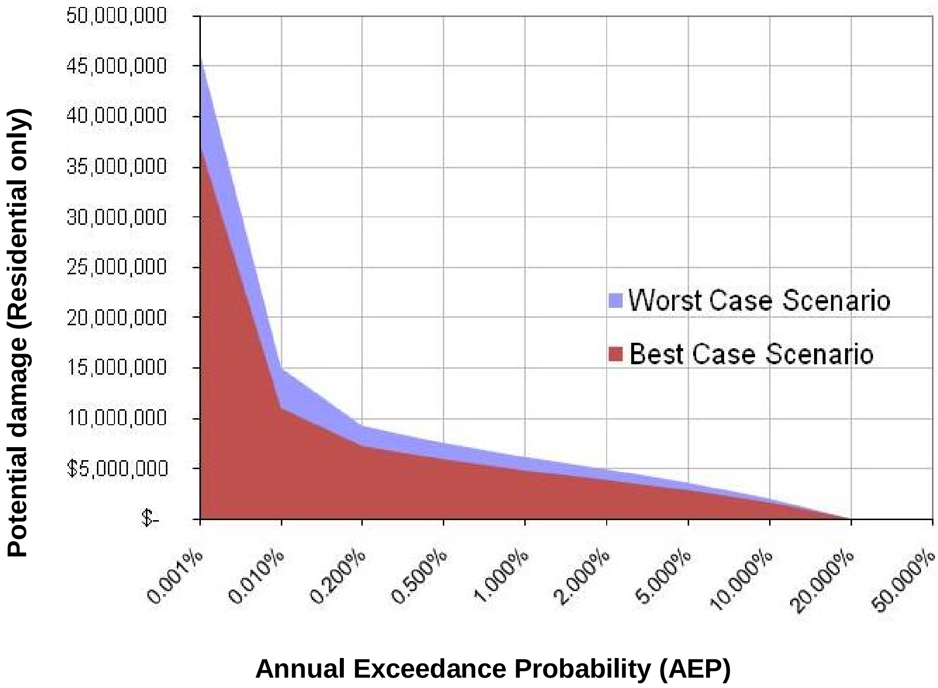


- **Figure 11. Estimated numbers of Millner houses inundated by 1% AEP (Q100) flood**

3.3. Flood Damages Report

A draft report titled "Rapid Creek Flood Damages Assessment. *Potential flood damages*" was prepared for the NT Government by SKM and issued on 02 August 2013. It provides a Probability vs. Potential Damage Curve for Rapid Creek, which gives the estimated potential damage for a given flood probability (AEP %). The curve is reproduced here as Figure 12.

A range of values for potential damage was considered (i.e. worst and best case scenarios) as shown in Figure 12.



- **Figure 12. Potential residential damage vs. Annual Exceedance Probability**

An Average Annual Damage (AAD) can be derived from this curve. AAD is a measure of the potential flood damage occurring every year as a result of floods in Rapid Creek, averaged over a long period of time. The total potential AAD of the Rapid Creek system was estimated to be in the range $481,000 to $610,000.

The Net Present Value (NPV) of the potential AAD was also determined. This represents the present day value of flood damages which can then be compared to the present day cost of any mitigation options to help determine their cost effectiveness. In theory, if an amount equal to the NPV was invested now, with interest, it would grow to a sum that would just cover future damages. The NPV is estimated to be in the range $10.8 million to $13.7 million. This assessment could be improved by survey of dwelling habitable floor levels.

The Average Annual Damage is estimated to be in the range $480,000 to $610,000.

This corresponds to a net Present Value of Damages of $10,800,000 to $13,700,000

It should be noted that the values quoted are potential flood damages, which may differ from actual flood damages. The actual damage caused by a particular flood event would approach the calculated potential damage if floodwaters entered and caused worst-case damage to property in the floodplain in its current condition.

Generally, the worst-case assumption is that nothing can be or will be done to remove susceptible valuables from the area facing inundation. However, significant reductions in potential damages can be achieved by relocating movable possessions to flood-free areas, where warning times are sufficient and the affected population is ‘flood aware’. Further discussion of flood damages is found in Appendix I.

4. Floodplain Risk Management Options

4.1. Introduction

The objective of this floodplain risk management options assessment was to derive an appropriate mix of options to effectively manage the full range of flood risk for the Rapid Creek floodplain. This process has been guided by the NT government. Key activities include:

- Examination of NT's flood risk management policies and planning instruments
- Review of existing flood warning arrangements
- Consultation with the NT Government about local issues and emergency responses
- Flood and hazard mapping
- Identification and assessment of flood risk management options
- Recommendations for priority options

There are basically three ways of managing flood risk:

1. Flood Modification Options
2. Response Modification Options
3. Property Modification Options

1. Flood Modification - by modifying the behaviour of the flood itself (for example construction of a levee to exclude floodwaters from an area).

- Flood Mitigation Dams/Weirs
- Detention Basins
- Levees
- Bypass Floodways
- Channel Modifications
- Floodgates

2. Response Modification - by modifying the response of the population at risk to better cope with a flood event (for example improving community flood readiness). Such measures include plans for:

- flood warning and effective use of warning time
- the protection and/or evacuation of an area
- the relief of evacuees, and
- the recovery of the area once the flood subsides

3. Property Modification - by modifying existing properties (for example house raising) and/or by imposing controls on property and infrastructure development. These measures include:

- land use planning including zonings and development controls
- voluntary purchase of high hazard properties

- voluntary house raising
- flood proofing of buildings, and
- flood access

The future risk of climate variation was considered in this study. Increased sea levels for the year 2100 prediction were used in the flood modelling. The effect was mostly limited to the area downstream of the Trower Road Bridge. A more detailed assessment could include consideration of the sensitivity of potential future increases in rainfall intensities.

4.2. Flood Modification Options

4.2.1. Flood Control Weir

There is an existing Flood Control Weir located about 1,500 m upstream of McMillans Road behind the "Airport Resort". The catchment area above the Flood Control Weir is 13.7 sq. km, which is 50% of the whole catchment area or 72% of the catchment area above Millner.

In relation to the Flood Control Weir, three aspects were considered:

1. Maintaining and/or upgrading of the Flood Control Weir to ensure it continues to mitigate floods
2. An examination of the impact on flooding if the weir were removed or continued to degrade to the extent that it no longer was effective in attenuating flood peaks
3. Raising of the flood control weir to further mitigate flooding in the suburbs downstream

   1. Maintaining the Flood Control Weir - the Flood Control Weir (refer Figure 13) was constructed by the NT Government on Defence land. It is understood that the Weir was initially constructed to improve the flood immunity of the Kimmorley Bridge at McMillans Road. The Weir has suffered damage from successive floods. It is essentially an embankment structure of earth and rock with a central slot through which Rapid Creek flows. Currently the central slot is covered in concrete revetment mattress to prevent further degradation.

Figure 13. Flood Control Weir

It is recommended that ownership of/responsibility for the Weir be clarified and regular inspection and maintenance be carried out to ensure the Weir continues to function.

2. Impact on flooding if there were no Flood Control Weir - The URBS and TUFLOW models were used to examine what would be the impact on flooding if the Weir did not exist. Figure 32 in Appendix B shows the increase in flooding in Millner for a 1% AEP (Q100) flood and Table 5 shows the additional number of properties that would be within the 1% AEP (Q100) extent of inundation. It is clear that maintaining the Flood Control Weir is important in mitigating flooding in Millner.

▪ **Table 5. Impact on 1% AEP (Q100) flooding if there were no Flood Control Weir**

	With Flood Control Weir	Without Flood Control Weir
Lots wholly within the extent of inundation	48	75
Lots partially within the extent of inundation	19	14
Total lots	67	89

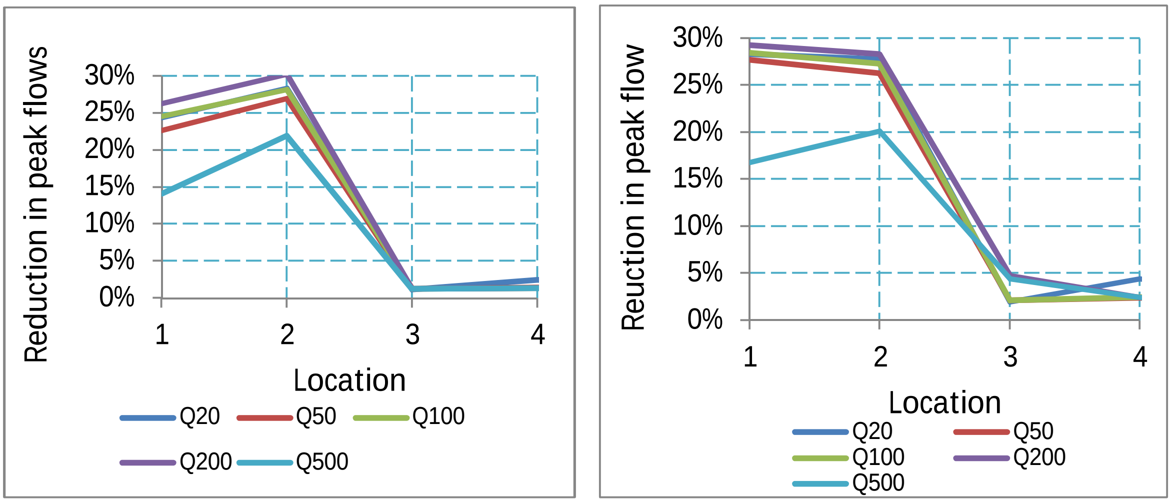
3. Raising the Flood Control Weir to further mitigate floods. An investigation into raising of the Flood Control Weir was undertaken during the flood study. Raising of the Weir embankment by 0.5 and 1.0 m was considered. The shape of the central flow slot in the embankment was assumed to be an upward projection of the original weir design shape.

The reductions in peak flows during floods are shown in Figure 14, where:

- location 1 = Flood Control Weir Outlet
- location 2 = Henry Wrigley Drive
- location 3 = = McMillans Road
- location 4 = Trower Road

> 33% more houses would lie within the area inundated by the 1% AEP (Q100) flood if the Airport Flood Control Weir had not been constructed or if it were allowed to deteriorate so as to become ineffective.

It is clear from Figure 14 that there are significant reductions in peak flows immediately downstream of the raised flood control weir, but beyond McMillans Road the differences are less significant. The reason for this is the peak flows entering Rapid Creek from the fully established urban areas and the airport grounds.



a. Raise embankment 0.5 m   b. Raise embankment 1.0 m

- **Figure 14. Impact of raising existing Flood Control Weir**

That is, for current conditions, raising the Flood Control Weir has little effect on flooding in the Millner area and is not considered a viable flood mitigation option.

However, if further development occur in the upper catchment (Refer Section 1.3.3), raising of the Flood Control Weir could be considered as a useful means of mitigating flows.

4.2.2. Detention Basins

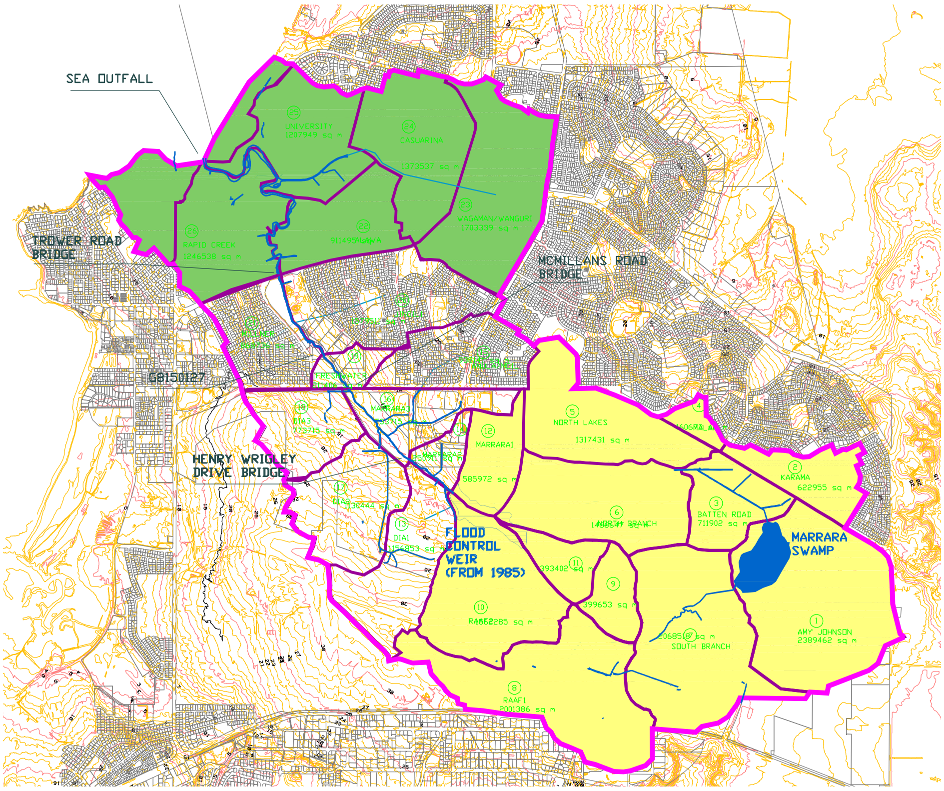
1. Possible basin locations

Figure 15 shows the Rapid Creek catchment area with the catchment outer boundary in pink. That part of the catchment area shaded green enters Rapid Creek downstream of Trower Road, where basins will have no impact on flooding in the major impact area, which is Millner.

The area shaded yellow enters Rapid Creek upstream of the existing Flood Control Weir. In Section 4.2.1 it is shown that raising the Flood Control Weir has little effect on the Millner area.

Similarly constructing new basins in the yellow area will have little effect on Millner.

Therefore, the only area where retention basins might be considered is between the green and yellow shaded areas. Ideally, basins would be located as close as possible to the Creek, in order to capture as much as possible of the local drainage systems.

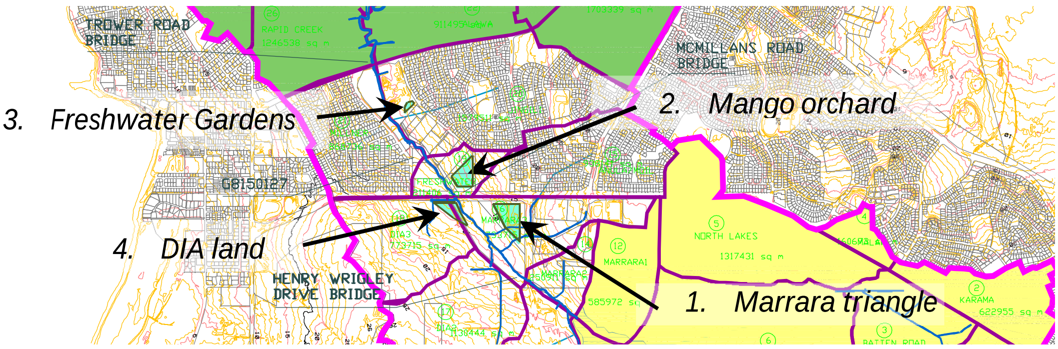


- **Figure 15. Rapid Creek upper and lower catchment areas**

Within these areas retention basins have been considered at:

1. The triangle of vacant crown land bounded by McMillans Road, Henry Wrigley Drive and Rapid Creek
2. The Mango orchard that lies between Rapid Creek and the Jingili Cemetery
3. Within the Freshwater Gardens opposite Sanders St
4. In the Darwin International Airport land near the intersection of McMillans Road and Charles Eaton Drive

These are shown in Figure 16.



- **Figure 16. Basin locations considered**

Disclaimer: Consideration of a retention basin site in this study should not be taken to mean that land is available, nor that other uses do not exist or are not planned for the land.

The impact of these basins and some combinations of these basins was modelled using URBS. Nominal areas and depths were adopted for the basins based on the size of the relevant parcel of land and topographic contours across the area. Notional outlet configurations were slotted weirs similar in form to, but smaller than, the designed weir shape for the existing Flood Control Weir. Hydrologic analysis using the URBS model was used to examine basins 1, 2, 3 and 4 and a number of combinations of basins. A combination of basins 1, 2 and 4 would give the most effective mitigation.

2. Impact of basins 1, 2 and 4

The TUFLOW model developed for the Flood Study was used to assess the change in flood behaviour that would result from construction of basins 1, 2 and 4. Inflow hydrographs for the 1% AEP event were run in the TUFLOW model to assess the change in flood levels. The relative change in 1% AEP flood (Q100) levels as a result of the option is shown in Figure 33 in Appendix B. The results showed that a 100 to 200mm reduction in flood levels would be achieved between McMillans Road and Trower Road.

The reduction in the number of properties within the extent of inundation of the 1% AEP (Q100) flood is shown in Table 6.

Table 6. Impact on a 1% AEP (Q100) flood of detention basins at selected locations

	Without detention basins	With detention basins 1, 2 and 4
Lots wholly within the extent of inundation for 1% AEP (Q100) flood	48	22
Lots partially within the extent of inundation for 1% AEP (Q100) flood	19	17
Total lots	67	39

The number of properties in the 1% AEP (Q100) floodplain could be reduced by about a third by diverting the runoff from:

- *the southern parts of Anula and Moil*
- *the north-eastern part of Marrara*
- *the southern part of Jingili*
- *the Darwin Airport*

into large enough detention basins.

Cost benefit analysis was carried out for this option and the results are in Section 4.2.7. A benefit cost ratio of 0.92 was calculated but this does not include the cost of land. Only the basin 1 site is vacant crown land and the other basin sites are in private ownership.

The cost of purchasing the land on which to construct these basins will make such a scheme uneconomic.

4.2.3. Channel modifications

Channel modifications are usually undertaken to either increase the capacity of the channel and/or improve the conveyance of floodwaters, which in turn will reduce peak flood levels. Channel modifications encompass a broad range of measures and include amplification, straightening, and concrete lining, removal of structures, dredging and channel hydraulic efficiency improvement to reduce the resistance to flow.

Two channel modification options for potentially lowering flood levels between McMillans Road and Trower Road were considered. They were:

- Channel hydraulic efficiency improvement
- Channel enlargement

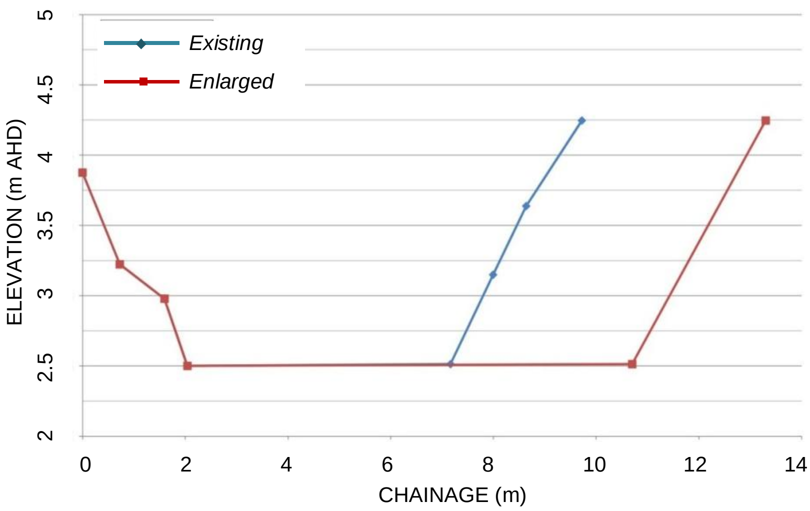


Figure 17. Channel enlargement typical cross section

The options were modelled in TUFLOW to assess their impact on flood behaviour. The channel hydraulic efficiency improvement options were represented by reducing the channel roughness by 50%. The main channel enlargement option was represented by increasing the channel waterway area by 50% and maintaining current vegetation cover. A typical cross section of the creek showing the extent of excavation required to achieve a 50% increase is shown in Figure 17.

The relative changes in 1% AEP (Q100) flood levels as a result of the options are shown in Figure 34, Figure 35, Figure 36 and Figure 35 in Appendix B. The channel hydraulic efficiency improvement option reduced flood levels by 70 to 190 mm between the Red Footbridge and McMillans Road respectively, however the flood level at Trower Road increased by 30 mm. The channel enlargement option reduced flood levels between Trower Road and McMillans Road by 10 to 90 mm respectively.

The numbers of properties affected are shown in Table 7 and Table 8.

The results of cost benefit analysis for channel enlargement are presented in Section 4.2.7.

Table 7. Impact on a 1% AEP (Q100) flood of channel hydraulic efficiency improvement

	Without channel hydraulic efficiency improvement	With channel hydraulic efficiency improvement
Lots wholly within the extent of inundation for 1% AEP (Q100) flood	48	41
Lots partially within the extent of inundation for 1% AEP (Q100) flood	19	17
Total lots	67	58

Table 8. Impact on a 1% AEP (Q100) flood of channel enlargement by 50%

	Without channel enlargement	With channel enlargement by 50%
Lots wholly within the extent of inundation for 1% AEP (Q100) flood	48	42
Lots partially within the extent of inundation for 1% AEP (Q100) flood	19	18
Total lots	67	60

4.2.4. Road Infrastructure

1. Kimmorley Bridge

Enlargement of the Kimmorley Bridge (McMillans Road Bridge), which has a low immunity – flooding almost every year – would not help mitigate flooding in Millner. Enlarging this bridge would only reduce levels for a short distance upstream of McMillans Road. There are alternate routes if McMillans Road is flooded. Access to the northern suburbs can be achieved by Trower Rd or via the Stuart Highway and Amy Johnson Drive without a major penalty on travel time.

However, it is recommended that a risk assessment of the flooding of the Kimmorley Bridge be carried out. The safety of persons as drivers or passengers of vehicles, together with pedestrian safety should be considered, noting that Section 2.6 shows that the crossing is a high hazard location with little warning time.

2. Trower Road Bridge

The options considered were:

- Enlarging the existing Trower Road Bridge opening
- Providing high level flood relief culverts under the approaches to the Trower Road Bridge

The Trower Road Bridge enlargement option was modelled in TUFLOW by doubling the existing waterway area of the Bridge. The flood relief culvert option was modelled by providing 13 no. 3 m wide x 1 m high reinforced concrete box culverts (RCBC) under Trower Road approximately 50 m west of the existing Trower Road Bridge.

The relative changes in 1% AEP flood levels as a result of the options are shown in Figure 38, Figure 39, Figure 40 and Figure 41 of Appendix B. The options reduced flood levels at Trower Road by between 200 to 300 mm with the flood relief culverts option providing the greatest reduction. The increased waterway areas under Trower Road would reduce 1% AEP flood levels between Trower Road and Levi Street. There would be negligible change to flood levels further upstream of Levi Street. A minor increase in flood levels of between 30 and 60 mm would occur downstream of Trower Road. The reductions in numbers of properties within the 1% AEP (Q100) floodplain are shown in Table 9 and Table 10.

- **Table 9. Impact on a 1% AEP (Q100) flood of enlarging Trower Rd Bridge**

	Without bridge enlargement	With bridge enlargement
Lots wholly within the extent of inundation for 1% AEP (Q100) flood	48	35
Lots partially within the extent of inundation for 1% AEP (Q100) flood	19	20
Total lots	67	55

- **Table 10. Impact on a 1% AEP (Q100) flood of Trower Rd Bridge relief culverts**

	Without relief culverts	With relief culverts
Lots wholly within the extent of inundation for 1% AEP (Q100) flood	48	37
Lots partially within the extent of inundation for 1% AEP (Q100) flood	19	19
Total lots	67	56

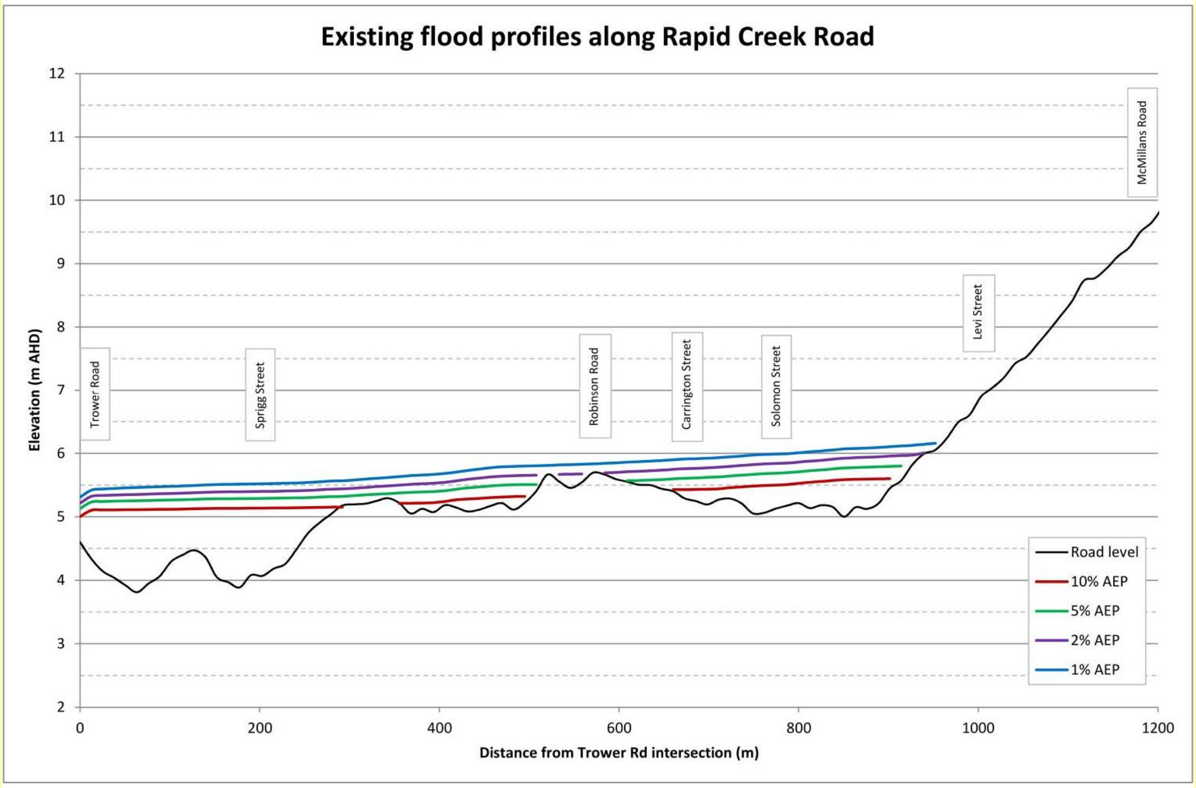
The results of cost benefit analysis for Trower Rd relief culverts are presented in Section 4.2.7.

4.2.5. Levees

Levees are built as a means of eliminating the inundation of buildings and yards during a flood event (up to the design flood height of the levee together with a freeboard allowance of say 0.5 m). Flood gates can be considered as a separate modification measure or as part of a levee design. Flood gates allow local waters to be drained from an area when the level of the creek is low but prevent floodwaters from entering (or exiting) when the creek is elevated.

Pumps are sometimes associated with levee designs. They are installed to remove local floodwaters behind levees when flood gates are closed or there are no flood gates. They are generally only suitable for small volumes of local floodwaters and have a high likelihood of failure (due to loss of power, lack of maintenance etc.).

A levee along Rapid Creek Road to prevent inundation of properties in Millner was considered. To determine appropriate heights of a levee the existing design flood profiles along Rapid Creek Road were plotted and are shown in Figure 18. To provide protection for the 1% AEP (Q100) event with an appropriate freeboard, a levee along Rapid Creek Road would need to be up to 2.0 m high near the intersection with Trower Road.



■ **Figure 18. Existing flood profiles along Rapid Creek Road**

A levee option to provide protection for the 1% AEP (Q100) flood event was assessed in the TUFLOW hydraulic model. The levee would commence near Levi Street and would extend along Rapid Creek Road for approximately 1,100 m. The average height of the levee would be about 1.5m.

Two alignments of the levee near the Trower Road intersection were tested as shown in Figure 19:

- Levee Option 1 – levee continues east along Trower Road until the bridge, thereby obstructing the existing flow path over the intersection.
- Levee Option 2 – the levee alignment was selected to so the existing flow path remains clear. Modifications to the intersection are required to accommodate this option.

The relative change in 1% AEP (Q100) flood levels as a result of Option 1 is shown Figure 42 in Appendix B. Option 2 would have less of an impact on flood levels with a maximum increase of 80 mm and therefore was not mapped.

▪ **Figure 19. Rapid Creek Road levee alignments considered**

There are a number of issues that need to be considered before construction of a levee along the western side of Rapid Creek. These are

- Impact on local drainage
- Increase in flood levels
- Amenity
- Ownership, operation and maintenance
- Residual risk
- Cost

These issues are discussed in the following sub-sections.

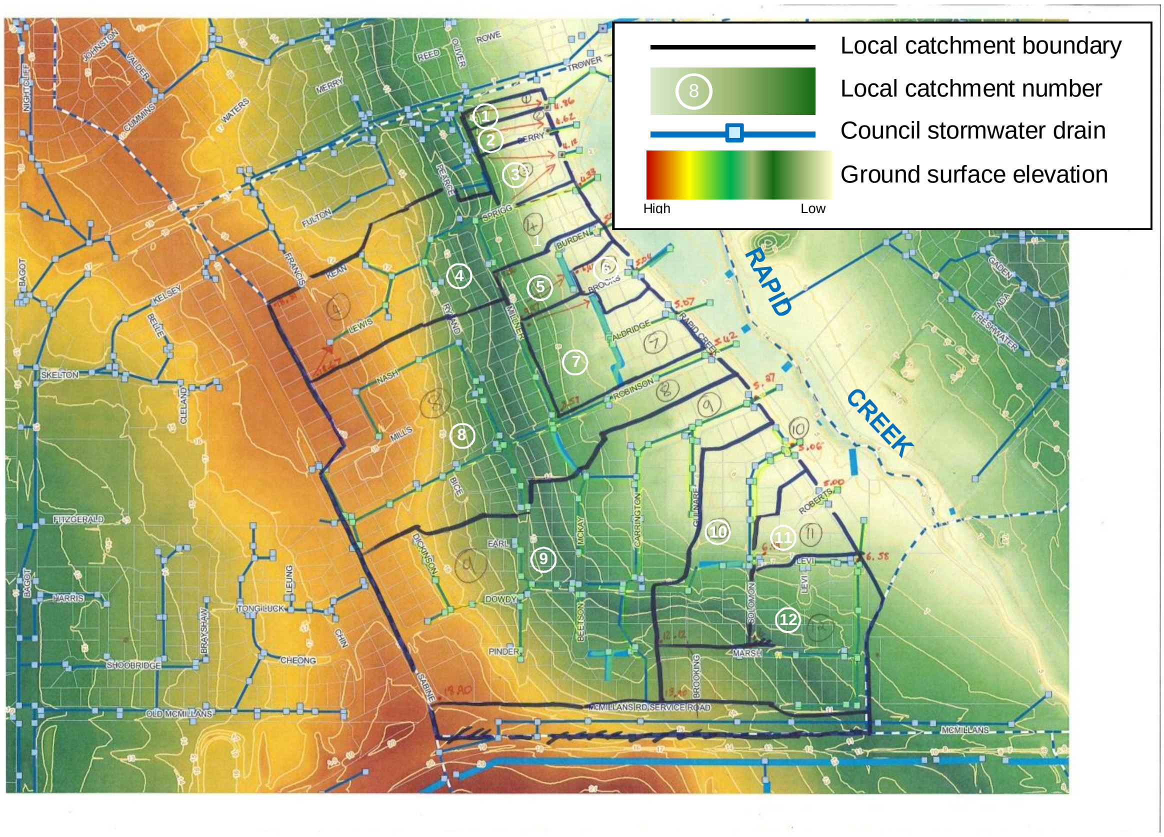
1. <u>Local drainage</u>

If a levee was constructed along the left (western) bank of Rapid Creek, it would keep floodwaters from Rapid Creek entering the low-lying parts of Millner. In order to do this, flood gates would be constructed to prevent water from flowing back up stormwater drains when the creek level is high.

This means that for the period when the Creek is high, the local runoff generated from the Millner sub-catchments cannot drain out. Any runoff coming from the Millner area during this period will lie in the streets of Millner until the Creek level falls.

The length of time when local drainage is prevented depends on the size and nature of the flood event. Typically, for a 1% AEP (Q100) flood, that would be about 1 hour.

There are 12 sub-catchment areas of Millner defined by the underground drainage system in the streets (See Figure 20.)



- **Figure 20. Millner local drainage catchments**

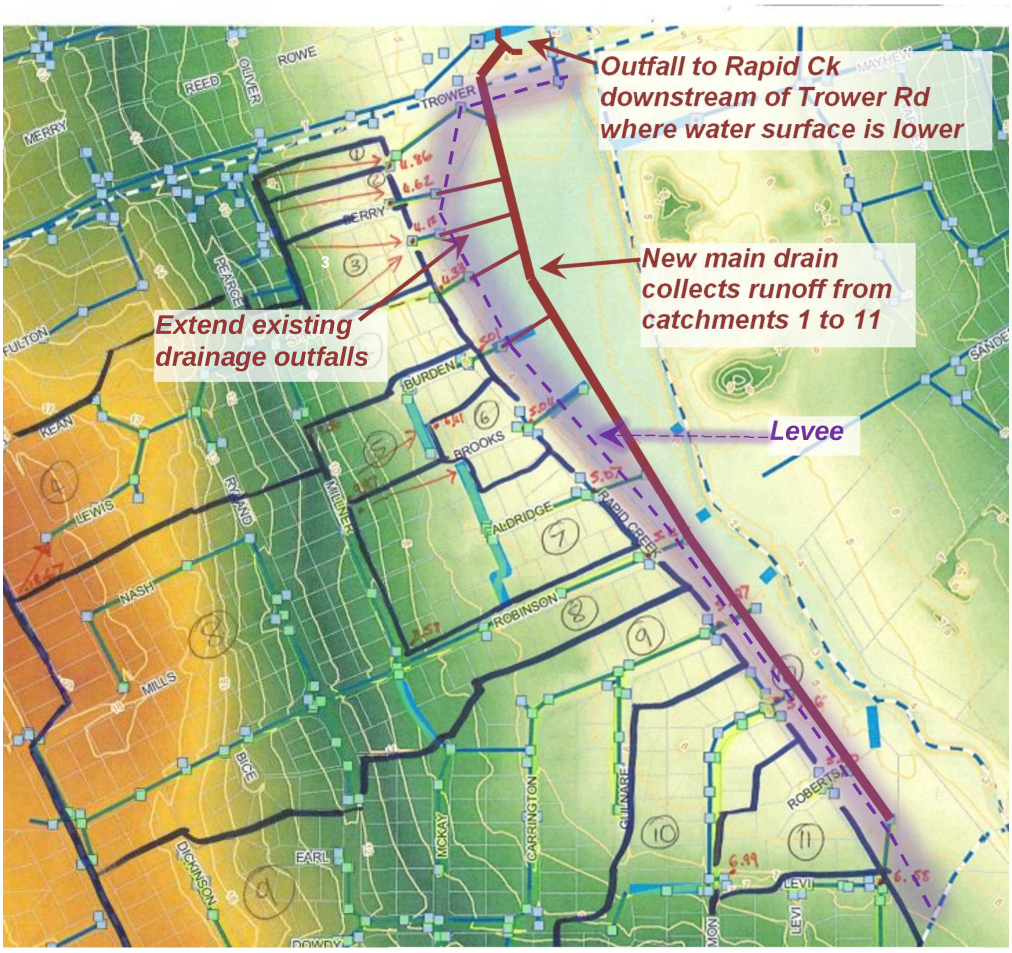
The sub-catchments vary in area up to 18.2 ha for catchment no. 9 which is directed across Rapid Creek Road at Carrington Street.

From this sub-catchment area, a significant volume of water would be stored behind the levee because it cannot escape. However, a more detailed hydrologic assessment is required to accurately estimate the local catchment runoff in relation to the timing of the flooding of Rapid Creek Road.

To pump this flow beyond the levee and maintain reasonable volumes in street storage would require very large and expensive high volume, low head pumps.

If such pumps are not installed, water from the local catchment could cause flooding of property in the low-lying areas independent of Rapid Creek.

Instead of pumping, it may be feasible to re-arrange the underground drainage outlets to divert the largest local catchment areas away from the lowest areas where levee protection is most required. Figure 21 shows diversion of the 11 Millner local catchment areas to discharge downstream of Trower Rd, where the water surface is lower (as Figure 18 shows).



■ **Figure 21, Possible drainage modifications associated with levee**

However this too would have a substantial cost. The cost of nearly 1 km of new drain linking up the 11 local catchment outfalls and carrying flows to the north of Trower Rd is estimated to be $10 million.

2. Amenity

A levee up to 2.0 m high will constitute a physical and visual barrier between the residential areas on the western side of Rapid Creek Road and the creek corridor. This will change the character of the area and reduce the amenity of the creek corridor. It also has the potential to reduce 'passive surveillance' of the creek corridor, which already has some problems with the rubbish left by long-grassers. These problems diminish in areas where a lesser levee height is required.

A levee to protect the streets of Millner can still be overtopped by a flood larger than the design flood standard adopted.

And low-lying houses behind the levee would be flooded when Rapid Creek rises to a level that closes the flood gates on the local drainage system, unless expensive drainage modifications were carried out

3. Increase in flood levels

The TUFLOW hydraulic model showed that introduction of a levee would increase flood levels in the main channel and right bank. Levee Option 1 was found to increase flood levels by 300 mm at Trower Road with the impact extending to just upstream of Levi Street near the Gauging Station. Blockage of the Rapid Creek Road/Trower Road intersection flow path (Option 1) would cause more flow to be diverted to the right (east) bank of the Creek and this would cause new areas to be inundated near the intersection of Trower Road and Freshwater Road. For Levee Option 2, the increase in flood levels is only 80 mm and the effect will not extend as far upstream.

4. Ownership, operation and maintenance

Clear arrangements would need to be made for who owns, operates and maintains the levee and any associated structures such as flood gates, pumps, flood walls and so on. It is clear that Darwin City Council has responsibility for the Millner drainage systems and therefore has a stake in the flood gates or pumped systems. It would make sense for Council to also own and maintain the levee. However, no discussions have yet been held with Council.

Typical maintenance requirements for earth levees include:

- maintaining appropriate vegetation to minimise erosion,
- making good any erosion that does occur
- Ensuring that any settlement does not compromise the design levee height
- Removing any inappropriate vegetation, for example larger diameter root growth that would penetrate the levee and allow water to pass through it
- Ensuring flood gates are free of debris and silt and remain operational
- Normal pump maintenance including switchboard/controls/power supplies

5. Residual risk

A properly maintained levee and local drainage system will eliminate inundation by floods up to the adopted design flood. For example, if a 1% AEP (Q100) design flood is adopted, then no damage would be expected for floods up to and including this flood. However, if a flood larger than the 1% AEP (Q100) flood occurs, the levee will be overtopped, floodwaters will enter the streets of Millner and damage can be expected.

6. Costs

The estimated cost of a levee along the left bank as shown in Figure 19 is $6.1 million. However, as discussed above, the relative levels and the size of the local drainage catchment areas are such that in the order of $10 million additional drainage works are required. This results in costs exceeding benefits for the levee (see Section 4.2.7.)

4.2.6. Comparison of options

The relative effectiveness of the measures examined can be seen from Table 11.

The changes of numbers of properties in or out of the flood plain reflect the mild slopes in some parts of the area inundated. That is, a small change in calculated still water height, say 200mm, might mean a 20 or 30 m change in the horizontal extent of flooding, equivalent to the width of a typical house block.

Table 11. Summary of impact of mitigation options considered

Flood modification option	Millner lots wholly within the extent of inundation for 1% AEP (Q100) flood	Millner lots partially within the extent of inundation for 1% AEP (Q100) flood	Total Millner lots inundated for 1% AEP (Q100) flood
Without existing flood control weir	75	14	89
Current	48	19	67
Enlarge channel	42	18	60
Channel clearing	41	17	58
Relief culverts Trower Rd	37	19	56
Enlarge Trower Rd Bridge	35	20	55
Detention basins 1, 2 and 4	22	17	39
Q100 Levee	0	0	0

This also means that in many cases, the depth of flooding in houses that can be "saved" by the measures listed in Table 11 is quite shallow.

A better indicator is the damage-cost avoided by construction of these measures as discussed in the following Section 4.2.7

4.2.7. Costs and benefits

Benefits of flood mitigation schemes have been estimated using the damage estimate spreadsheets from the flood damages study [SKM 2013 d]. Table 12 shows these estimates.

Table 12. Reduction in damages for total protection to selected design standards

Design standard (Protect all property up to)	NPV Residual Damages[2]		NPV Reduction in damages	
	Best case	Worst case	Best case	Worst case
No mitigation	$10,800,000	$13,700,000		
5% AEP (Q20)	$4,900,000	$ 6,200,000	$ 5,900,000	$ 5,200,000
2% AEP (Q50)	$2,900,000	$ 3,700,000	$ 7,900,000	$ 7,700,000
1% AEP (Q100)	$2,000,000	$ 2,500,000	$ 8,800,000	$ 8,900,000

These values can be used to estimate the costs and benefits for mitigation options.

For some options, such as levees, total protection up to a design standard can be achieved. For example, the construction of a 2% AEP (Q50) levee can be taken to mean that for all floods smaller than the 2% AEP flood there is no damage. In this case the benefits can be calculated directly from Table 12.

For all of the flood modification options considered, the estimated costs exceed the benefits, which are calculated as savings in future flood damages.

For other options, such as detention basins, a reduction in flood peak occurs across a wide range of design floods and the reductions are calculated as proportional reductions in damage (based on the relative contributions of various floods (See for example the Potential Flood Damages Report [SKM 2013 d].) However if any of these options are considered further, the costs savings should be confirmed using flood calculated levels from interpolated flood surface contours (as was the case for the initial damages assessment.)

[2] NPV means Net Present Value of all future damages expressed in today's dollars

- **Table 13. Costs and benefits of selected mitigation options**

Scheme	Refer Section No.	Design standard	Benefit (=reduction in flood damages) [1]	Indicative Cost	Ratio of benefits to costs
Detention basins 1, 2 and 4	4.2.2	N/A	$6,600,000	$ 7,200,000 [2]	0.92
Channel enlargement	0	N/A	$1,900,000	$ 3,400 000	0.56
Relief culverts Trower Road	4.2.4	N/A	$3,900,000	$ 6,100,000	0.64
Levee alongside Rapid Creek Road	4.2.5	Q100	$8,900,000	$16,100,000	0.55

1 Reduction in flood damages taken as average of best and worst cases

2 Does not include cost of purchase of land for the detention basin site – so actual benefit cost ratio will be lower

Table 13 indicates that the costs exceed the benefits in all of the cases considered and there is no single structural mitigation option that ‘solves’ the problem of flooding in the suburb of Millner.

There may be combinations of options not yet examined that produce a benefit cost ratio closer to 1.0. There may be schemes that protect part of the Millner area and produce a benefit cost ratio greater than 1.0 when the only that part area is considered. These however are beyond the scope of the present study and would require further investigations.

4.3. Response Modification Measures

4.3.1. Flood warning

BOM is responsible for provision of warnings of dangerous weather to the Australian community, with the aim of minimising injury and damage. BOM issues the following warnings (among others)

- Tropical cyclone warning services
- Severe weather warning services
- Severe thunderstorm warnings.

The service is provided from the Bureau's NT regional forecasting centre, information is then transmitted to authorities such as Police, the NT Emergency Services (NTES) and to radio and television stations.

The warning times are much longer for these and potentially give many hours’ notice to residents. However, these warnings typically apply across the Greater Darwin Region. The likelihood of severe weather or thunderstorms for the region may or may not mean heavy rain over the Rapid Creek catchment area.

BOM also has responsibility Australia-wide for flood warning services and provides such a service for most major rivers in Australia. However, it is understood that BOM considers Rapid Creek a "flash flooding" stream and therefore doesn't issue specific flood warning advices.

Weather conditions and current warnings can also be accessed through links in the SecureNT website. Secure NT describes itself as a "gateway to information on preparing for and getting through emergency situations in the Northern Territory". It provides links to various agencies, displays preparedness and warning information, has links to audio streaming from ABC radio and users can upload their own emergency information in real time through social media links.

Department of Land Resource Management (DLRM) advises that it provides flood warnings for Rapid Creek and relies on auto-information of Creek water level rises at the stream gauging station 450 m downstream of McMillans Road. There are a series of trigger levels, the lowest of which is a "Watchpoint" and highest being a "Major" category (about a 5% AEP or Q20 event). Alerts issued to NT Emergency Services (NTES) at lower flood events are necessary due to the short time to peak for most events and hence limited emergency response times. DLRM also rely on the Bureau of Meteorology's (BOM) alerts regarding "severe weather warning" and "flood threat advice".

During a flood event, DLRM informs (NTES) of the alerts which then responds accordingly. NTES works with NT Police to provide best emergency responses based on need.

The Bureau of Meteorology issues and updates severe weather, cyclone and thunderstorm warnings for the Greater Darwin Area based on likely weather conditions.

However, it is difficult to develop an effective warning system specific to a small catchment such as Rapid Creek because of the relatively short response time.

Early warning automatic rainfall stations in the catchment area could provide the earliest possible specific warning for Rapid Creek.

One such station exists at Marrara and a system could be developed to disseminate meaningful information to Rapid Creek residents based on heavy rain trigger levels

In the 1% AEP (Q100) event, depths of inundation of up 0.8 m above floor level would be experienced by some properties near Rapid Creek Road (Section 2.6), with approximately 28 residences experiencing flooding above floor level (refer Section 1.2.1). The threatened houses are in the flood fringe for a 1%AEP (Q100) flood (Section 2.6) and some (but not all) residents may be able to stay in their houses. However some residents may wish to leave regardless of the anticipated depth of flooding.

The location of vulnerable people is known to health agencies and Non Government Organisations (NGOs) and evacuations or rendering of assistance is organised by these. The amount of time for evacuation depends on the available warning time.

Ideally, providing sufficient warning time has the potential to reduce the social impacts of the flood as well as assisting health agencies, NGOs and NTES. Adequate flood warning, if available, gives residents time to move goods and vehicles above the reach of floodwaters and to evacuate from the immediate area. The effectiveness of a flood warning scheme depends on the:

- maximum potential warning time before the onset of flooding
- actual warning time provided before the onset of flooding. This depends on the adequacy of the information gathering network and the skill and knowledge of the operators
- flood awareness of the community responding to a warning

- **Figure 22. Typical Weather Alert Station**

Although flood warning has the potential to reduce the social and economic impacts of a flood, it is difficult to develop an effective warning system for a small catchment such as Rapid Creek. This is due to the relatively short response time from the start of the rain to the time of the flood peak (about 1 hour). However, improvements can be achieved if an early warning ALERT station can be implemented in the catchment that relies on rainfall data as an indicator in addition to the current Gauge runoff/creek flow response.

ALERT stations communicate by radio and report every 1 mm of rainfall to the local base station and other floodwarning centres and websites. A TM station may also be viable which is connected to the public telephone network. The automatic alert could go to DLRM and NTES and potentially websites, SMS or Voicemail messages to residents. A trigger level could activate DLRM staff that would monitor and send additional alerts to identified agency staff such NTES and resident representation. Currently DLRM is investigating this warning system approach and this should be supported.

A case study of flood warning for small catchments with short response times is in Appendix B.

4.3.2. Public Information and Raising Flood Awareness

The success of any flood warning system and the 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 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?

Good information is currently available on the SecureNT website and it is understood that this information is reviewed after each wet season and after significant individual events.

A community with high flood awareness will suffer less damage and disruption during and after a flood because people are aware of the potential risks of the situation. Residents can be expected to effectively respond to imminent danger 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
- history of residence,
- whether an effective public awareness program has been implemented

An issue for Rapid Creek is the higher percentage of rental accommodation and therefore more transient population. 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 the level of awareness diminish as the time since the last flood increases. A major hurdle is often convincing residents large floods will occur in the future. Some residents may oppose an awareness program because they consider it reduces the value of their property. However this should not hinder the continued need to inform and receive feedback from the community.

A suitable catchment wide flood awareness program could be implemented by NT Government using appropriate elements from the following Table 14.

- **Table 14. Possible Flood Awareness Options**

Method	Comment
Letter/Pamphlet	These may be sent (annually or biannually) with water/sewer rate notices or separately. A database of flood liable properties/addresses makes this a relatively inexpensive and effective measure. The pamphlet can inform residents of subsidies, changes to flood levels or any other relevant information.
School Project or Local Historical Society	This provides an excellent means of informing the younger generation about flooding. It may involve talks from various authorities and can be combined with topics relating to water quality, estuary management, etc.
Displays at, Library, Schools, Shopping Centres, Local Markets	This is an inexpensive way of informing the community and may be combined with related displays.
Historical Flood Markers or Depth Indicators on Roads	Signs or marks can be prominently displayed in parks, on telegraph poles or such like to indicate the level reached in previous floods. Depth indicators on roads advise drivers of potential hazards.

Method	Comment
Articles in Local Newspapers	Ongoing articles in the newspapers will ensure that the problem is not forgotten. Historical features and remembrance of the anniversary of past events make good copy.
Collection of Data from Future Floods	Collection of data assists in reinforcing to the residents that NT Government is aware of the problem and ensures that the design flood levels are as accurate as possible.
Types of Information Available	A recurring problem is that new owners consider they were not adequately advised that their property was flood affected during the purchase process. Need to develop effective way to advise interested parties, when they inquire during the property purchase process, regarding flood information currently available, how it can be obtained and the cost.
Flood Preparedness Program	Providing information to the community regarding flooding helps to inform it of the problem and associated implications. However, it does not necessarily adequately prepare people to react effectively to the problem. A Flood Preparedness Program ensures that the community is adequately prepared.

Storm Surge mapping has been released and can be found on the SecureNT website under “Cyclones”.

Appendix C gives examples of flood awareness options.

4.4. Property Modification Options

Property modification measures refer to modifications to existing development and/or development controls on property and community infrastructure for future development.

These measures include:

- land use planning, including zonings and development controls
- voluntary purchase of high hazard properties
- voluntary house raising
- flood proofing of buildings, and
- flood access

On the Rapid Creek floodplain, there are potentially more than 67 residential affected by the 1% AEP (Q100) flood. Of these, approximately 28 are believed to have floor levels of habitable rooms close to the ground.

4.4.1. Short to Medium Term Options

1. Voluntary House Purchase

   In some jurisdictions, voluntary purchase has been contemplated where:

   - Flooding is frequent
   - The risk to life or property is high, and
   - There are no other viable options.

The process involves the acquisition frequently inundated of residential properties in high hazard areas and demolition of the residence to remove it from the floodplain. Generally the land is returned to open space; however there may be an opportunity for a new house to be built at a higher floor level.

Voluntary purchase is mainly implemented in higher risk areas over a long period as a means of removing isolated or remaining buildings and thus freeing both residents and potential rescuers from the danger and cost of future floods. If left as open space, it also helps to restore the hydraulic capacity of the floodplain (storage volume and waterway area).

Voluntary purchase has no environmental impacts although the economic cost and social impacts can be high. Many residents do not accept voluntary purchase because it would have significant impact on their community and way of life. Among these concerns are:

- in many cases residents may not wish to move for a reasonable purchase price
- progressive removal of properties may impose stress on the social fabric of an area
- it may be difficult to find alternative equivalent priced housing in the nearby area with similar aesthetic values or features

The cost of implementing such a scheme for Rapid Creek would exceed the benefits. As an example, the flood damages spreadsheets were used to estimate the benefit of purchasing 6 ground level houses in Millner, which are estimated to be flooded to a depth of 0.3 m or more during the 1% AEP (Q100) flood. The estimated reduction in flood damages if those houses are removed is $1,700,000 to $2,500,000. If the average purchase price is say $650,000, the total spend would be $3,900,000 and the benefit/cost ratio would be in the range 0.44 to 0.64.

Even if some cost could be recouped by selling the land for development such a scheme is likely to be uneconomic. Given the cost and the disruption to the community, this option is <u>not recommended</u> at this stage.

2. <u>House Raising</u>

House raising is widely used to eliminate inundation of habitable floors. This approach provides more flexibility in planning, funding and implementation than voluntary purchase. 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. However it does not reduce the external hazard, evacuation issues or yard/garage damages.

Its application is limited as it is not suitable for all building types. The most flood-affected houses on the Rapid Creek floodplain are brick on ground slab construction and hence aren't readily suitable for raising. There would also be a residual (continuing) flood risk for the residents. Therefore this option is <u>not recommended</u> at this stage.

- **Figure 23. Example of house raising**

An option could be to add a second storey addition and modify the lower floor for potential inundation. The feasibility depends on the structural capacity of the existing building. It is also likely to cost more than simple house raising. $2 million for the identified slab-on-ground properties in the areas most at flood risk.

3. Flood Proofing

Flood proofing involves the sealing of entrances, windows, vents, etc. to prevent or limit the ingress of floodwater. It is generally only suitable for brick buildings with concrete floors and it can prevent ingress for outside water depths up to approximately one metre. Greater depths may cause structural problems (buoyancy) unless water is allowed to enter.

None of the houses in the Rapid Creek floodplain experience flooding at depths exceeding 1.0 m in a 1% AEP (Q100) flood, although such depths are possible for larger floods.

Effective flood warning is required to allow time to put barriers into place.

For Rapid Creek, short warning times restrict emergency options but property scale solutions for the community to help themselves could reduce flood damages.

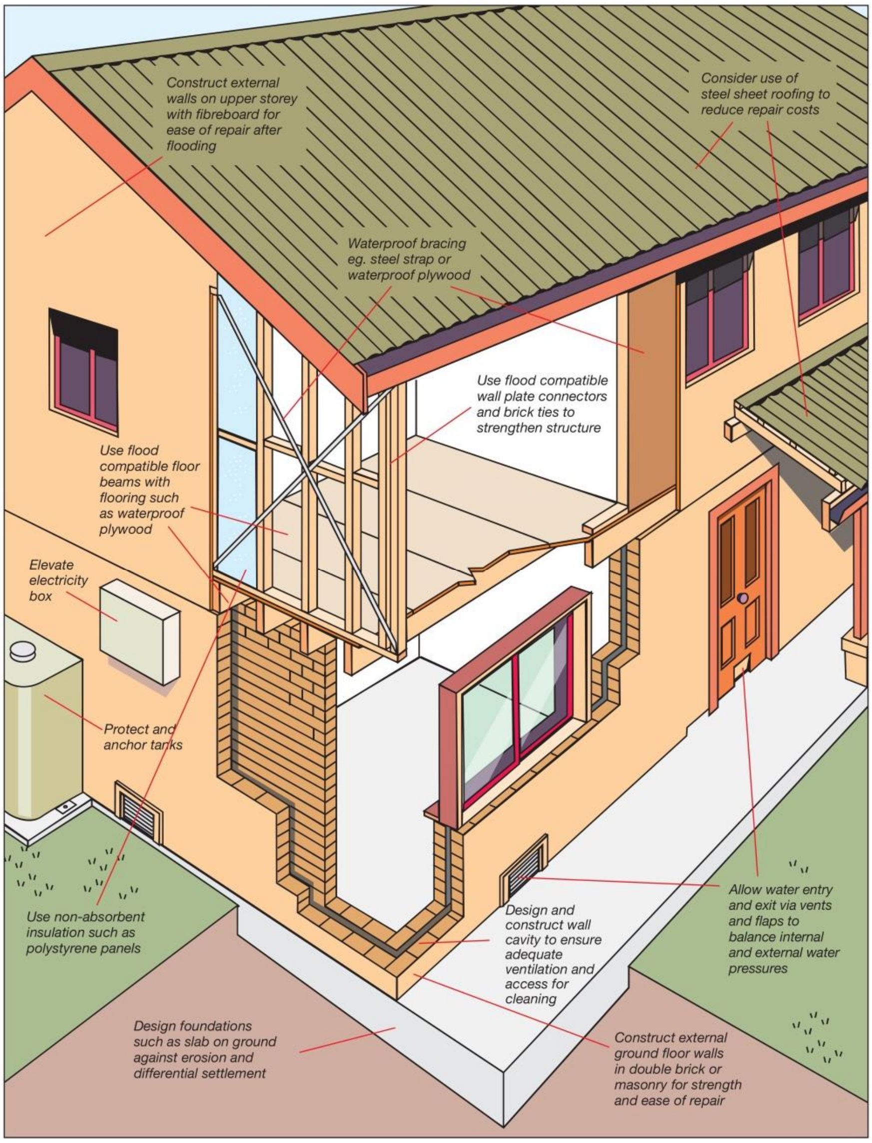
Flood proofing may be more appropriate for commercial buildings where there are likely to be fewer entrances that need to be sealed off when a flood approaches. However, where flooding is shallow, it is a low to moderate cost option for the Government and could be part of a coordinated approach and linked to other planning measures.

4. Flood resilient construction

Flood resilient construction means constructing buildings that are less affected by floodwaters, facilitating quicker and easier clean up and recovery. Unlike flood proofing, floodwaters are allowed to pass into and through buildings. This eliminates concerns with accumulation of pressure from rising floodwaters on barriers or flood gates.

Good flood resilient construction ensures that:

- The structure is soundly built with no weaknesses resulting from poor workmanship
- The construction is clean so that building waste (e.g. mortar and scrap materials) is not left in building cavities to attract or trap moisture
- Edges, surfaces and joints of components are well sealed in order to minimise water uptake.



- **Figure 24. Example of Flood Resilient Construction**
- **(Source: NSW HNFMC 2006)**

Buildings should be appropriately oriented in relation to the direction of movement of floodwaters. Structural form and detailing should minimise moisture accumulation and absorbency, with appropriate materials, fittings and joinery to allowing rapid drying out.

The Australian Building Control Board (ABCB) has a draft standard for "Construction of Buildings in Flood Hazard Areas." [ABCB January 2013].

A possible option is Government provision of support officers to provide advice and audits for individual properties and small-scale funding of measures. Outcomes could include property audits, property Flood Resilience Plans, upgrade grants, and insurance premium reviews. Flood audits have the added advantage that residents audited can be encouraged to prepare personal flood emergency plans.

4.4.2. Medium to Long Term Options

1. <u>Land use Planning and Development Control</u>

The existing land use occupying the Rapid Creek floodplain is primarily fully developed residential with a mixture of single and two storey private and public housing. Some non-urban land use typified by larger properties is also present. Master planning for the Airport and Defence lands upstream of McMillans Road indicates a mixture of business, office, retail and community uses. It may be prudent for NT Government to undertake a strategic review of the current planning to consider how future development will complement the Airport Master Plans.

In relation to flood planning, 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 or redeveloped properties likely to be affected by flooding to acceptable levels.

The NT Planning Scheme provides for the Defined Flood Event (DFE), generally being the 1% AEP (Q100) flood. Habitable areas are to be 300mm above the DFE. The current zoning of affected urban properties is Residential SD (Single Dwelling) and there are also a small number of non-urban larger properties. This control is designed to manage future flood risk. There is also regulation surrounding buildings in flood prone areas in the NT Building Regulations, under the Building Act. This is discussed in Section 1.5.3 of this report.

Possible planning and control options include:

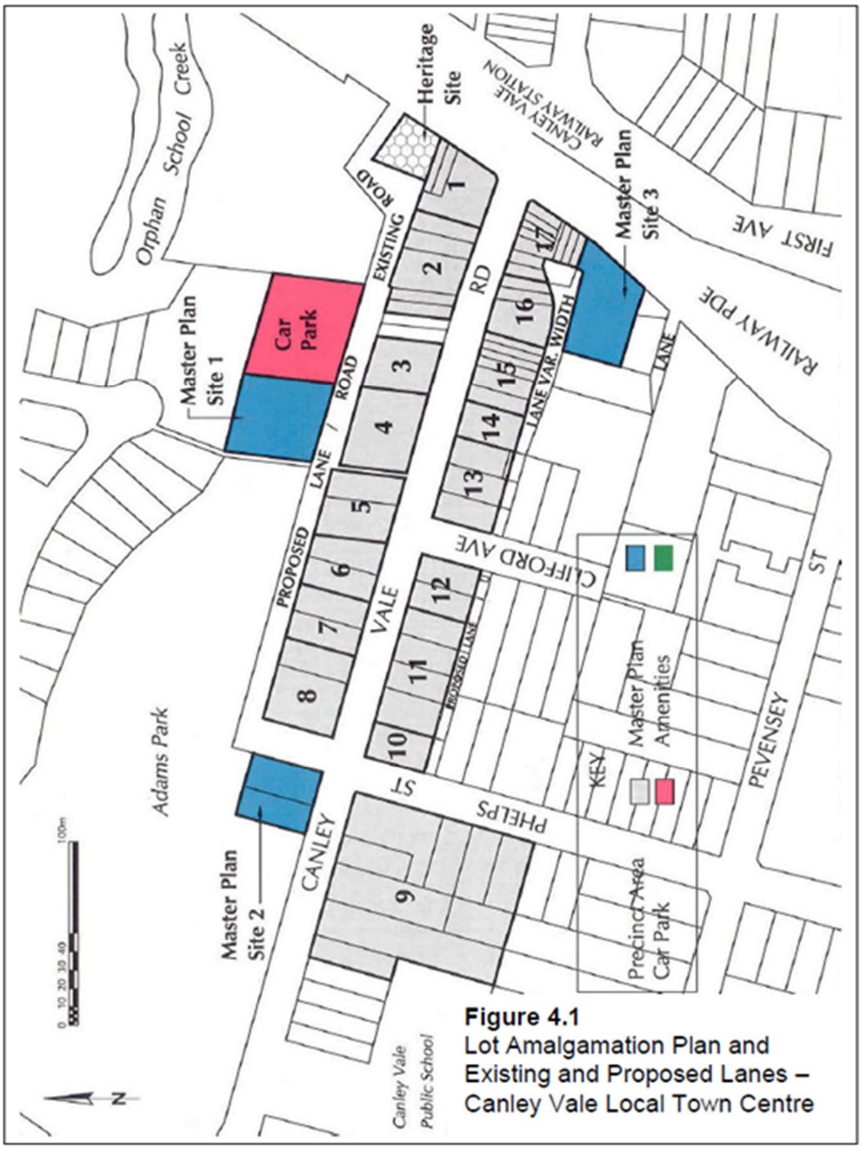
- Review of the current zoning and relevance of strategic plans for the area. Consideration of a new Master Plan that could include a mixture of redevelopment including residential and commercial land uses. This redevelopment would also provide for a reduction in flood risk by appropriate building designs and improved emergency response measures. Issues include: nature of redevelopment consistent with adjacent land use strategies; developer contributions; Creek foreshore plans; etc.

- Development of a possible Flood Risk Management Development Control Plan to manage flood risk (rezoning). DCP could cover future site access, filling, freeboard, floor levels, services, building structural soundness, building materials and fencing. This DCP could also be customised for other floodplains in Darwin.
- Consideration of impacts on downstream communities of future catchment development including Darwin International Airport and Department of Defence lands.

- **Figure 25. Residence with Habitable Areas above Flood Level**
- **Source: NSW FDM [2005]**

- **Figure 26. Commercial Building on Floodplain**
- **Source NSW FDM [2005]**

- **Figure 27. Commercial Development Flood Mitigation**
- **Source HNFMC, 2006**



- **Figure 28. Example of Precinct Plan near a Creek**
- **Source: Fairfield City Council**

5. Options Assessment and Recommendations

5.1. Summary of potential impacts

Each option considered has the potential to impact on the environment of the social or economic wellbeing of the community. Table 15 summarises these impacts.

- **Table 15. Summary of potential impacts of strategies**

Strategy	Potential Impacts						
	Cost	Environment	Amenity	Property values	Traffic/ access	Residual risk	Community disruption
Enlarge channel	Not cost effective	Extensive clearing of left bank habitat.	No long term impact on amenity	No significant impact	No impact	Substantial residual risk will exist	Short term impact on parkland
Channel clearing	Not expensive	Extensive but selective clearing in creek corridor	Short term impacts (noise dust). Increase in visibility through corridor	No significant impact	No impact	Substantial residual risk will exist	Short term impact on parkland
Relief culverts Trower Rd	Expensive and not cost effective	Minor clearing close to Bridge to facilitate works	Minor long term impact on amenity	No significant impact	Short term major disruption to traffic	Substantial residual risk will exists	Short term noise, dust, construction traffic. Short term traffic disruption
Enlarge Trower Rd Bridge	Expensive and not cost effective	Minor clearing close to Bridge to facilitate works	Minor long term impact on amenity	No significant impact	Short term major disruption to traffic	Substantial residual risk will exist	Short term noise, dust, construction traffic. Short term traffic disruption

Strategy	Potential Impacts						
	Cost	Environment	Amenity	Property values	Traffic/ access	Residual risk	Community disruption
Detention basin 1 only	Expensive and marginally cost effective	Some clearing of habitat. Mostly modified or degraded at present	Minor long term impact on amenity	No significant impact	Possible minor impact on traffic entering airport	Some residual risk will exist	No significant disruption
Detention basins 1, 2 and 4	Expensive and marginally cost effective	Clearing of existing habitat. (Encouraged to revegetate after construction)	Land to be acquired. Change in use. Impact on existing Rapid Ck corridor upstream of McMillans Rd	No significant impact	Possible minor impact on traffic entering airport.	Some residual risk will exist	Short term noise, dust, construction traffic. Short term traffic disruption to Henry Wrigley Dr and McMillans Rd
Q100 Levee	Expensive and not cost effective	Extensive clearing along line of levee. Mostly grassed parkland but some creek habitat	Visual and physical barrier between Millner residential area and Rapid Ck corridor	Likely impact on value of property which currently has views of creek corridor	May involve disruption to or even closure of Rapid Creek Road	Residual risk will exist	Short term noise, dust, construction traffic. Short term and possibly long term traffic disruption to McMillans Rd
Flood warning	Not expensive compared to other options	No impact	No impact	May have some impact	No impact	Risk remains. What changes is how that risk is managed	Minimal disruption
Evacuation	Not expensive compared to other options	No impact	No impact	May have some impact	No impact	Risk remains. What changes is how that risk is managed	Minimal disruption
Flood awareness/ preparedness	Not expensive compared to other options	No impact	No impact	May have some impact	No impact	Risk remains. What changes is how that risk is managed	Minimal disruption
Voluntary house purchases	Expensive and not cost effective	No impact	No impact	Will have some impact	No impact	Risk unchanged for properties	Minimal disruption

Strategy	Potential Impacts						
	Cost	**Environment**	**Amenity**	**Property values**	**Traffic/ access**	**Residual risk**	**Community disruption**
						not purchased	
House raising	Expensive and not suited concrete brick on slab houses	No impact	No impact	May have some impact	No impact	Risk unchanged for properties not raised	Minimal disruption
Flood proofing	Less expensive	No impact	No impact	May have some impact	No impact	Risk unchanged for properties not flood proofed. Risk of damage unabated for larger floods than standard of flood proofing	Minimal disruption
Flood resilient construction	Not expensive for new houses and additions	No impact	No impact	May have some impact	No impact	Reduces risk to property damage. No change to risk to personal safety	Minimal disruption
Land Use/ development controls	Expensive but may be private sector driven	Change in character of the area	Change in types of residence	Significant impact on property values	Traffic generation impacts. Changed access conditions	Design to minimise residual risk	Significant disruption during to demolition of existing and re-development to new residential, commercial, retail formats

5.2. Options Assessment

This flood risk management options assessment has relied upon information and guidance from the NT Government, SKM's studies of flood behaviour, damage and option costings and options identification consistent with guidelines from NFRAG [2012] and NSW Floodplain Development Manual [2005].

The options were developed to cover flood, property and response modification measures, together with preliminary consideration of their social, economic and environmental consequences. Recommendations from this options assessment will inform the preparation of an Action Plan. The Action Plan aims to achieve a balanced response to managing flood risk for the Rapid Creek community.

The selection of suitable options requires the consideration of community aspirations and what can be done to reduce the flood risk. Generally options should be framed around strategies to reduce the risk to the community and to public infrastructure, either by reducing the vulnerability or the exposure to the impacts of flooding, or by improving the resilience of communities to respond to floods. Suitable measures may include better land use planning and development controls, improved information to inform emergency management planning, improvements to flood warning systems, or works to protect areas from flooding.

When assessing options it is important to consider how effective each option is in managing the risk and how important that issue is for the specific community. The effective management of risk generally involves a mix of management options. It is unusual for a single management option to manage the full range of flood risk to existing and future development.

Table 16 provides an assessment of the options considered in this study. From the priorities identified, a preliminary set of recommended options is provided in Section 5.3. This is intended to be a tool to assist the NT Government's determination of an Action Plan.

Table 16. Options Assessment

OPTION	PURPOSE	DESCRIPTION	ECONOMIC ASSESSMENT	VIABILITY	COMMENTS
A. FLOOD MODIFICATION:					
RETARDING BASINS	Reduce flows and therefore flood levels by storage of flood peaks.	Five locations were considered for retarding basins to intercept and temporarily store floodwaters contributing from urban areas. Work is clear land and excavate to construct basins to store inflows to Rapid Creek from main drains. Construct spillways for outflow from basins to Rapid Creek including erosion protection. Three basins Biggest reduction in flooding for three basins in the vicinity of McMillans Road, intercepting runoff from: • North-western corner of Darwin Airport • Anula and Marrara • Southern end of Jingili and Moil One basin Only one basin site is currently on public land and intercepts runoff from the Anula and Marrara areas.	Estimated benefit/cost ratio = 0.92 Possibly higher benefit cost ratio than for 3 basins	Uneconomic and would require land acquisition, change in land use, clearing of some existing habitat and works on the existing floodplain. Not considered viable. Clearing of largely degraded existing habitat in the floodplain.	Worthy of further investigation. Could form part of a suite of options including increased waterway in Trower Road and smaller levee along Rapid Creek Road.
	Management of the existing Flood Control Weir within Darwin Airport.	Inspect and maintain the existing flood control weir after flood events.	Relatively low cost of regular inspections and maintenance and occasional after-flood repairs	Viable	The flood control weir is an important flood mitigation structure that reduces flood levels downstream by up to 400mm in a 1% AEP (Q100) event.
CHANNEL MODIFICATIONS	Increase creek waterway area to reduce flood levels.	Clear vegetation and excavate one side of the channel to increase waterway area by 50%. Reinstate and revegetate.	Estimated benefit/cost ratio= 0.56	Uneconomic, limited effectiveness and would require destruction of habitat and construction phase impacts. Not considered viable.	Preventative maintenance that reduces the build up of resistance to flow (siltation and debris) near major waterway structures is preferred..
ROAD MODIFICATIONS	Increased waterway to pass more flow under formation thus reducing upstream flood levels and improving road access	Trower Road 1. Relief culverts Install additional culverts at a high level in the approaches to the Trower Road Bridge 2. Enlarge bridge opening Excavate and widen the opening of Trower Road Bridge with new culverts and sloping bridge abutments. Doubling the size of the existing opening was considered. McMillans Road Install additional culverts under McMillans Rd	Estimated benefit cost ratio = 0.64 Benefit/cost ratio likely to be less than 0.64 Benefits not calculated - does not reduce flood impact in Millner. Benefit is in improved access and reduced risk to users of Kimmorley Bridge.	Uneconomic and limited in effectiveness (impact reduces with distance upstream of Trower Road). Not considered viable at this time. No reduction in flooding downstream of McMillans Rd. Not considered viable at this time.	Viability may increase as bridge structures approach the end of their life and need replacing. Raising of the existing flood control weir may be a more cost effective way of improving Kimmorley Bridge immunity.
LEVEES	Contain floodwaters within the creek corridor up to the design standard of the levee (e.g 1% AEP) .	Option 1. Construct a levee along the eastern side of Rapid Creek Road from Levi Street to Waters Street, including across Trower Road. The levee would be of earth construction up to 2.0 m high with concrete masonry walls in the vicinity of Rapid Creek Road joining to high ground' at the bridge centreline. Option 2 Construct a levee along the eastern side of Rapid Creek Rd from Levi St to Robinson Rd. Return the levee to 'high ground' formed by raise Rapid Creek Rd up to 0.3 m in the vicinity of Robinson Rd. The levee would be of earth construction up to 1.0 m high.	Estimated benefit/cost ratio = 0.55 Estimated benefit/cost ratio = 0.90	Uneconomic because of the cost of modifications to the local Millner drainage systems. Impacts on amenity of the creek corridor. Not considered viable. Not viable on its own. No reduction in flooding for streets north of Robinson Road.	Levees can prevent inundation of residential areas impacted by both Creek flooding and storm surge. (Reduction in storm surge damage not taken into account in this study.) The levee would generally be over a metre high and over two metres high in the 200m section immediately to the south of Trower Road. Apart from cost, the levee option will have many issues including blockage of local drainage from the Millner catchment, visual amenity, building footprint encroaching on the Creek, access to the Creek and road access.

RAPID CREEK FLOODPLAIN RISK MANAGEMENT OPTIONS ASSESSMENT

OPTION	PURPOSE	DESCRIPTION	ECONOMIC ASSESSMENT	VIABILITY	COMMENTS
B. RESPONSE MODIFICATION:					
FLOOD WARNING	Enables people to evacuate if required and take measures to reduce flood damages.	Monitor weather conditions, rainfall and Creek levels in real time. Issue advice of likely severe weather or thunderstorms (Bureau of Met.) Issue alerts to NTES based on the attainment of trigger levels (DLRM). Issue advice of closure of McMillans Rd to DoT. Gauge readings could trigger an automated alert to NTES and potentially SMS or Voicemail to residents	Relatively low cost.	Further investigation of warning/alert options is recommended.	Warning time for thunderstorms and severe weather can be 6 or more hours but is for greater Darwin area, not just for Rapid Creek. Warning based on Rapid Creek gauge trigger levels is specific to Rapid Creek but warning time is time is short (say, 30 to 60 minutes). Warning times between 60 minutes and 6 hours may be possible if related to real time information from rain gauges in the upper catchment area. The feasibility should be investigated.
EVACUATION PLANNING	To ensure that evacuation can be undertaken in a safe and efficient manner.	The NT Government currently has a coordinated approach via it's NTPF& ES Strategic Plan. This could be supplemented to further assist the local community to increase understanding of preparedness, how people will evacuate during a flood and what needs to be undertaken after the flood etc.	Relatively low cost.	Viable	Recommended to build on the existing Plan to enhance information to residents of preparedness and emergency actions.
PUBLIC INFORMATION AND RAISING FLOOD AWARENESS	Provide information to minimise flood damages and reduce the flood risk.	Disseminate information pamphlets, conduct flood awareness sessions, questionnaires etc. Provide flood information into schools. Link to storm surge flooding awareness and cyclone preparedness.	Benefits likely to be significant for relatively low cost.	Viable	A cheap and effective method but requires continued effort. Recommended: • Release new flood mapping • Build on the current Government strategy for raising public flood awareness for Rapid Creek and possibly other floodplains • Further develop NT Flood Information on SecureNT website. • Possible formation of local community support groups e.g. "Floodsafe" groups

OPTIONS	PURPOSE	DESCRIPTION	ECONOMIC ASSESSMENT	VIABILITY	COMMENTS
C. PROPERTY MODIFICATION OPTIONS:					
HOUSE RAISING	Prevent flooding of existing buildings by raising habitable floor levels.	1. Raise whole house by supporting under and jacking up	Relatively high cost	Not viable. Many of the worst-affected houses are of brick construction on a concrete slab and not suitable for raising.	An estimated 28 houses have habitable rooms at risk of flooding during the 1% AEP (Q100) flood.
		2. Add a second storey addition and modify the lower floor for potential inundation.	Relatively high cost	May be viable in some cases if works subsidised to include flood resilient construction. May depend on the structural capacity of the existing building	See also FLOOD RESILIENCE
FLOOD PROOFING AND FLOOD RESILIENCE	Reduce flood impacts by either: 1. Temporary barriers to inundation of buildings/properties by floodwaters., or 2. Allow floodwaters through a building which is constructed with flood tolerant materials and forms of construction	Provision for lightweight flood gates in doorways, driveways. Work in conjunction with solid fences, raised garden beds and/or (sealed) walls of the building to exclude floodwaters Construct ground level with flood tolerant materials and forms of construction, which allow floodwaters to pass through but quickly dry out and allow easy cleaning for resumption of normal use	Low to moderate cost depending upon building. May be economic for elevated houses with habitable rooms in upper level.	May be viable with Government assistance for residents to carry out modifications/extensions to existing houses. Consider on a case-by-case basis. Limited effectiveness unless there is an appropriate flood warning system.	More suitable for shallow flooding in non-residential buildings but may apply to some residential buildings. Less suitable for deeper floods where excessive water pressure can cause seepage under barriers. Allows community to help themselves. A coordinated approach could include property audits, upgrade grants and insurance premium reviews.

RAPID CREEK FLOODPLAIN RISK MANAGEMENT OPTIONS ASSESSMENT

OPTIONS	PURPOSE	DESCRIPTION	ECONOMIC ASSESSMENT	VIABILITY	COMMENTS
VOLUNTARY HOUSE PURCHASE	To remove flood liable houses from the floodplain. Redevelopment of the site with compliant buildings is also an option.	Government purchase of worst-affected properties and: 1. Leave sites vacant, or 2. Re-develop with higher and/or flood resilient buildings	High cost. Benefit cost ratio 0.44 to 0.64 for 6 worst affected properties. High cost but some costs may be able to be recovered	Potential impact on property values. Social disruption. Likely to be unpopular.	Not recommended.
LANDUSE PLANNING & DEVELOPMENT CONTROL	To encourage new development that reduces flood risk to an acceptable level.	Possible actions include: 1. Review the current zoning and relevance of strategic plans for the area. Consideration of a new Master Plan that could include a mixture of medium density re-development including residential and commercial. Locate new residential development above flood levels/away from the floodplain, commercial/retail development at lower levels/closer to the floodplain and recreational developments lowest 2. Development of a Flood Risk Management Development Control Plan (DCP) to manage flood risk through re-zoning. DCP could cover future site access, filling, freeboard, floor levels, services, building structural soundness, building materials and fencing.	Planning effort by Agencies is relatively low cost. Re-development strategies could rely on private sector investment.	May be viable in the long term with private sector investment	Recommended: • Strategic Development Plan for the catchment • Review current planning controls for consistency with strategic plans • Consider a Flood Risk Management DCP
	To minimise impacts of future catchment development or re-development	Introduce guidelines on new development or redevelopment within the catchment area such as caps on percentage of directly-connected impervious area, on-site detention to maintain peak discharges at pre-existing levels or modifications to existing street drainage systems to include water sensitive urban design features.	Initial cost passed on to developer.	Viable	Consult Development Consent Authority and Council with a view to developing and implementing guidelines.

NOTES:

1. Benefit cost ratio is the ratio of benefits – calculated as a reduction in the value of flood damages – to initial cost. A benefit cost ratio of more than 1.0 means the proposed strategy is economic.

5.3. Recommendations

Recommendations include a mix of measures selected from the three types of modification options. Specific recommendations include:

- Rapid Creek is maintained in a manner that reduces the build-up of resistance to flows that can occur as a result of siltation of hydraulic structures and accumulation of rubbish and debris over time
- Programmes are put in place to raise community awareness, disseminating flood information through various media.
- A programme of flood audits is put in place. Individual houses/properties would be examined and no obligation advice given on the feasibility of increasing flood resilience. Residents would be encouraged to adopt personal flood action plans. This would also include policies and guidelines developed to inform floodplain residents how best to prepare for floods, including how to respond in a safe manner and so as to minimise the time and cost taken for recovery
- An improved flood warning system based on rainfall be implemented to give residents as much advance warning as possible
- Ongoing consultations are held with Defence and Darwin International Airport with a view to mitigating any adverse impacts of future catchment development in their areas and planning measures be used to ensure development or re-development in other parts of the catchment is not of a type and extent that would worsen flooding
- The existing flood control weir be maintained to ensure its ongoing ability to mitigate flood peaks from the upper catchment and to minimise its risk of failure during a major flood
- Options are examined with a view to re-developing the floodplain in the areas most at risk (the suburb of Millner) through planning and zoning changes. These would be structured so as to take effect over a longer period of time and be driven by market forces, but would result in a reduction in overall risk to life and property to Rapid Creek flooding
- Upgrade of the McMillans Road and Trower Road crossings of Rapid Creek. These crossings should be of a high standard as they carry major arterials linking the inner suburbs to the northern suburbs, including to the Darwin Public and Private Hospitals. When these structures meet the end of their life, flood mitigation options should be considered in proposals to replace them
- Undertake a consultation process
  A rigorous public consultation program would include:
  - A newsletter provided to local residents, stakeholders and those who previously had been involved in flood related matters as part of the Flood Study,
  - follow up telephone calls to key respondents,
  - floodplain management committee meetings,
  - workshop/site inspection and interviews with some key stakeholders,
  - public exhibition of material.

6. References

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Department of Lands Planning and the Environment, *Rapid Creek Planning Concepts and Land Use Objectives* 2000

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Sinclair Knight Merz for NT Government Department of Lands Planning and the Environment *Rapid Creek Flood Damages Assessment. Potential Damages.* August 2013 (d)

Sinclair Knight Merz for NT Government Department of Construction and Infrastructure *Rapid Creek Flood Study. Preliminary investigation into flood mitigation options*, August 2013 (e)

7. Glossary of Floodplain Management Terms

Action Plan	A sequence of steps that must be taken, or activities that must be performed well, for a strategy to succeed. IN the context of this report an action plan has three major elements: ▪ specific tasks ▪ time horizon ▪ allocation of responsibility
Annual Exceedance Probability- **AEP**	The probability flood reaching or exceeding a particular magnitude in any one year. (see also ARI)
Average Recurrence Interval - **ARI**	The result of statistical data which estimates the probability that a particular rainfall event (or intensity) will be equalled or exceeded at a particular place within a particular time period. It should be noted that this does <u>not</u> mean that a 1:100 year flood (Q100) will only occur once every 100 years. (see also AEP)
Australian Height Datum - **AHD**	A common national surface level datum approximately corresponding to mean sea level.
Bathymetry	Description of the shape of the ocean bed or other water body (underwater contours etc.). The measurement of depths of water.
Catchment	The land area above a specific location draining through a main stream, tributary streams or constructed drainage system, such that all outflow is directed to a single point.
Design floods	Design floods are standard floods which are investigated in flood studies and form the basis of hydrologic and hydraulic analysis and floodplain mapping. They are typically calculated from design storms using calibrated and/or verified hydrologic models. In the case of Rapid Creek the design floods calculated have included 10%AEP (Q10), 5%AEP (Q20), 2%AEP (Q50), 1% AEP (Q100), 0.5%AEP (Q200) and 0.2%AEP (Q500). The PMF has also been calculated.
Detention	Detention devices capture and temporarily store stormwater runoff during major (infrequent) storm events. Stormwater is then discharged to the drainage system at a controlled rate to mitigate potential downstream flooding impacts.
Development <u>Infill development</u> <u>New development</u>	 Refers to the development of vacant blocks of land that are generally surrounded by developed properties. Refers to development of a completely different nature to that associated with the former land use. E.g., the urban subdivision of an area previously used for rural purposes. New

	development involves re-zoning and typically requires major extensions of existing urban services, such as roads, water supply, sewerage and electric power.
Re-development	Refers to rebuilding in an area. E.g., as urban areas age, it may be necessary to demolish and reconstruct buildings.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
Emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
Flash flooding	Flooding which is sudden and unexpected and generally caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse. Also coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
Flood awareness	An appreciation of the likely effects of flooding and knowledge of relevant flood warning, response and evacuation procedures.
Flood control weir	A weir is a barrier across a river designed to alter its flow characteristics. A flood control weir is a barrier that aims to alter flooding characteristics downstream by storing water upstream of the weir and reducing the flood peak as a result of attenuation by storage.
Flood fringe	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood mitigation standard	ARI of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
Floodplain	Area of land which subject to inundation by floods up to and including the PMF event
Floodplain mapping	Floodplain mapping typically shows the calculated extent of inundation of a floodplain

	for a series of design floods. Floodplain mapping can also show additional information such as depths of flooding, floodway and flood fringe zones, flood hazard zones, floodwater surface contours and so on.
Floodplain risk management options	Measures that may be feasible for the management of a particular area of the floodplain.
Flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
Flood readiness	An ability to react within the effective warning time.
Flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. Degree of risk varies with circumstances across the full range of floods. Flood risk is divided into 3 types: existing, future and continuing. ▪ Existing flood risk**:** the risk a community is exposed to as a result of its location. ▪ Future flood risk**:** the risk a community may be exposed to as a result of new development. ▪ Residual flood risk**:** the risk a community is exposed to after floodplain risk management measures have been implemented. E.g. for a town protected by levees, the residual flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
Flood storage areas	Those parts of the floodplain that are important for temporary storage of floodwaters during the passage of a flood. The loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. It is necessary to investigate a range of flood sizes before defining flood storage areas
Floodway	The area of the floodplain where a significant discharge of water occurs during floods and often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow or a significant increase in flood levels.
Freeboard	Provides reasonable certainty that the risk exposure is actually provided. It is a factor of safety typically used in relation to the setting of

	floor levels, levee crest levels, etc.
Habitable room	A living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom, bathroom, enclosed laundry or workroom
Hazard	Source of potential harm or situation with potential to cause loss. In relation to flooding, has potential to cause damage to the community. Hazard is generally defined as Low, Medium and High.
Hydraulics	Term given to the study of water flow in waterways; in particular, flow parameters such as water level and velocity.
Hydrology	Term given to the study of the rainfall and runoff process; in particular, the elevation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
Levee	A levee is a wall that separates floodwaters from an area from which floodwaters are to be excluded. Levees can be earth structures but flood walls can be constructed to serve as levees in areas where there is insufficient space to have earth levees.
Local drainage	Pits and underground pipe systems, mostly under the control of Council, which collect runoff from the streets and carry it to locations where it discharges to a stream, river, estuary lake or dam.
Mainstream flooding	Inundation of normally dry land occurring when water overflows natural or artificial banks of a stream, river, estuary, lake or dam.
i. Minor, moderate and major flooding <u>Minor flooding</u> <u>Moderate flooding</u> <u>Major flooding</u>	 causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
Mitigation measures	Measures that modify the flood, the property or the response to flooding. Examples may include voluntary purchase, house raising, flood

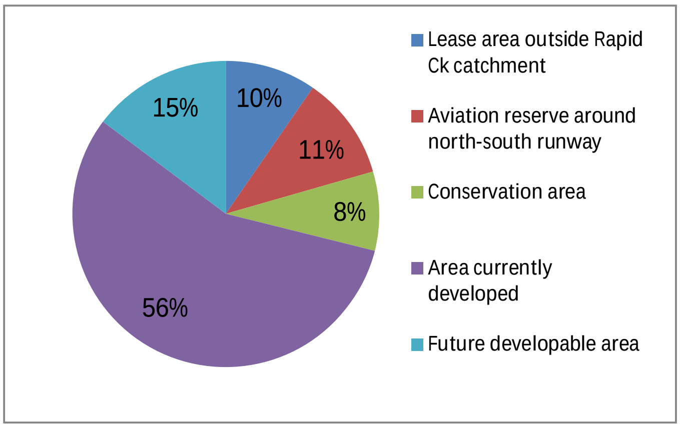
	warning system, evacuation plans, retarding basins, etc.
Peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood - **PMF**	The largest flood that could conceivably occur at a particular location, usually estimated from PMP coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. However, the PMF defines the extent of the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Rainfall = Probable Maximum Precipitation - **PMP**	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends.
Risk	Chance of something happening that will have an impact and is measured in terms of consequences and likelihood. In the context of this glossary, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall which actually ends up as stream flow.
Storm Surge	Storm surge consists of two components: ▪ the increase in water level caused by the reduction in barometric pressure (barometric setup); and ▪ the increase in water level caused by the action of wind blowing over the sea surface (wind setup).
Stormwater	All surface water runoff from rainfall, predominantly in urban catchments.

Appendix A Future Development

1. Airport Development

NT Airports leases the Darwin Airport land from the Commonwealth and therefore the Airport lies outside of the NT Planning Scheme. However, NT Airports is required to submit a Master Plan every 5 years to seek approval from the relevant Commonwealth Government Minister for any proposed development works. The last such plan approved was in 2010 and is shown in Figure 30. An additional hatching has been overlaid to show the predominant area yet to be developed. The Rapid Creek catchment area is overlaid on the NT Airports Master Plan in Figure 31.

Figure 29 shows that only 15% of the lease area is potential future developable area.



▪ **Figure 29. Breakdown of airport lease area**

This future developable area represents just 2.4% of the Rapid Creek catchment above Millner[3] and its development alone will not have a significant impact on Rapid Creek flows.

2. Berrimah North development

It is understood that there are proposals to develop land around Amy Johnson Drive.

It is also understood that there is a possibility of development within the eastern fringe of the DIA/Defence land.

However, development of these areas is not likely to have a huge impact on flooding in the northern suburbs beyond McMillans Road, because these areas are also a small percentage of the total Rapid Creek Catchment. In addition, attenuation of peaks from these areas would occur in both the Marrara Swamp and the storage behind the existing Flood Control Weir.

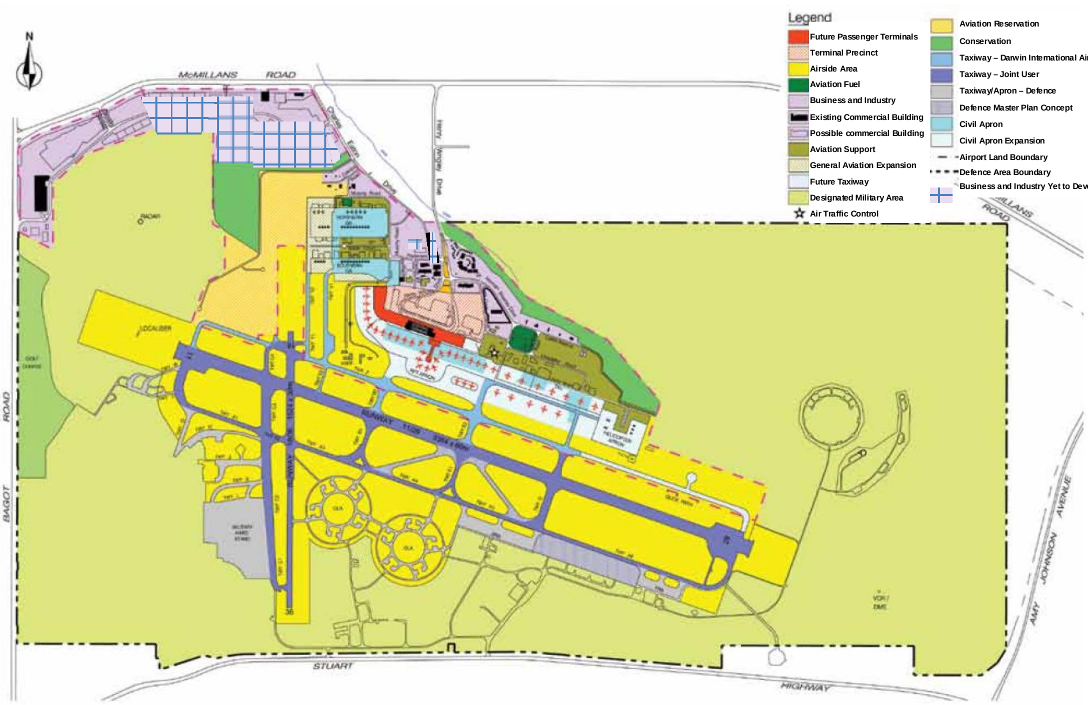
3. Infill development

If a policy of infill development and/or densification of existing built up suburbs is pursued, there could also be impacts on the Rapid Creek catchment. While NT Government may be undertaking some work to investigate a strategy to develop these areas, there are no current outcomes to inform this study.

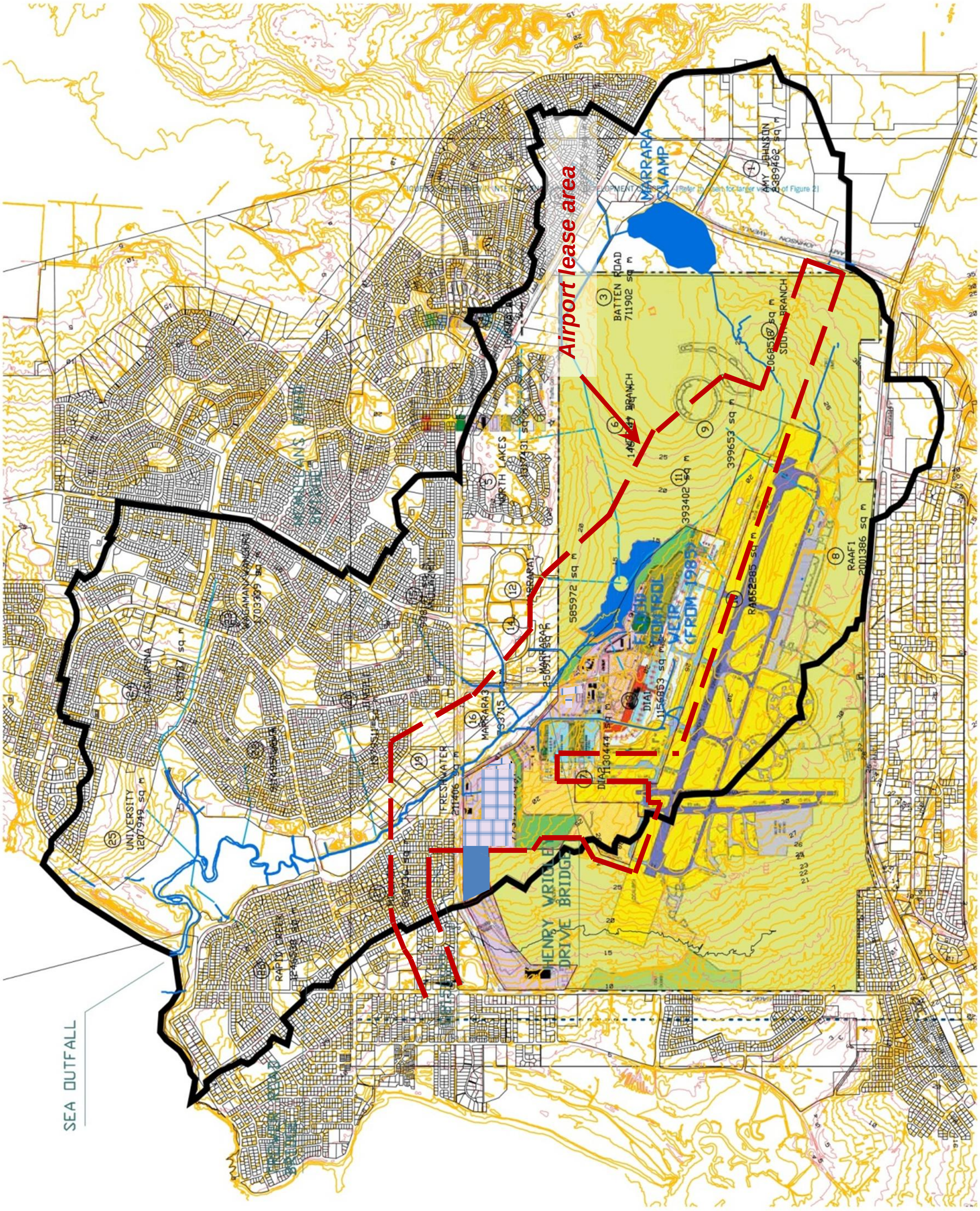
[3] The catchment area to the gauging station G8150127 is taken to be the area to the most upstream part of Millner which is affected by flooding.

4. Overall impact

Individual developments in these areas cannot be shown to have a significant impact on flooding in the northern suburbs. However, if all of these developments were to happen then there could be some impact. Further investigation is recommended to determine measures to manage any impacts of future developments in the catchment area, particularly for areas downstream of the Flood Control Weir.

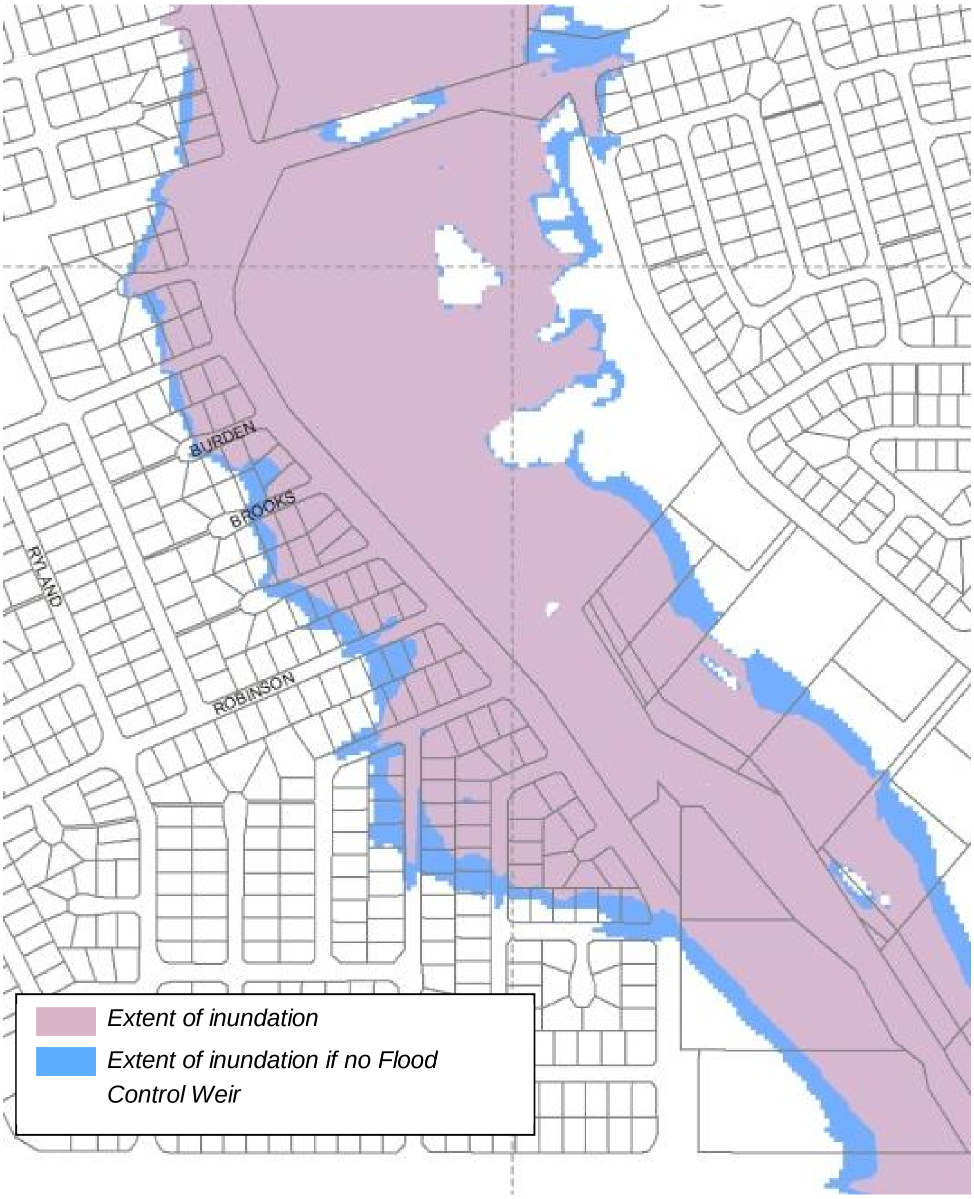


■ **Figure 30. NT Airports Master Plan for development**

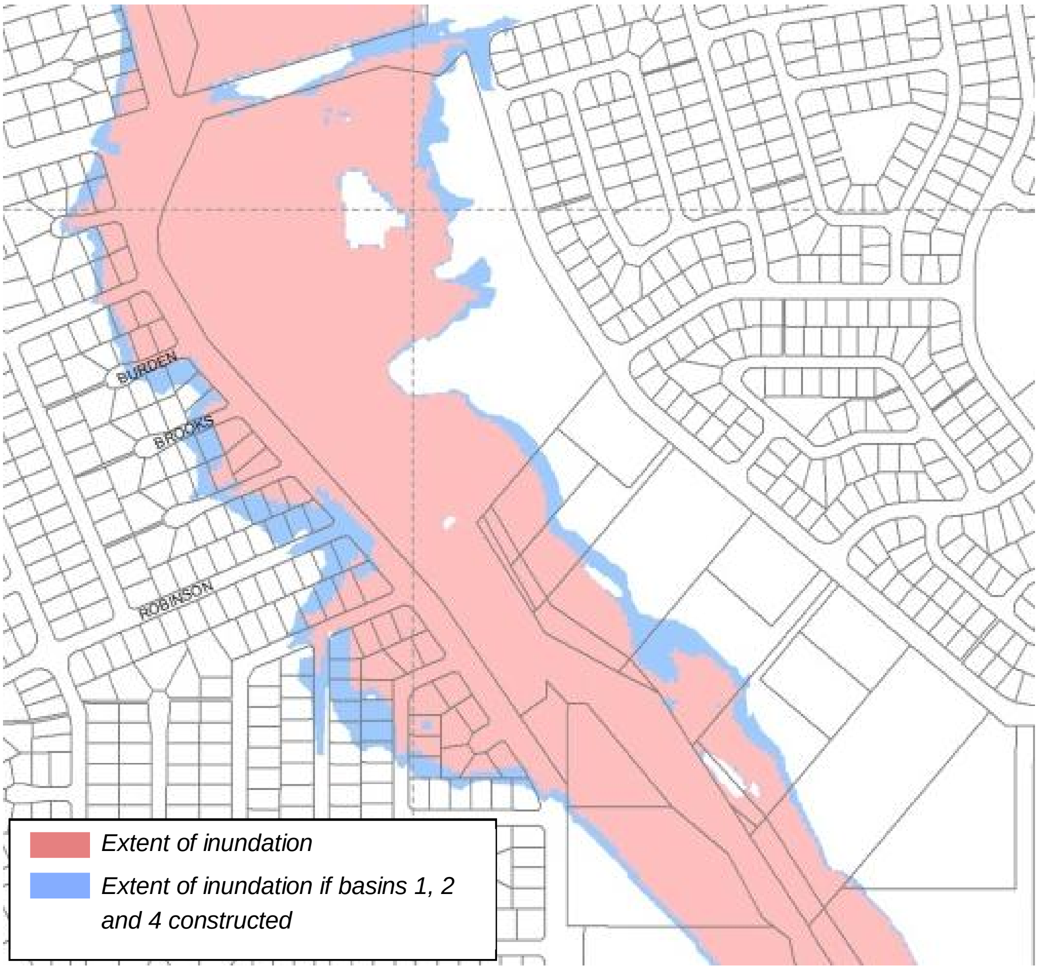


■ **Figure 31. Airport development in context of Rapid Creek catchment**

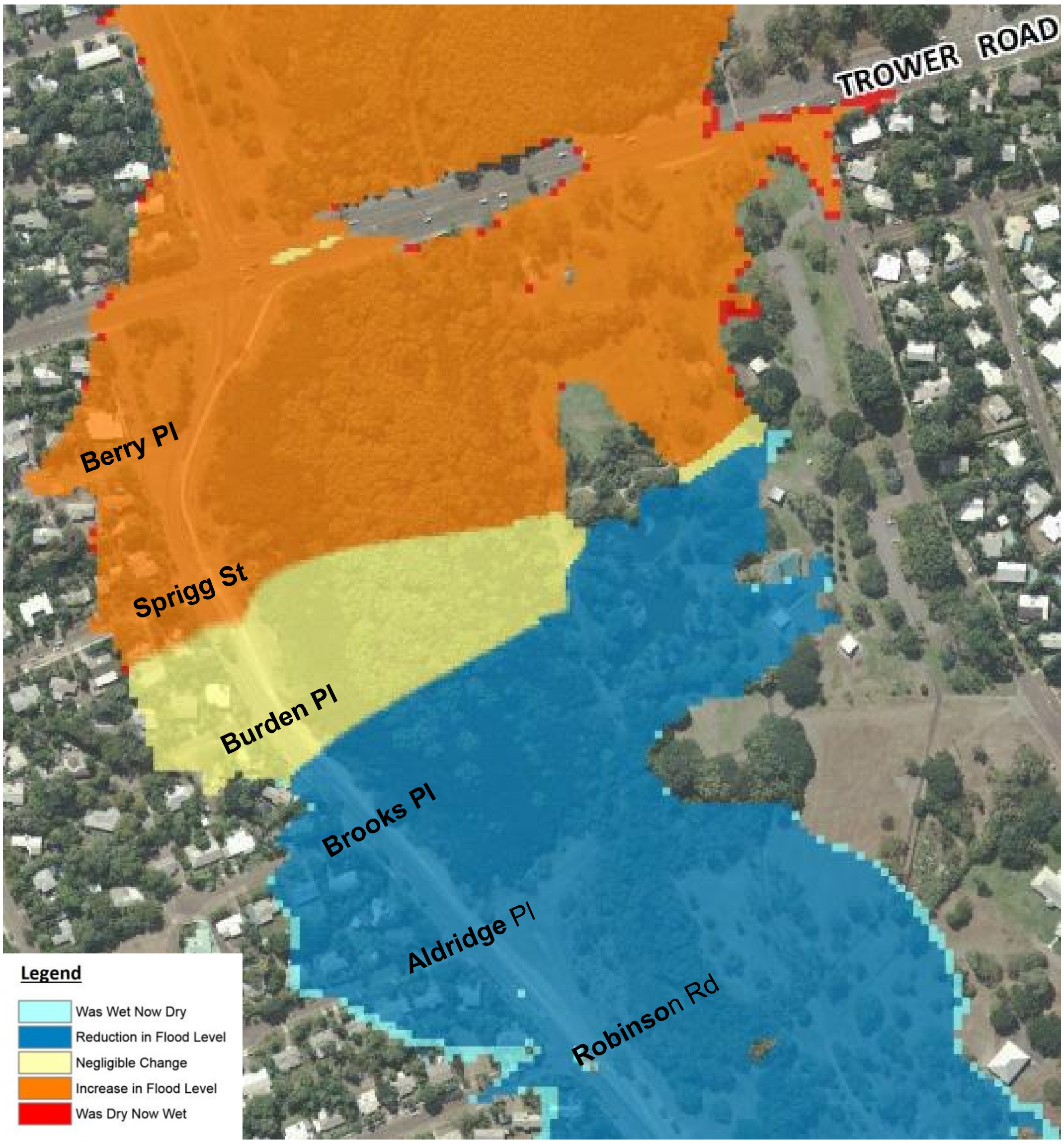
Appendix B Changes in flood extents for flood modification options



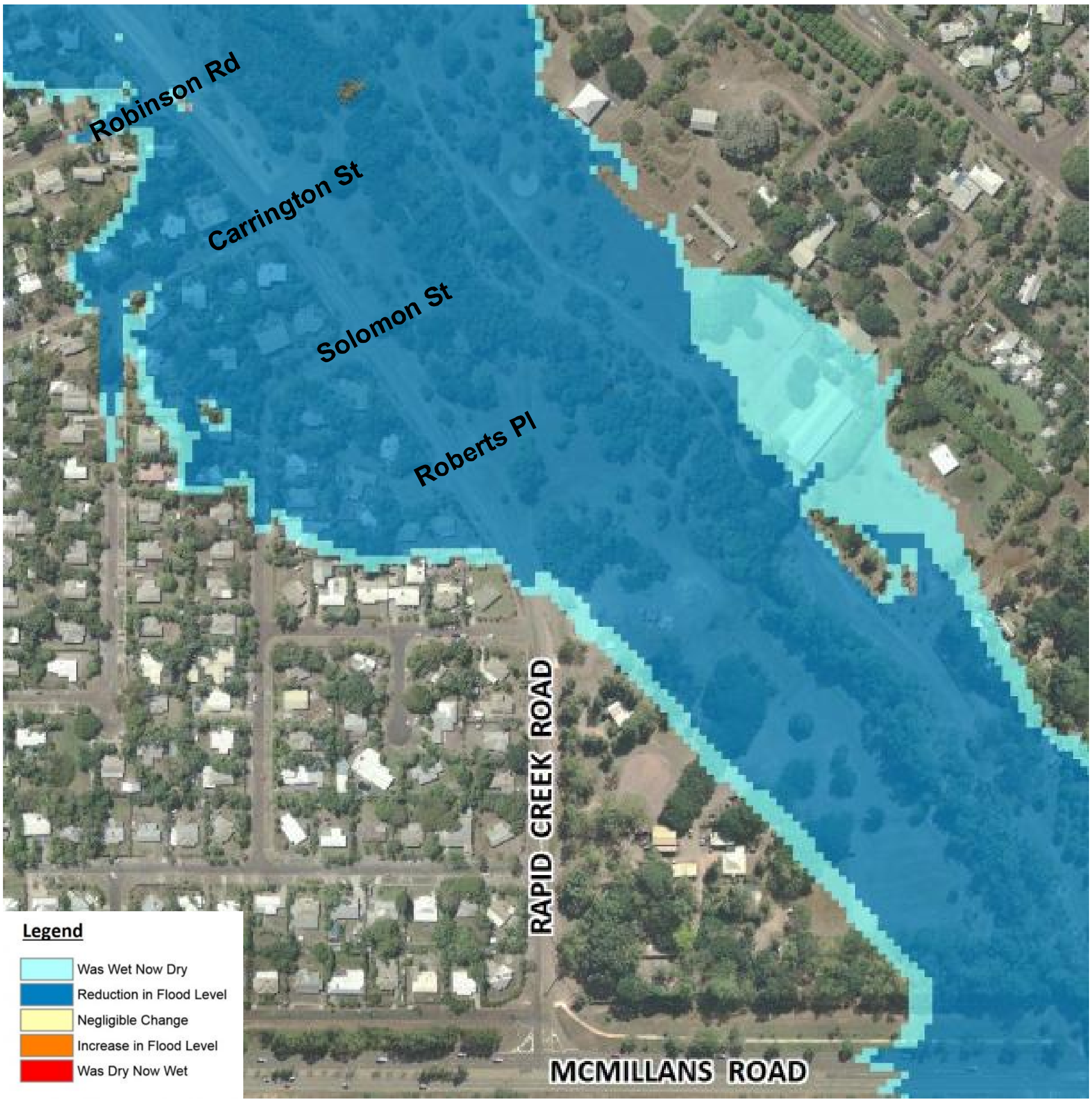
- **Figure 32. Calculated increase in 1% AEP flooding if there were no flood control weir**



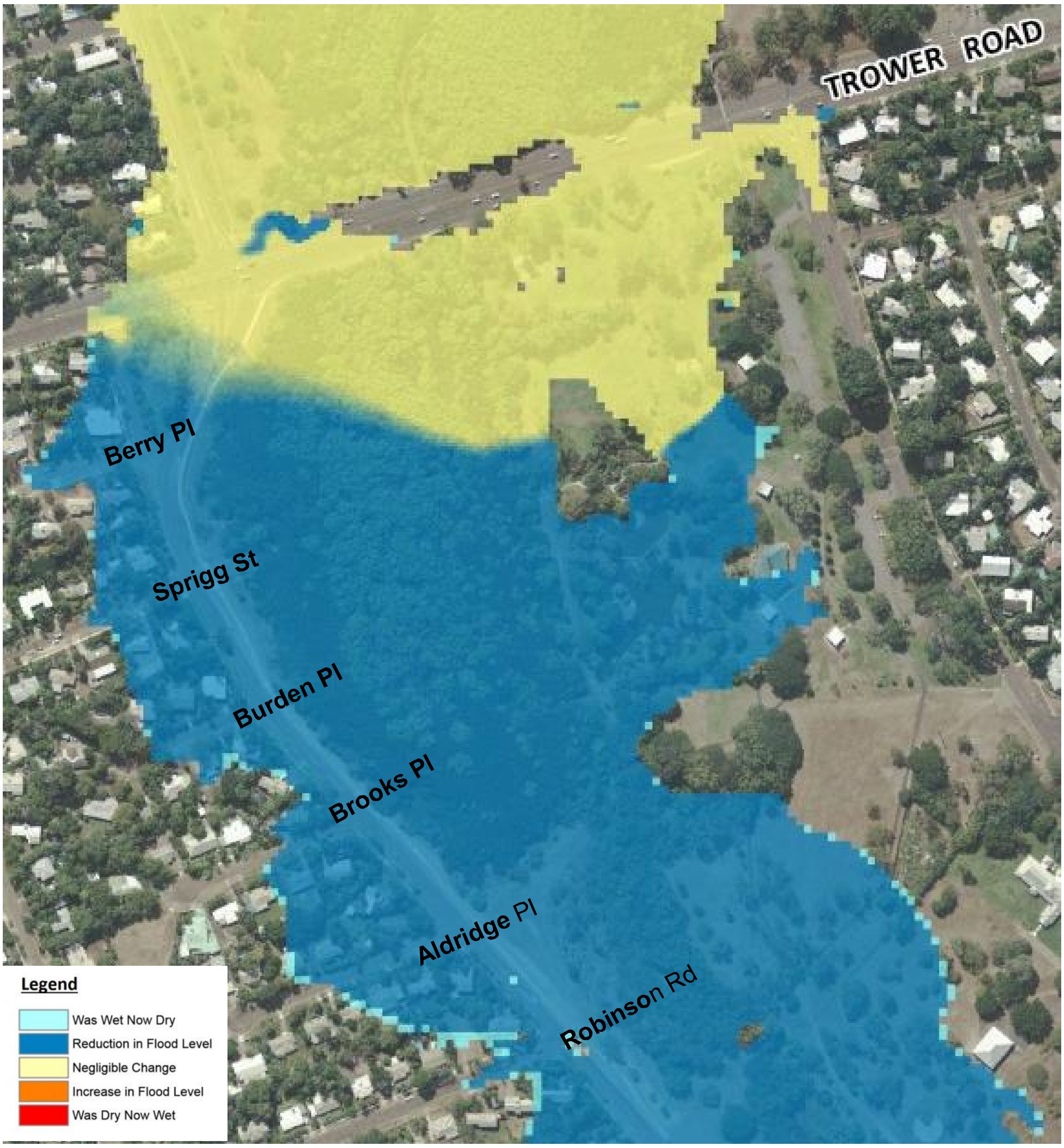
- **Figure 33. Impact of retention basins**



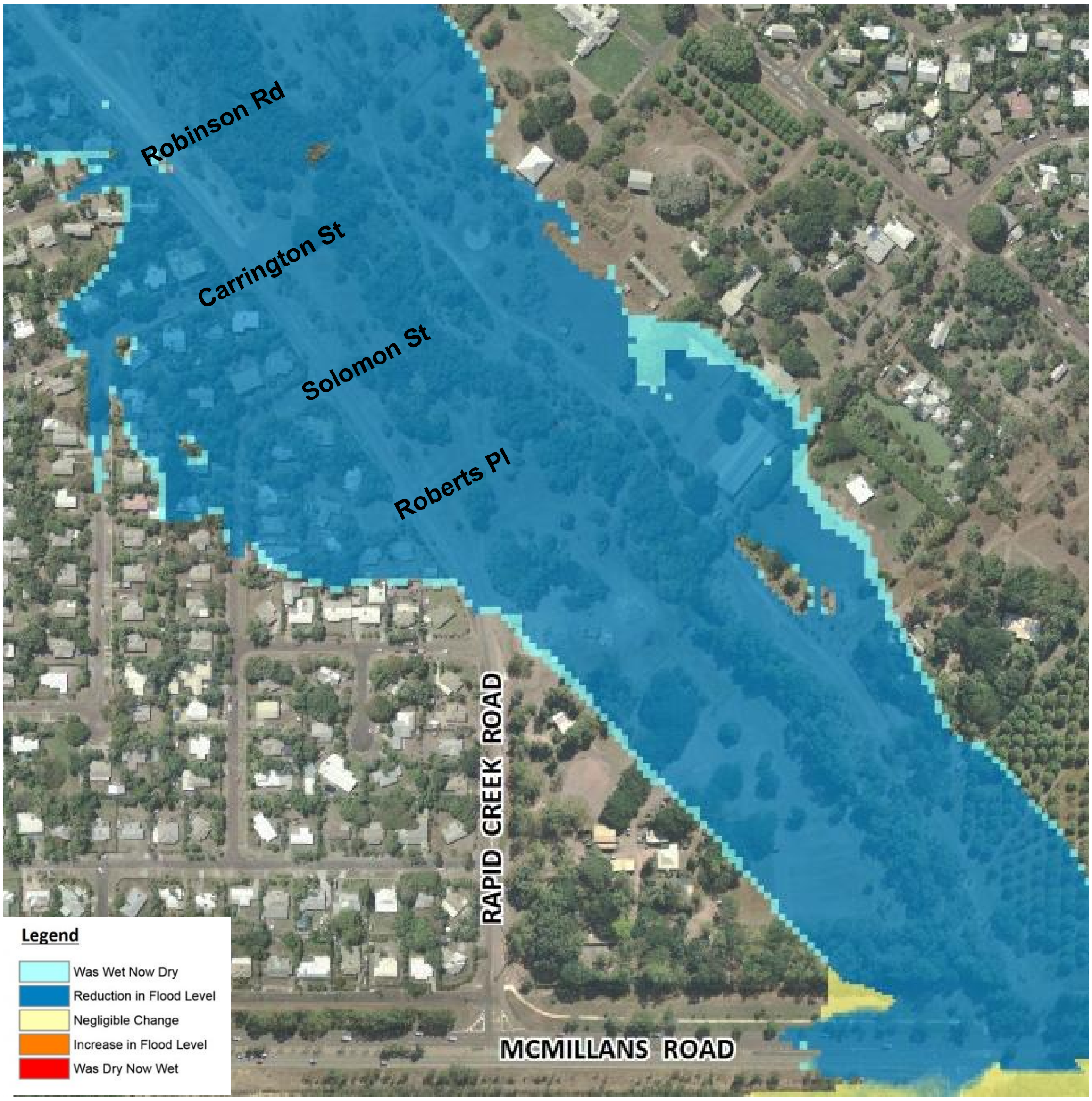
- **Figure 34. Impact of channel clearing – 1% AEP - lower Millner**



- **Figure 35. Impact of channel clearing – 1% AEP - upper Millner**



- **Figure 36. Impact of channel enlargement - 1% AEP – lower Millner**



- **Figure 37. Impact of channel enlargement - 1% AEP – upper Millner**

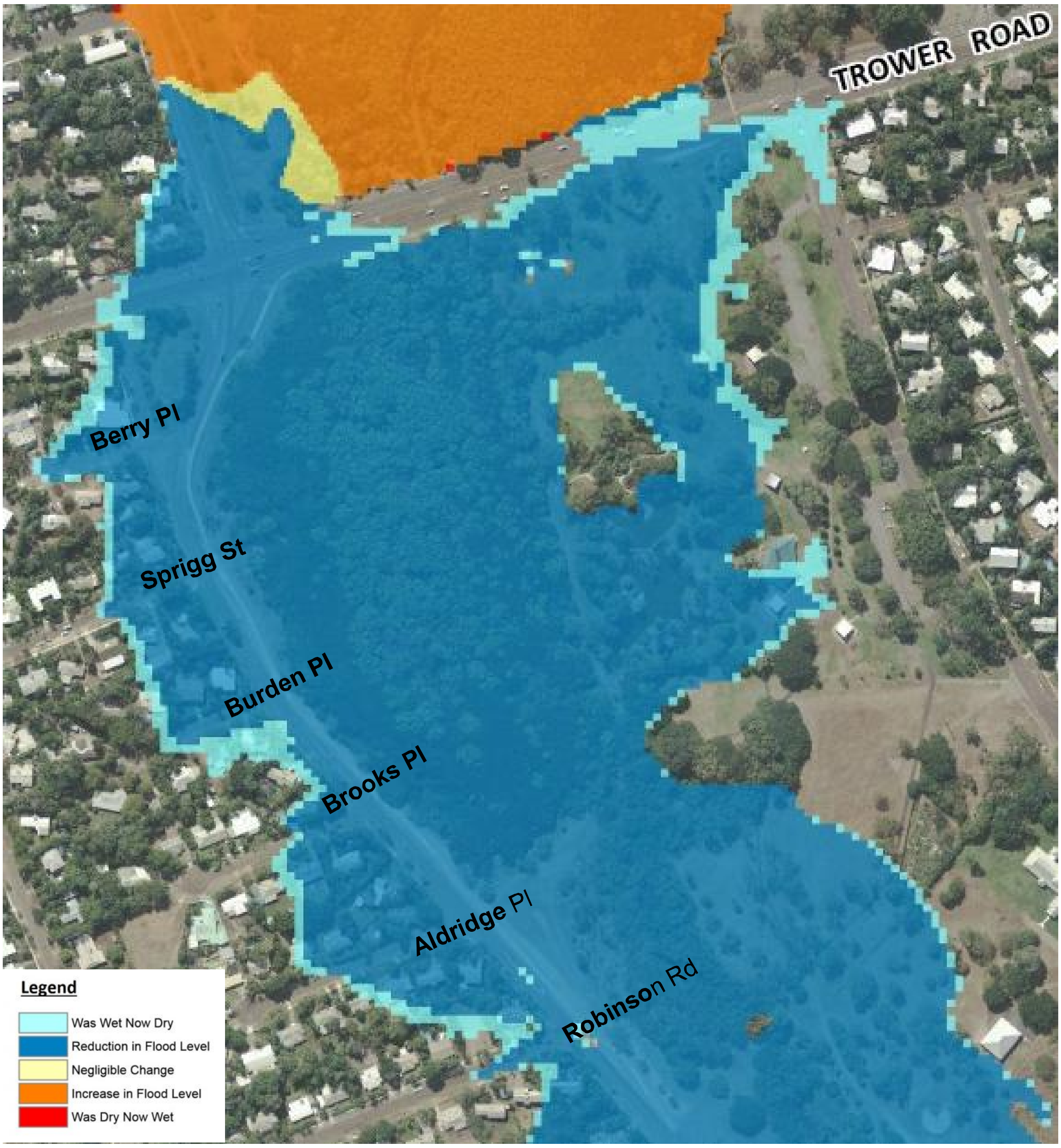
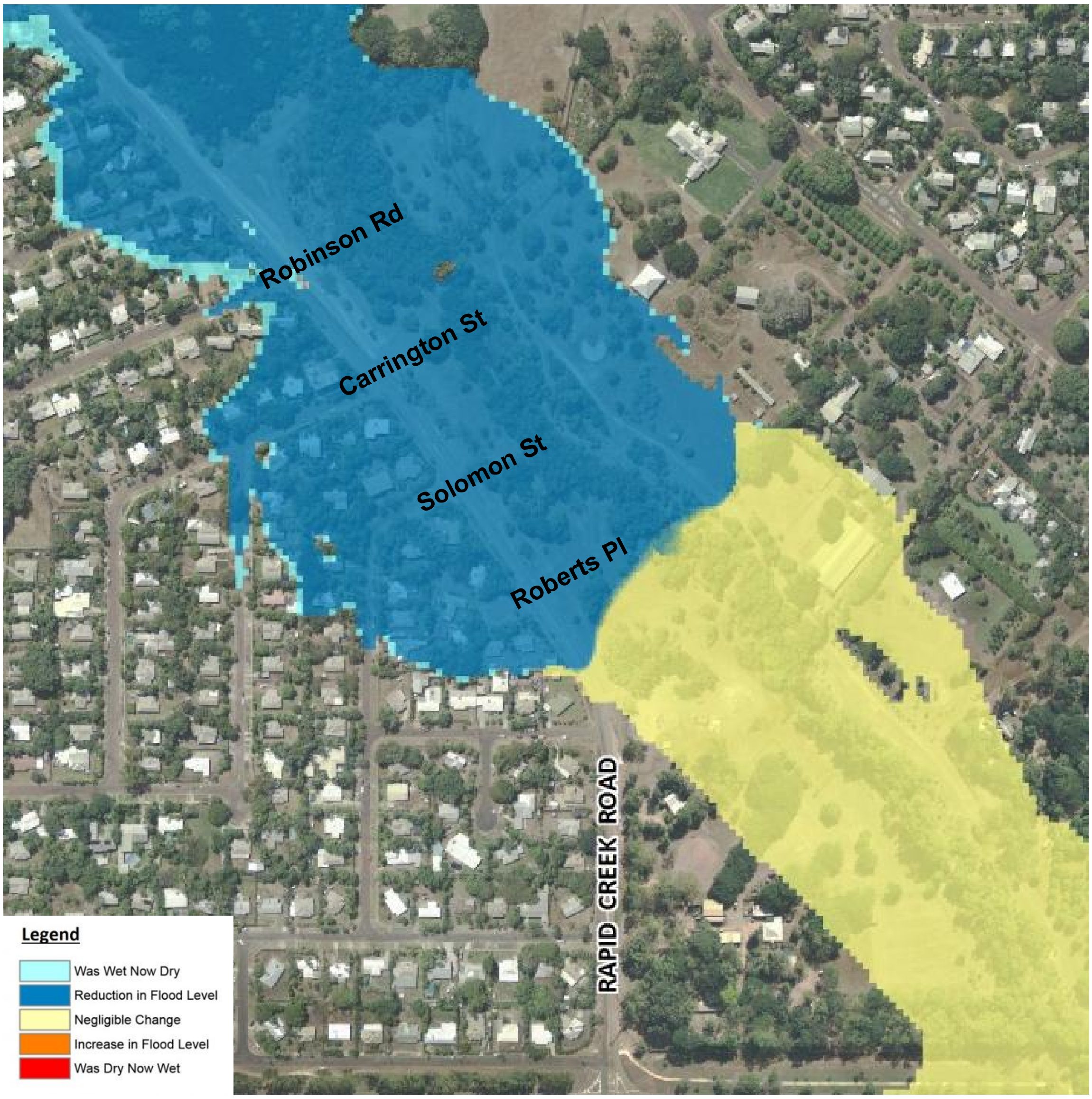
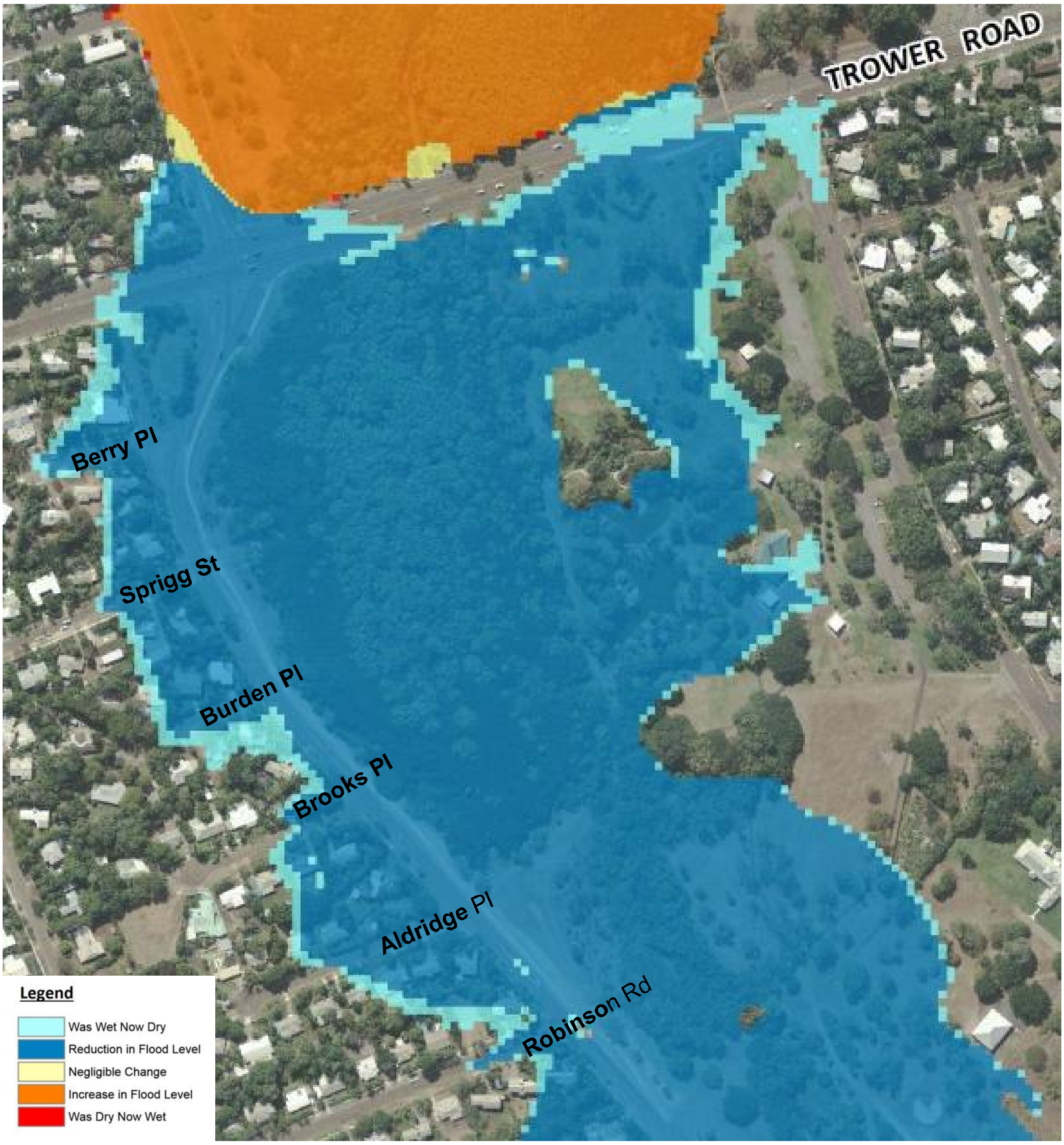


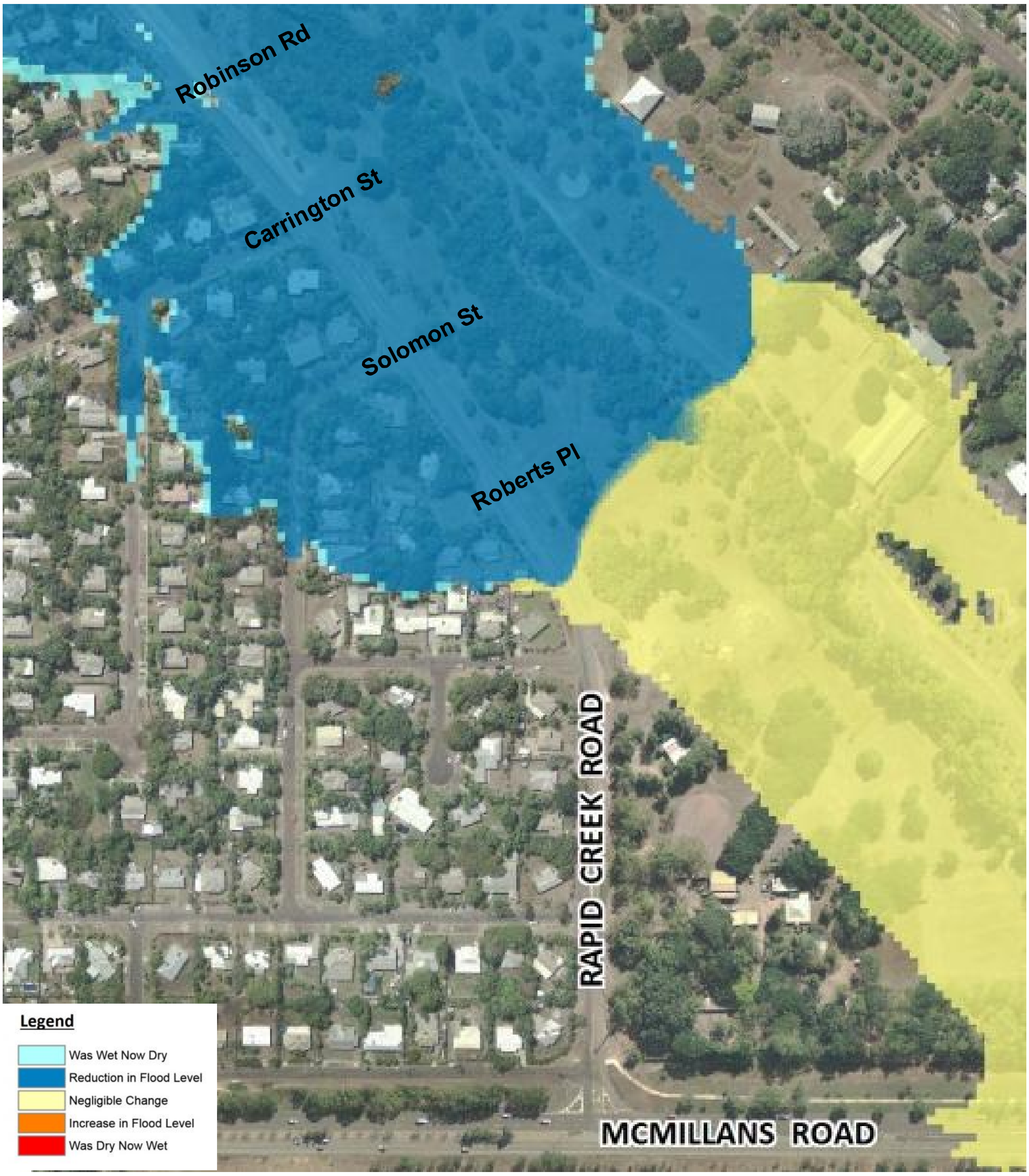
Figure 38. Impact of enlarging Trower Road Bridge opening – 1% AEP lower Millner



- **Figure 39. Impact of enlarging Trower Road Bridge opening – 1% AEP upper Millner**



- **Figure 40. Impact of flood relief culverts in Trower Road 1% AEP – lower Millner**

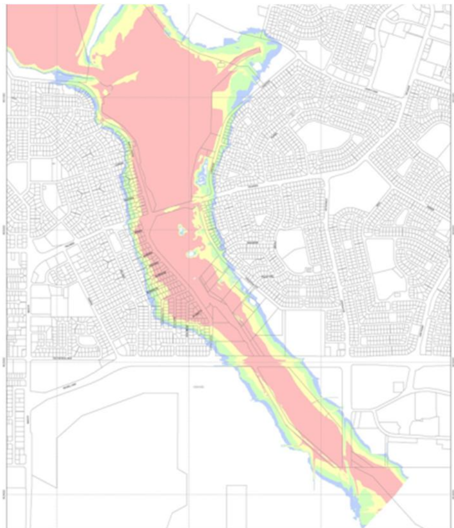


▪ **Figure 41. Impact of flood relief culverts in Trower Road 1% AEP – upper Millner**

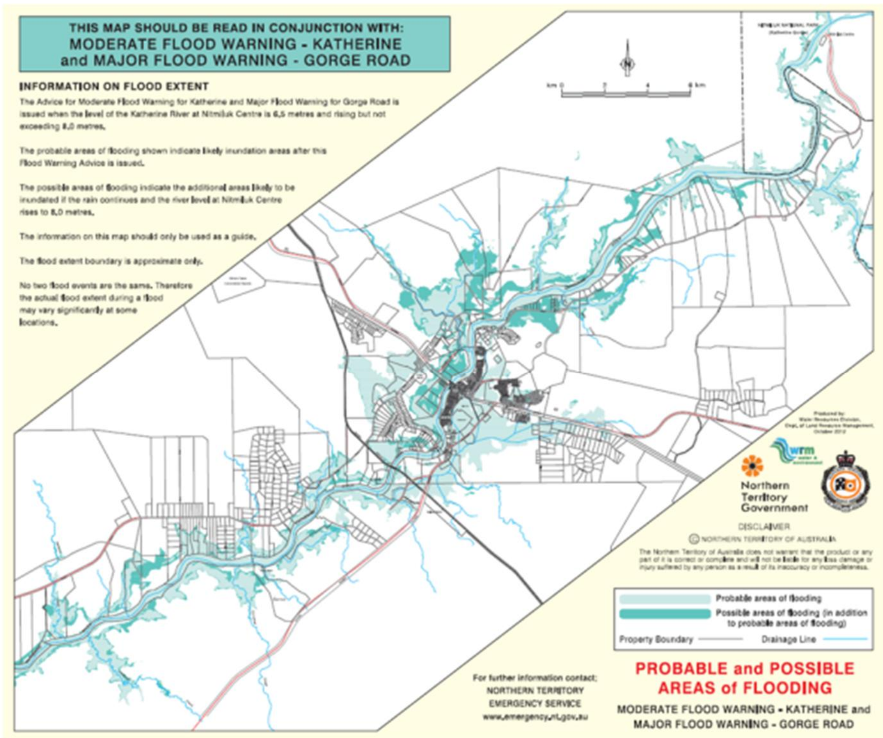
Figure 42. Impact of Rapid Creek Road levee (Option 1)

Appendix C Flood awareness options

- **Figure 43. Examples of Flood Awareness Options – Flood plain mapping**



a. Typical Rapid Creek Floodplain mapping from SKM, 2013 b



b. Example of fully annotated floodplain mapping on NT Government web-site

Southern Downs Regional Council
Flood Informed
Property Report

DISCLAIMER

The predicted peak flood levels presented within this report are derived from flood modelling results based upon Council's best available information at the time of modelling. These predicted flood levels for a particular property are dependent upon the assumptions and data used within the flood modelling. Floor levels are based on a survey conducted in 2011. Ground levels are accurate to plus or minus 0.15m.

The predicted peak flood levels presented within this report are based on flooding of the Condamine River. Flooding may result from other sources including local waterways, overland flow or flash flooding. Council has not provided information regarding overland flow or other flooding events.

The photo image presented within this Report is intended to visually represent flood levels of different flood event. The lines indicating peak flood height against house features are calculated based on assumptions of standard heights of reference objects. The reference object used in this case is a door and the assumed height is 2.04m. Any discrepancy between actual and assumed heights of the door will affect the accuracy of the flood heights depicted.

The Property Report is a guide only and should not be used or relied upon for development purposes. If you are planning to renovate or build, Council recommends you engage a Registered Professional Engineer of Queensland to undertake a thorough assessment of all flood risks specific to the property.

Council makes no warranty or representation regarding the accuracy or completeness of a Flood Informed Property Report. Council disclaims any responsibility or liability in relation to the use or reliance by any person on a Flood Informed Property Report.

Southern Downs Regional Council
Flood Informed
Property Report

Southern Downs Regional Council

PROPERTY DETAILS

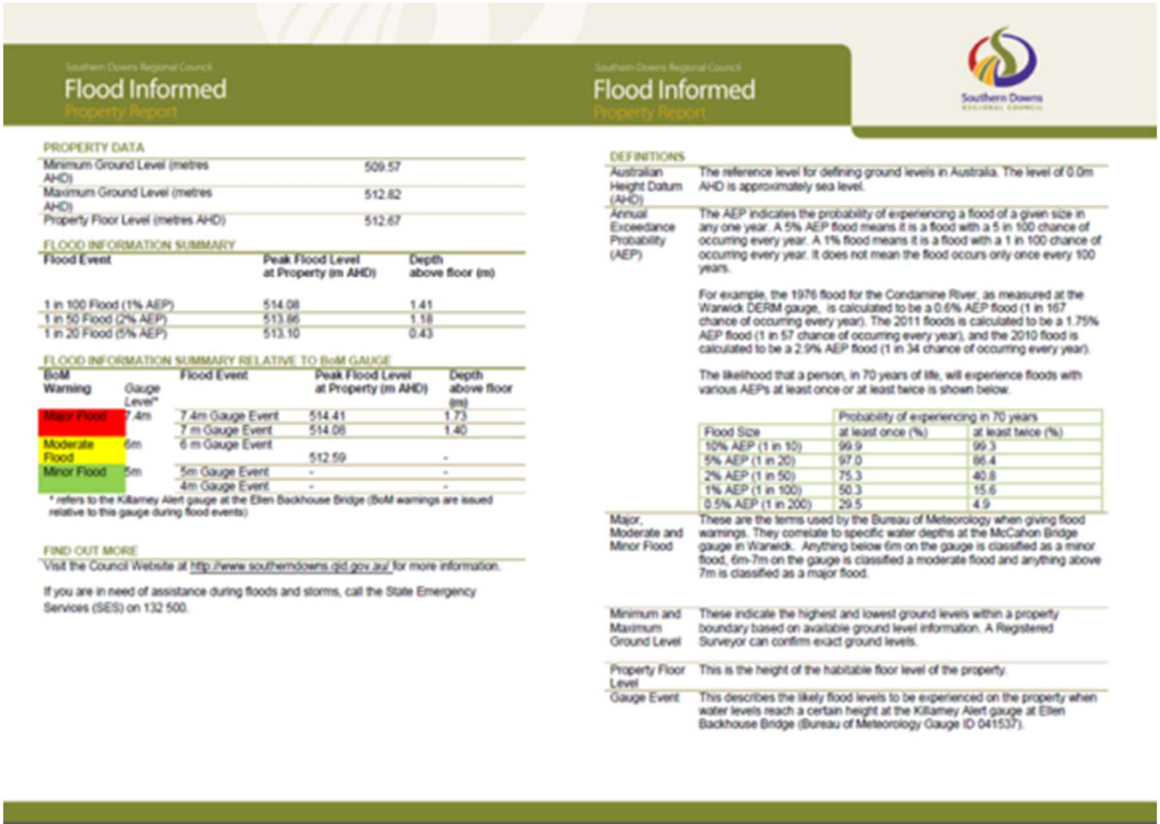
Address: 42 Willow Street, KILLARNEY QLD 4373

Lot Details: 1RP56809

PHOTO IMAGE OF PROPERTY FLOODING

The floor level of this building corresponds to a gauge level of between 6.00m and 6.20m. This means that when waters reach between 6.00m and 6.20m at the Ellen Backhouse Bridge gauge in Killarney, flood waters on your property will likely reach the floorboards of this building.

c. Example flood information Southern Downs Regional Council (QLS) web-site



Southern Downs Regional Council
Flood Informed
Property Report

PROPERTY DATA

Minimum Ground Level (metres AHD)	509.57
Maximum Ground Level (metres AHD)	512.82
Property Floor Level (metres AHD)	512.67

FLOOD INFORMATION SUMMARY

Flood Event	Peak Flood Level at Property (m AHD)	Depth above floor (m)
1 in 100 Flood (1% AEP)	514.08	1.41
1 in 50 Flood (2% AEP)	513.86	1.18
1 in 20 Flood (5% AEP)	513.10	0.43

FLOOD INFORMATION SUMMARY RELATIVE TO BoM GAUGE

BoM Warning	Gauge Level*	Flood Event	Peak Flood Level at Property (m AHD)	Depth above floor (m)
Major Flood	7.4m	7.4m Gauge Event	514.41	1.73
		7 m Gauge Event	514.08	1.40
Moderate Flood	6m	6 m Gauge Event	512.59	-
Minor Flood	5m	5m Gauge Event	-	-
		4m Gauge Event	-	-

* refers to the Killarney Alert gauge at the Ellen Backhouse Bridge (BoM warnings are issued relative to this gauge during flood events)

FIND OUT MORE

Visit the Council Website at http://www.southerndowns.qld.gov.au/ for more information.

If you are in need of assistance during floods and storms, call the State Emergency Services (SES) on 132 500.

Southern Downs Regional Council
Flood Informed
Property Report

Southern Downs Regional Council

DEFINITIONS

Australian Height Datum (AHD)	The reference level for defining ground levels in Australia. The level of 0.0m AHD is approximately sea level.
Annual Exceedance Probability (AEP)	The AEP indicates the probability of experiencing a flood of a given size in any one year. A 5% AEP flood means it is a flood with a 5 in 100 chance of occurring every year. A 1% flood means it is a flood with a 1 in 100 chance of occurring every year. It does not mean the flood occurs only once every 100 years. For example, the 1976 flood for the Condamine River, as measured at the Warwick DERM gauge, is calculated to be a 0.6% AEP flood (1 in 167 chance of occurring every year). The 2011 floods is calculated to be a 1.75% AEP flood (1 in 57 chance of occurring every year), and the 2010 flood is calculated to be a 2.9% AEP flood (1 in 34 chance of occurring every year). The likelihood that a person, in 70 years of life, will experience floods with various AEPs at least once or at least twice is shown below.

	Probability of experiencing in 70 years	
Flood Size	at least once (%)	at least twice (%)
10% AEP (1 in 10)	99.9	99.3
5% AEP (1 in 20)	97.0	86.4
2% AEP (1 in 50)	75.3	40.8
1% AEP (1 in 100)	50.3	15.6
0.5% AEP (1 in 200)	29.5	4.9

Major, Moderate and Minor Flood	These are the terms used by the Bureau of Meteorology when giving flood warnings. They correlate to specific water depths at the McCahon Bridge gauge in Warwick. Anything below 6m on the gauge is classified as a minor flood, 6m-7m on the gauge is classified a moderate flood and anything above 7m is classified as a major flood.
Minimum and Maximum Ground Level	These indicate the highest and lowest ground levels within a property boundary based on available ground level information. A Registered Surveyor can confirm exact ground levels.
Property Floor Level	This is the height of the habitable floor level of the property.
Gauge Event	This describes the likely flood levels to be experienced on the property when water levels reach a certain height at the Killarney Alert gauge at Ellen Backhouse Bridge (Bureau of Meteorology Gauge ID 041537).

d. Example flood information Southern Downs Regional Council (QLD) web-site

Flood Check Property report

Property

Reference: Lot 18 Plan RP161038

[redacted]
BURPENGARY EAST QLD 4505

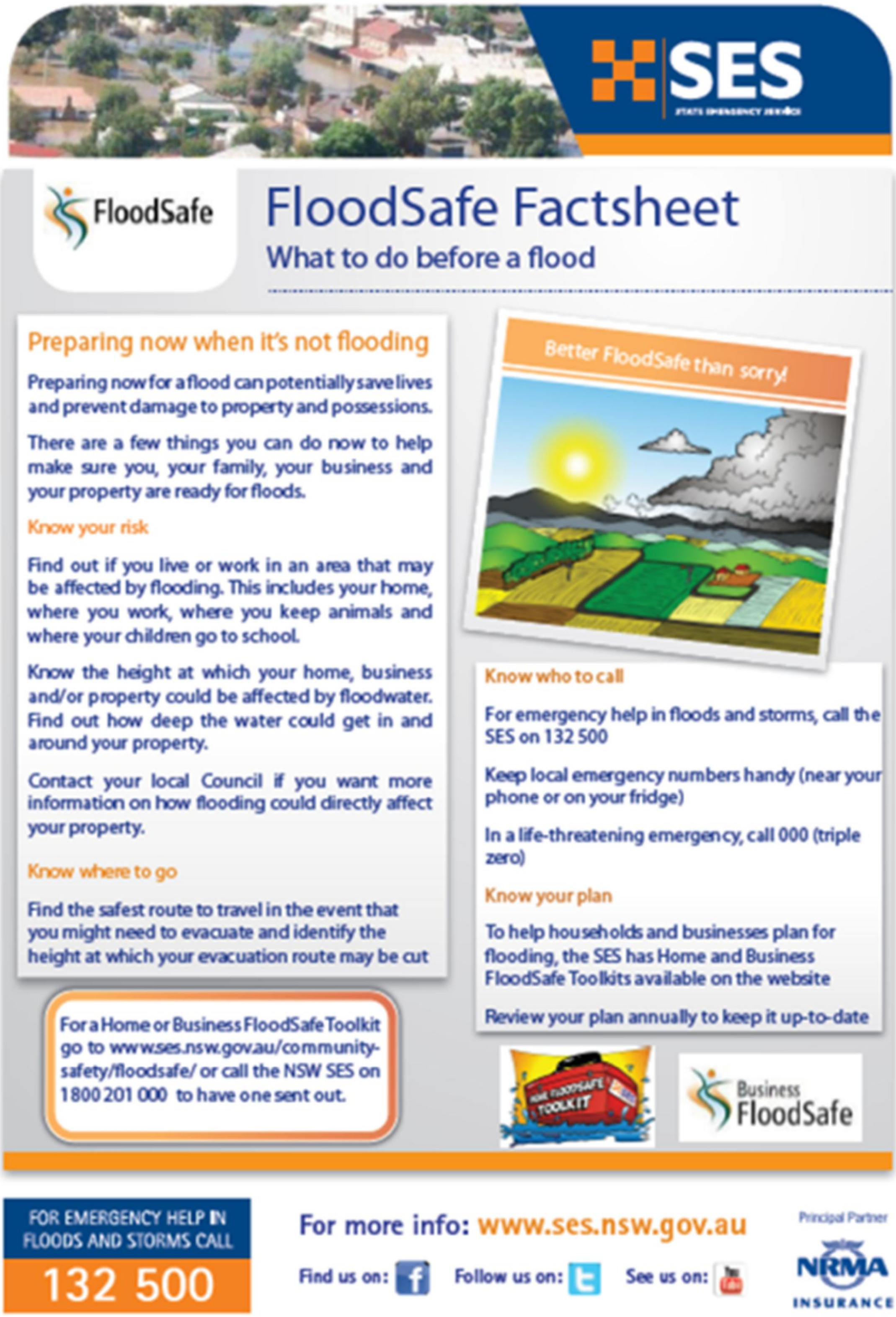
Flood Summary

River and Creek *River and creek flooding occurs when water levels rise and escape the main channel following long durations of heavy rain.*	**AFFECTED**	**High likelihood** Parts of this property are within the calculated extent of a flood that has a 5% annual chance of occurring. There is a high likelihood of a flood of this size occurring in a normal lifetime.
Overland Flow *Overland Flow describes the gullies and depressions where runoff is expected to flow following intense rain.*	Not Affected	This property is outside Council's known overland flow path mapping extents. However small unmapped overland flow paths exist that may affect any property after intense rains.
Tidal Inundation *Tidal inundation occurs on coastal land where sea levels fluctuate based on the position of the sun and the moon.*	**AFFECTED**	**Negligible likelihood** Parts of this property are outside the expected range of normal seasonal tides but may be affected by storm tide.
Storm Tide *Storm Tide inundation occurs on coastal land where extreme weather conditions raise the sea levels to above the normal tide levels.*	**AFFECTED**	**Medium likelihood** Parts of this property are within the calculated extent of an uncommon flood that has a 1% annual chance of occurring. There is a medium likelihood of a flood of this size occurring in a normal lifetime.
Planning Information *When planning new works there may be additional requirements to consider.*	**AVAILABLE**	**Flood planning information is available** Refer to page 4 of the Technical Summary.

www.moretonbay.qld.gov.au | Phone 3205 0555

Moreton Bay Regional Council

e. Example individual property flood audit checklist (Moreton Bay Regional Council)



SES
STATE EMERGENCY SERVICE

FloodSafe

FloodSafe Factsheet

What to do before a flood

Preparing now when it's not flooding

Preparing now for a flood can potentially save lives and prevent damage to property and possessions.

There are a few things you can do now to help make sure you, your family, your business and your property are ready for floods.

Know your risk

Find out if you live or work in an area that may be affected by flooding. This includes your home, where you work, where you keep animals and where your children go to school.

Know the height at which your home, business and/or property could be affected by floodwater. Find out how deep the water could get in and around your property.

Contact your local Council if you want more information on how flooding could directly affect your property.

Know where to go

Find the safest route to travel in the event that you might need to evacuate and identify the height at which your evacuation route may be cut

For a Home or Business FloodSafe Toolkit go to www.ses.nsw.gov.au/community-safety/floodsafe/ or call the NSW SES on 1800 201 000 to have one sent out.

Better FloodSafe than sorry!

Know who to call

For emergency help in floods and storms, call the SES on 132 500

Keep local emergency numbers handy (near your phone or on your fridge)

In a life-threatening emergency, call 000 (triple zero)

Know your plan

To help households and businesses plan for flooding, the SES has Home and Business FloodSafe Toolkits available on the website

Review your plan annually to keep it up-to-date

Home FloodSafe Toolkit

Business FloodSafe

FOR EMERGENCY HELP IN FLOODS AND STORMS CALL
132 500

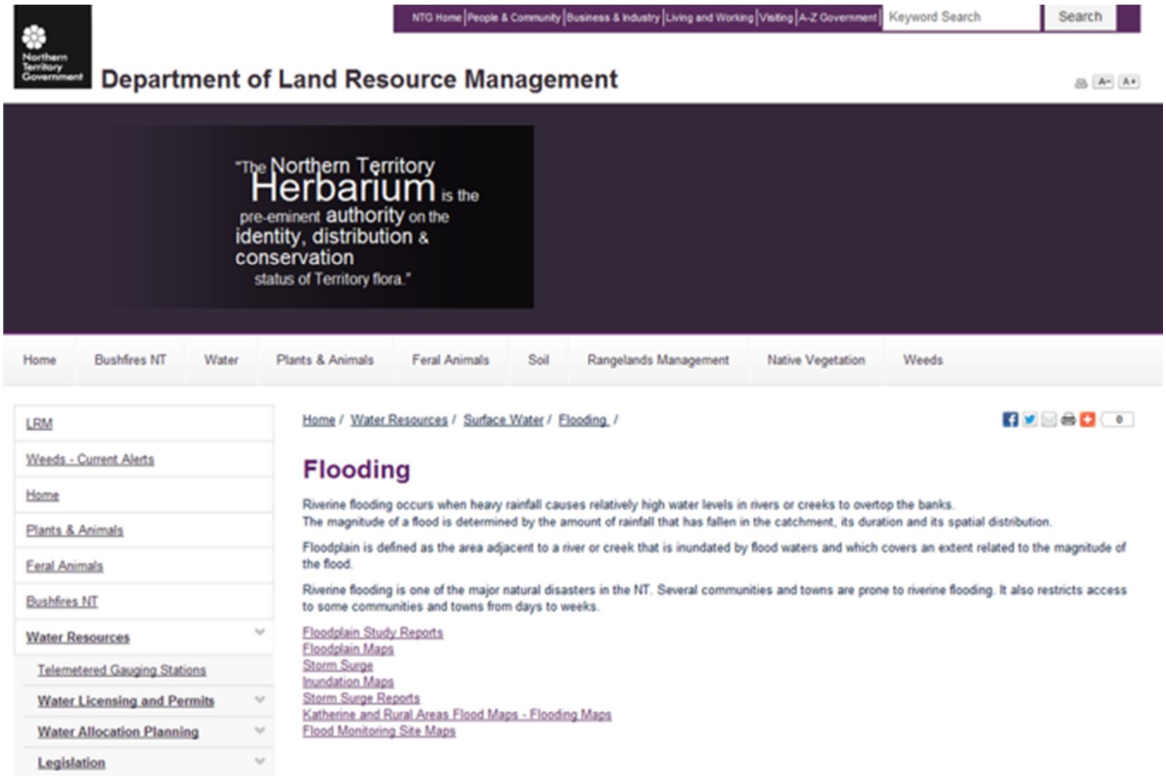
For more info: www.ses.nsw.gov.au

Find us on: Follow us on: See us on:

Principal Partner
NRMA INSURANCE

f. Example flood preparedness fact sheet (NSW State Emergency Services)

g. Example flood information web-site (Brisbane City Council)



h. Existing NT Department of Land Resource Management website reference to flooding

Appendix D Floodwarning case study

Case study Sydney Northern Beaches (Pittwater, Warringah and manly Council) [Reference: Millner, D *Flash Flood Warning System for Sydney's Northern Beaches (Undated)*]

The aim of the program is to develop a basic flash flood warning system for the community, by strategically installing rainfall, water level and flow gauges. This has come about through the recommendations in Floodplain Risk Management Plans developed for various Northern Beaches catchments, all stating a flood warning system is a suitable method of managing the flood risk to residents.

Catchments are generally less than 10 km^2 with a critical storm duration for 1% AEP of 2 hours and times to peak of between 1 to 4 hours.

A public webpage has been designed to provide the community with the real time gauged information, to help inform them on where flooding may be occurring. All data from the rainfall gauges will be uploaded to the webpage every 2 minutes and all water level gauges every 15 minutes. The data will be supplied to BoM to support their Severe Weather and Flash Flood warnings.

The basis of the flood warning system is a series of rainfall, water level and flow gauges with the data provided via an interactive webpage and series of trigger levels and alarms for relevant decision makers. A Master plan was developed to specify the program of works and order of priority for implementation of each gauge.

ALERT Process

Webpage

The aim of the webpage is to provide actual rainfall and water level data in real time to the community, SES and The Councils for reducing the risk to life and property from flooding.

The webpage advises the community of the trigger levels for rainfall that could potentially flood problems. The trigger levels for rainfall are used in the flood warning system as the catchments typically experience flash flooding with little or no time to respond to trigger levels from water level gauges. The webpage provides up to date information on how much rainfall each gauge has received within three hours and 24 hours and 96 hours. Figure 9 shows the logo used on the webpage to advise the community of these rainfall amounts.

Rainfall data is uploaded to the internet every two minutes and water level gauges are displaying levels every 15 minutes. The timeframes used were selected taking into account the memory and electronic storage space needed for all the data as well as providing the Councils and SES with suitable data.

Future Actions

To increase the community's awareness of flood risk areas, it is proposed the webpage will become an interactive social media style webpage that residents will be able to upload photos of "live" flooding as they experience it onto a map. This will advise other residents of actual inundated areas that should be avoided.

As shown in the community survey, residents would like to be advised of an imminent risk through the use of SMS'. The use of SMS' is used by other agencies during emergencies to advise residents of imminent danger and is considered effective in getting the message to impacted residents. Future improvements will incorporate alerts via SMS.

TECHNICAL DETAIL – RAIN GAUGES, WL GAUGES AND TELEMETRY

The rain gauges operate on the tipping bucket principle. A receiver of 200mm diameter collects the rainfall, which is strained by metal gauze before being passed through a siphon to a two compartment bucket mounted in unstable equilibrium. Tips of the metal bucket occur with each pre-determined volume of precipitation collected; this is specified as 0.5mm for all Northern Beaches gauges. A reed switch detects these events and produces a momentary contact closure signal for logging on a data logger, which records each event as a time stamp (usually to 1-second resolution). An example of this type of gauge is shown in following Figure.

Rain Gauge on Great Mackerel Beach

Telemetry

Data from rain gauges can be communicated using a range of telemetry systems: radio, telephone, mobile phone, internet protocol (IP) and satellite systems. While IP telemetry can provide clients access to time series data in near-real time, it is reliant upon the NextG network which, may be affected by power and base station outages. The Northern Beaches network relies on the IP telemetry system with additional power sources, such as solar and battery to reduce the potential implications of a failure in the NextG network. The incoming raw data will be available to external users to view via the webpage every two minutes.

WATER LEVEL GAUGES

The current water level gauges installed across the Northern Beaches are using four different systems of data capture:

- Gas purge pressure system: the water level is determined by a pressurised constant flow of nitrogen gas through a line to a fixed point in the water column known as the orifice. The pressure in the line builds up to the same pressure as the water at that depth, this pressure is measured by the pressure sensor and converted into a water level by the data logger. The system relies on the principle that water depth is proportional to pressure
- Solid state Float well: the water level is sensed by a float connected to a shaft encoder.
- Submersible pressure transducer: the water level is determined by a vented pressure sensor and converted into a water level by the data logger.
- Ultrasonic/radar sensors: pulses are transmitted from the transducer towards the water and are reflected by the water back to the sensor. The elapsed time from emission to reception of the signals is dependent on the distance and hence the water level can be determined.

The logging systems consist of Campbell Scientific data loggers which record water levels every 15 minutes.

Water Level Gauge at great Mackerel Beach

Appendix E Bureau of Meteorology Warnings

STANDARD PRODUCTS OUT IN THE PUBLIC

1. Flood Threat Advice:

This is issued for the Top End as a whole regional (Greater Darwin Area) outlook specifying the following on the web; this is issued when the rainfall intensity reaches 10Yr ARI and this seems to be the threshold level.

- Average forecast 24hr/48hr (2^{nd} day)/72hr (3^{rd} day) and 96hr(4^{th} day) rainfall
- The 24hr rainfall has a higher certainty and the lowest for the fourth day forecast.
- Issued once a day usually in the morning but may be updated in the evening depending on the severity of the rainfall
- It could specify areas of interest (e.g.: along the coast from A to B; rural area etc.)
- It would specify the average rainfall and a range as well (e.g.: 50mm over the 24 hours and at isolated places it may go up to 80mm)
- This advice may go over a couple of days.

Warning time: 24hrs.

NTG Response:

- Community Advice – Read the flood threat advice; follow the radar for rain locations, its movements as well as the intensity.

2. Severe Weather Warning -

This is issued again on the web but focussed on a larger local area when the rainfall models predict some clarity on the area of impact. This is issued when the rainfall intensity reaches 10Yr ARI and this seems to be the threshold level.

- Issued every six hourly
- Only for a 24hr period

Warning Time: 6hrs

NTG Response:

- Community Advice – Read the Severe Weather Warning advice; follow the radar for rain locations, its movements as well as the intensity.

3. Severe Thunder Storm Service:

This is issued when thunder storm activities happen out of a rainfall cell without much warning. Advice provided in the web.

- Announcement over the radio and TV scrolls
- Area of interest very local
- Movement of Rain Band provided
- Advice lasts for couple of hours.

Warning Time: 1hour

NTG Response:

- Community Advice – Read the Severe Thunder Storm advice; follow the radar for rain locations, its movements as well as the intensity.

4. No tailor-made products for Flash Flood system or for non-Flash Flood System form the Bureau.

NTG Response:

- Community Education Awareness

RAINFALL RECORDERS:

- At present there are 3 rainfall recorders in the vicinity but outside of the catchment.
- They are 3 continuous rainfall recorders: Nightcliff; Marrara; and Pineland.
- Darwin Airport is a 24hr recorder.
- There is no rainfall recorder within the catchment

NTG Response:

- Provide a Threshold levels for rainfall intensity to the Bureau.

Appendix F Climate change and storm surge

Storm surge occurs when sea levels near coastal areas rise as a result of storms. Typically for Rapid Creek, storm surge will be associated with the reduced pressure at the centre of tropical cyclones. This reduced central pressure allows a bulge in sea level and when these cross the coast sea levels will rise in waterways that discharge to the sea. Other factors can also contribute to the storm surge such as strong winds causing wave set up, wave run-up as waves move up the coastal fringe and a funnelling effect as seawater surges up coastal inlets.

The worst case will happen when storm surge coincides with high tide.

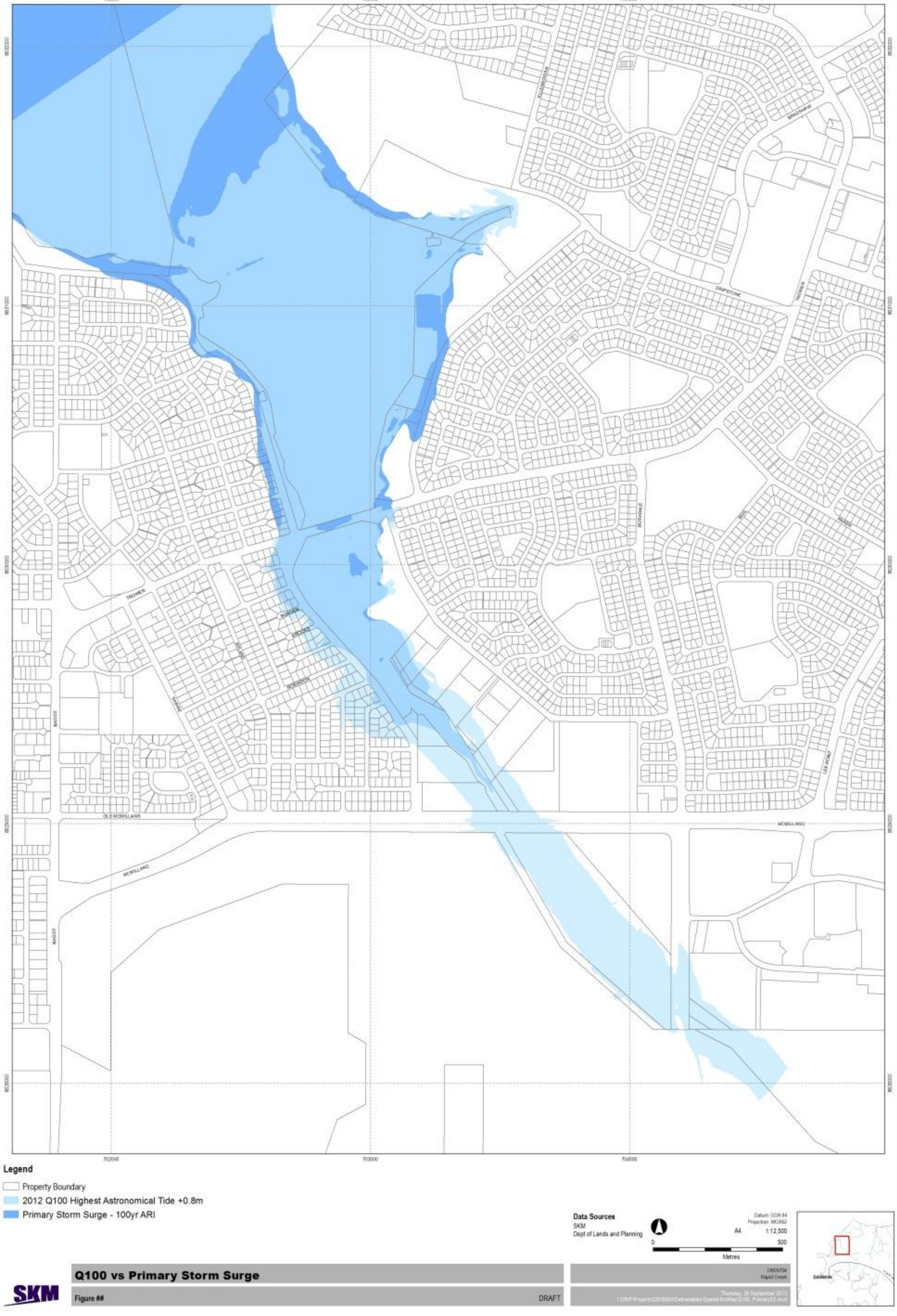
Storm surge mapping for Darwin was updated in 2011 and the results are available on the NT Government Land Information System.

Two zones of storm surge are mapped:

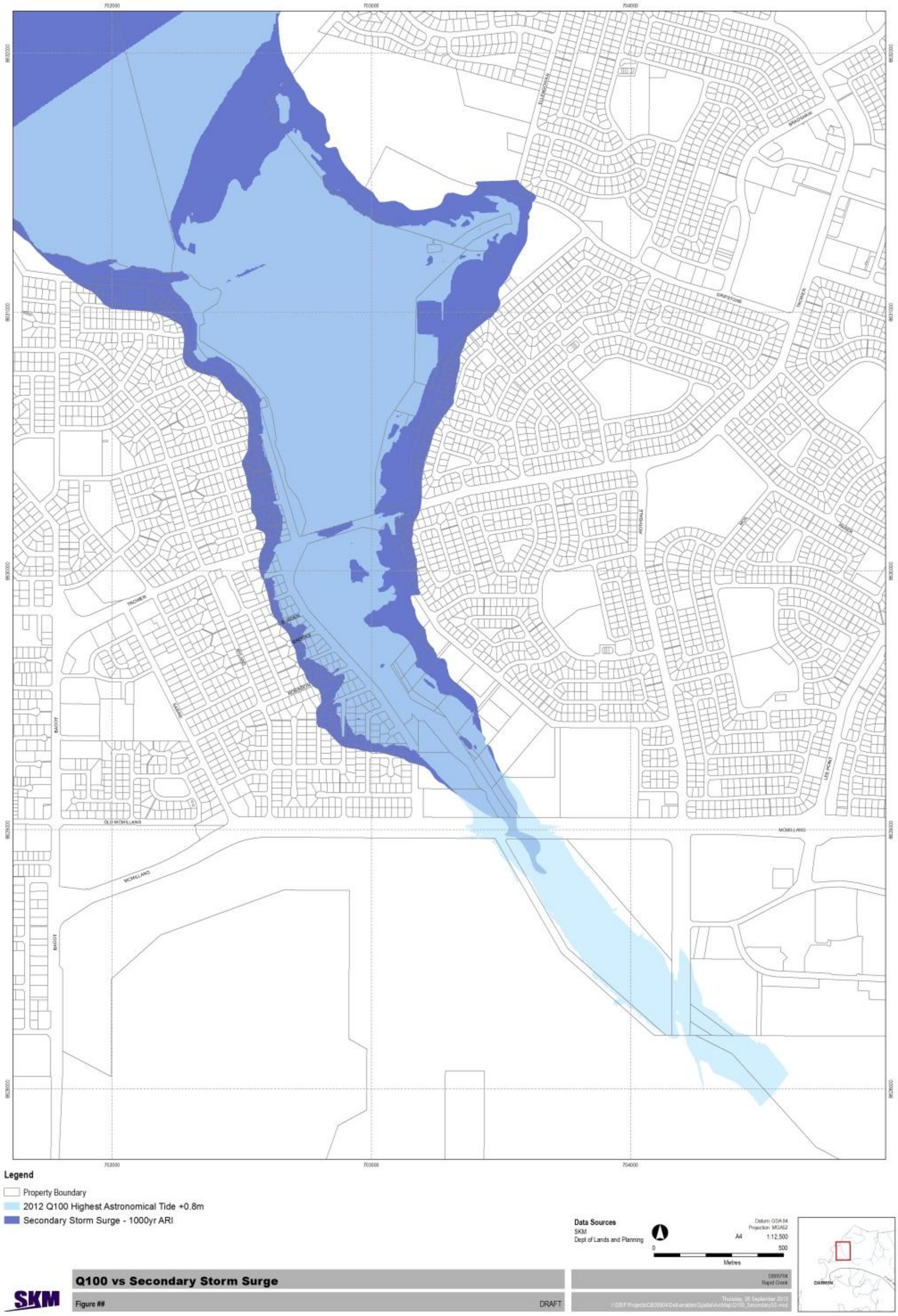
- The primary storm surge zone (Annual Exceedance Probability 1%)
- The secondary storm surge zone (Annual Exceedance Probability 0.1%)

The storm surge mapping can be compared to the Rapid Creek Flood Mapping. Figure 44, Figure 45 and Figure 46 , show that for the lower Rapid Creek catchment, many of the same properties are potentially affected by both flash flood and storm surge.

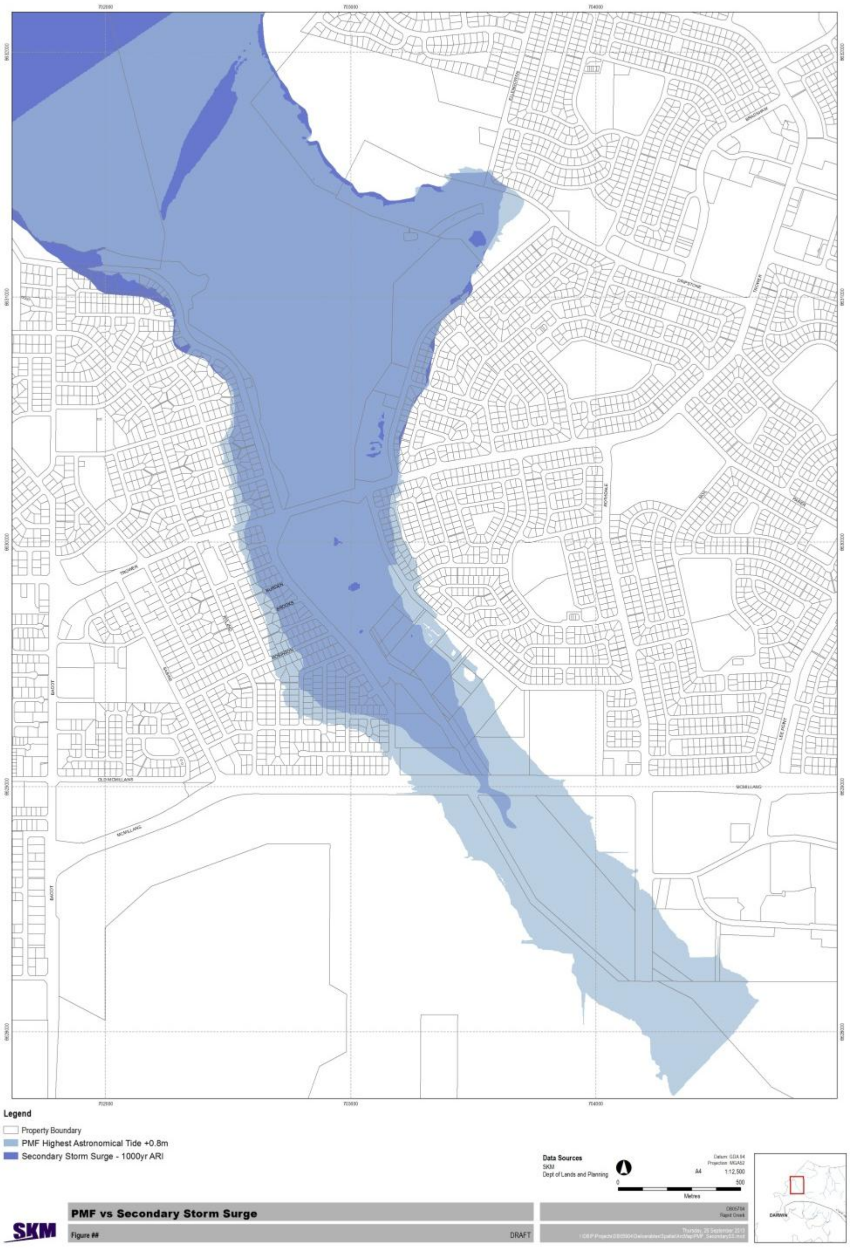
This means that flood awareness and flood preparedness campaigns for storm surge and flash flood can overlap and also that the evaluation of costs and benefits of mitigation measures against flash flooding should also include benefits in mitigation of storm surge impacts.



- **Figure 44. Comparison of 1% AEP (Q100) and Primary Storm Surge Zone**



- **Figure 45. Comparison of 1% AEP (Q100) and Secondary Storm Surge Zone**



■ **Figure 46. Comparison of PMF and Secondary Storm Surge Zone**

Appendix G Selected results of hydrology study

Hydrographs of flow at locations along Rapid Creek were required for input to a hydraulic model that was used to calculate the extent of flooding of Rapid Creek downstream of the Flood Control Weir.

Flood frequency analysis was carried out using the Generalised Extreme Value distribution. Flood frequency curves were fitted for both the raw data series and a series adjusted to conditions that prevail after the construction of the Flood Control Weir 500 m upstream of Henry Wrigley Drive in 1985. The Generalised Extreme Value distribution was considered to fit the ranked and plotted flood peak data reasonably well for both series and flood frequencies were adopted for floods up to Q500 for the post weir series with an LH shift of zero.

The adopted flood frequencies were as shown in Table 17 and Figure 47.

Table 17. Adopted flood frequencies

ARI (yrs)	AEP	Qpeak (m3/sec)	Lower Conf. Interval	Upper Conf. Interval
2	0.500	**38**	31	46
5	0.200	**68**	56	78
10	0.100	**88**	72	103
20	0.050	**108**	86	131
50	0.020	**134**	102	174
100	0.010	**155**	114	217
200	0.005	**176**	124	268
500	0.002	**204**	134	341

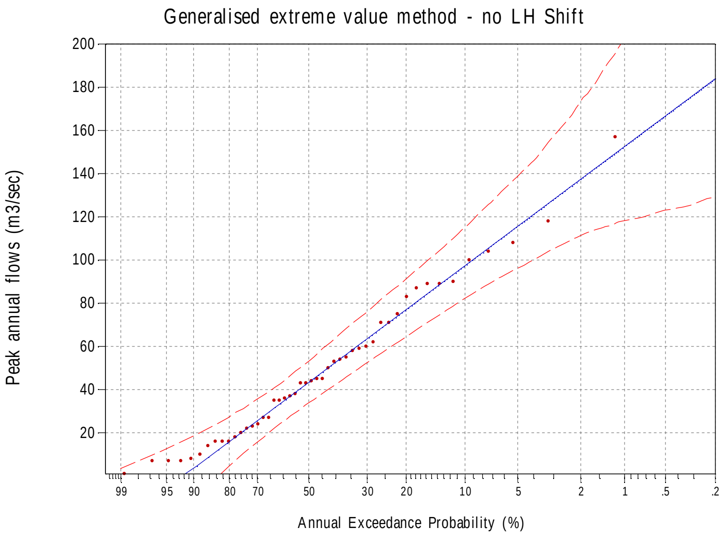
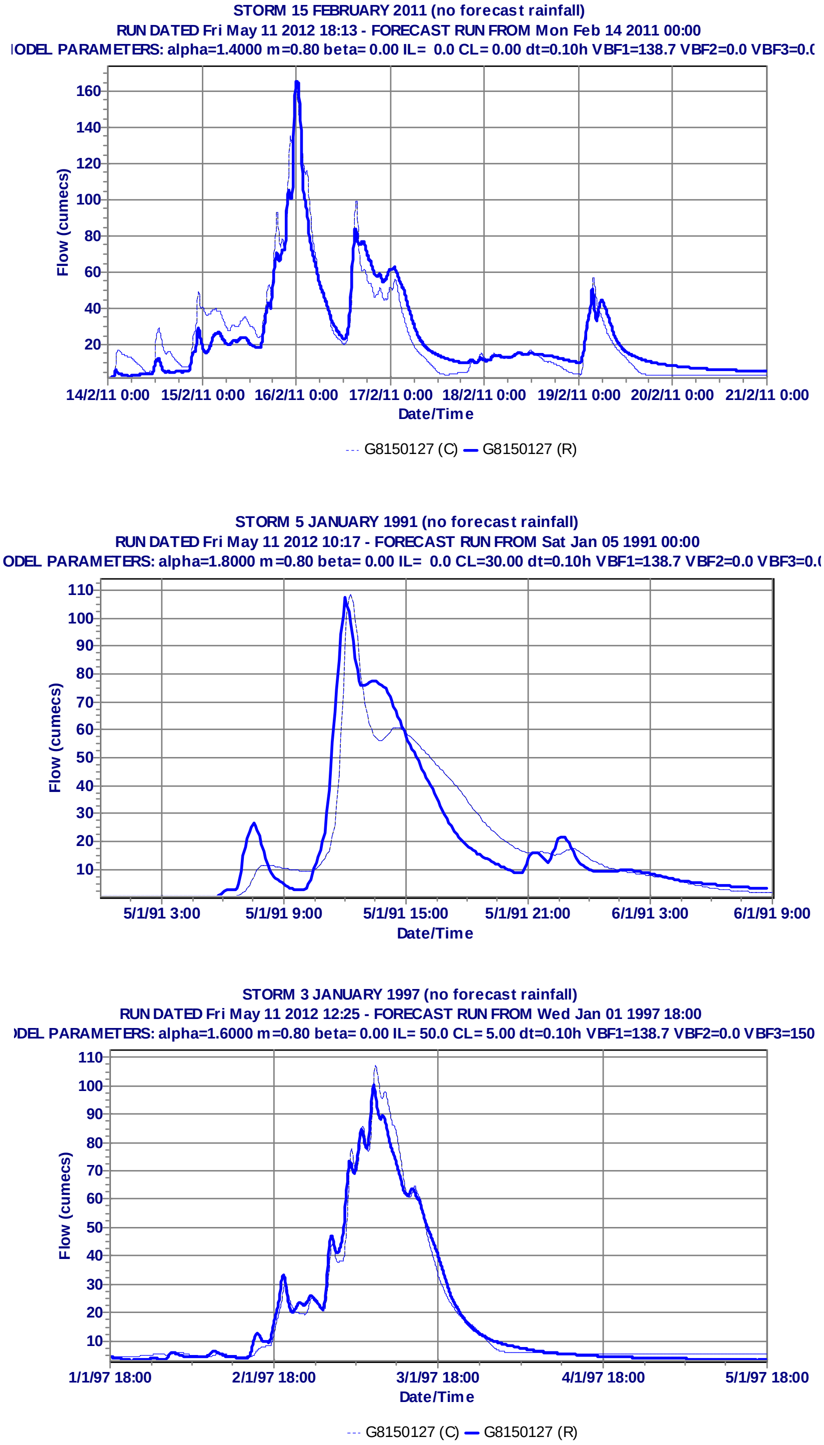


Figure 47. Adopted flood frequency curves

During calibration, the URBS model successfully modelled the majority of 26 events considered. Recorded and calculated hydrographs are shown for the three largest events on record in Figure 48.



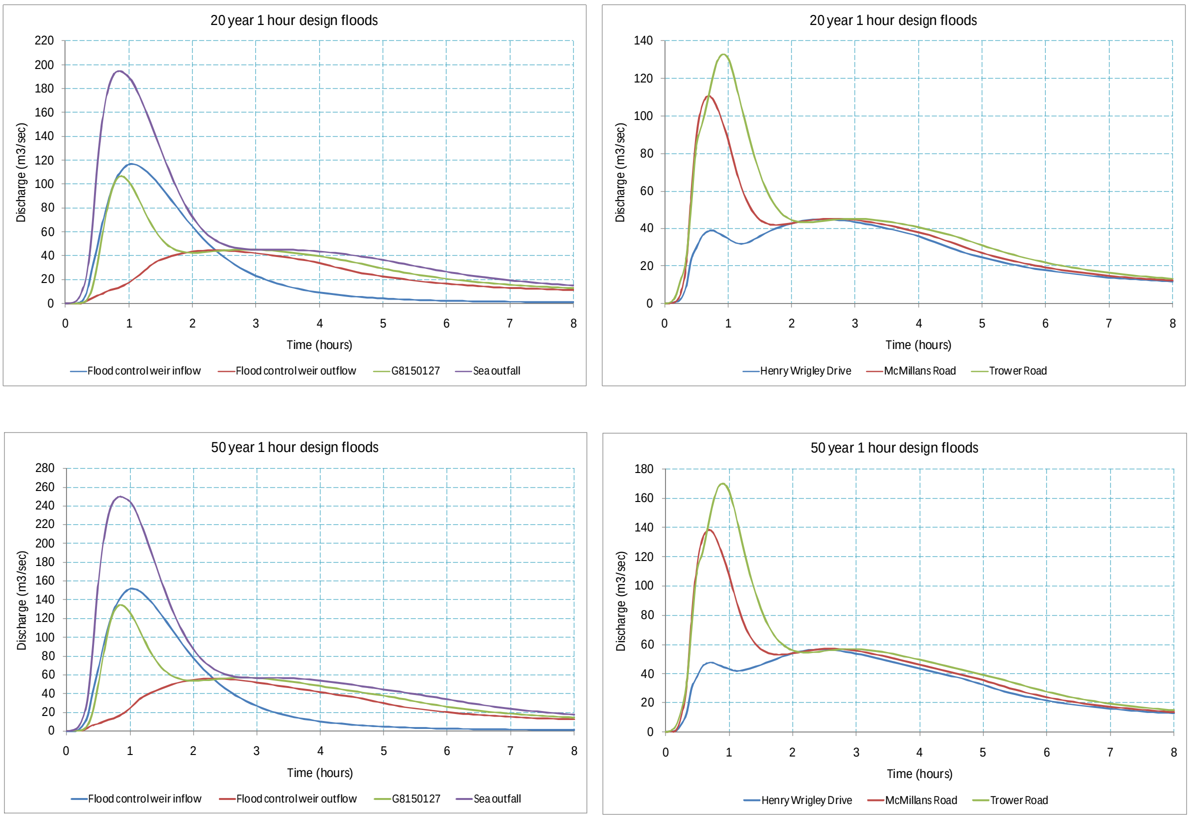
- **Figure 48. Recorded and URBS-calculated hydrographs for 3 largest floods on record**

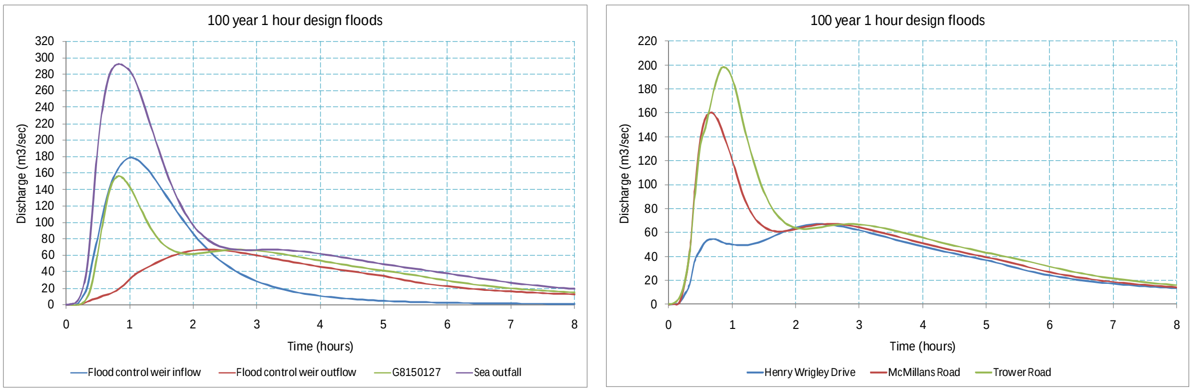
The parameters derived from the calibration runs were assessed against regional prediction equations and the URBS Basic model was used for design runs. Adjustment of loss factors was able to be used in a consistent manner to produce calculated design flows of the same order as those from the results of the flood frequency analysis (Table 18.)

- **Table 18. Comparison of peak discharges from design runs & flood frequency analysis**

ARI (years)	AEP (Annual exceedance probability)	Initial loss (mm)	Continuing loss rate (mm/hr)	Peak discharge calculated from URBS design runs (m3/sec)	Peak discharge adopted from flood frequency analysis (m3/sec)
5	0.200	27.5	3.0	67.5	68
10	0.100	27.5	2.0	88.4	88
20	0.050	21.0	2.0	108	108
50	0.020	19.0	2.0	134	134
100	0.010	17.5	2.0	156	155
200	0.005	16.0	1.5	177	176
500	0.002	15.0	1.5	205	204

Hydrographs of flow for design floods (Q20, Q50, Q100, Q200, and Q500) and the probable maximum flood have been used in the hydraulic modelling. Typical design flood hydrographs are shown in Figure 49.





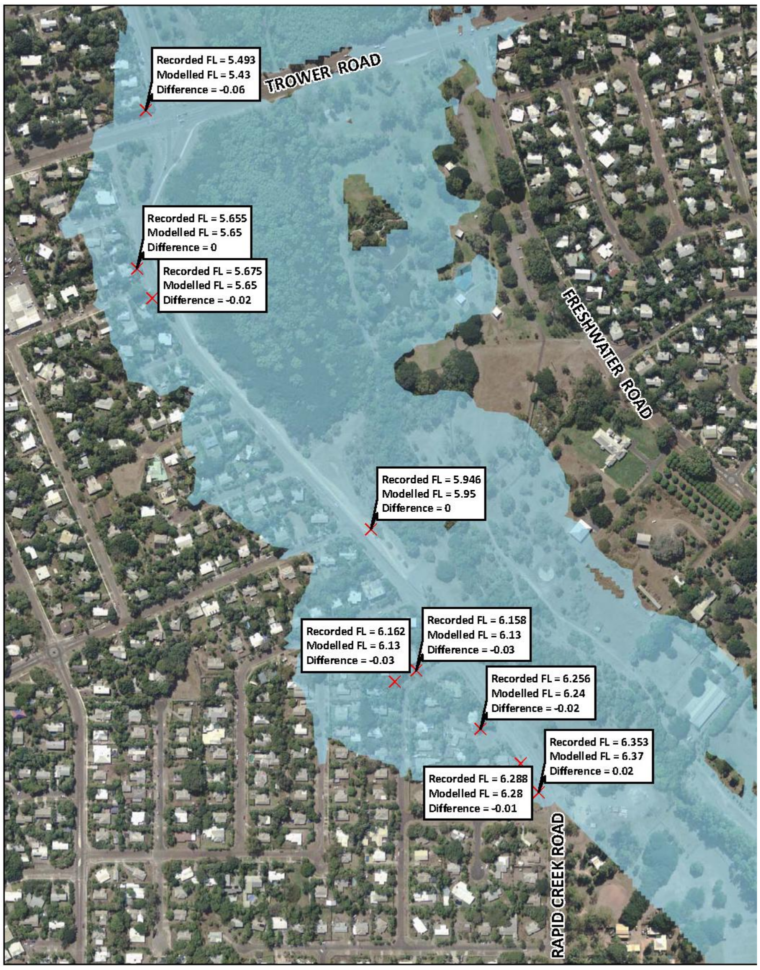
▪ **Figure 49. 1 hour design flood hydrographs**

SINCLAIR KNIGHT MERZ
SKM

Appendix H Selected results of hydraulic analysis

<u>TUFLOW hydraulic model calibration</u>

Nine flood marks from the flood of February 2011 were surveyed between Trower Rd and McMillans Rd, the majority adjacent to residential areas on the left overbank area of the creek. There is very good agreement between the modelled and surveyed levels with 8 of the 9 modelled peak flood levels within 0.03 m or 30 mm of the surveyed flood marks. The modelled flood level at the ninth location is within 60 mm of the surveyed level.



▪ **Figure 50. Calibration of TUFLOW model in Millner area**

Another nine flood marks were surveyed between McMillans Road and the Flood Control Weir. Six modelled levels show good agreement and are within 0.1m of the recorded levels. However, three modelled levels show a poorer fit and are lower than the recorded level by between 0.13 m and 0.27 m. The poorest fit is to the recorded level upstream of Henry Wrigley Drive. The poor fit could be the result of either:

- Blockage of the Henry Wrigley Drive culverts during the February 2011 event causing an increase in the recorded upstream flood level.
- The URBS model underestimating the peak flow from the flood control weir.
- Local turbulence.

<u>Calculation of Flood Levels for Design Floods</u>

Design inflow hydrographs for input to the TUFLOW hydraulic model were extracted from the URBS hydrologic model and a static downstream water level boundary was applied for each scenario. The model was run for multiple duration storm events so that critical flood heights, depths and velocities were obtained. Design durations modelled typically ranged from the 45 minute storm up to the 6 hour storm.

The results of maximum flood height, depth, and velocity depth product were determined for each scenario and used as inputs to the floodplain mapping. Maximum flood heights were also used to prepare design flood profiles.

Flow and stage hydrographs at selected locations along the creek were also output from the model in order to confirm the critical duration was captured at each location. Critical durations typically ranged from the 1 hour storm to the 4.5 hour storm for all design recurrence intervals. Figure 51 shows flow hydrographs extracted from the TUFLOW model for the Q100 with mean sea level design flood scenario.

The 1% AEP (Q100) hydrographs are indicative of the design recurrence intervals modelled and show the following key characteristics of design flood behaviour in Rapid Creek:

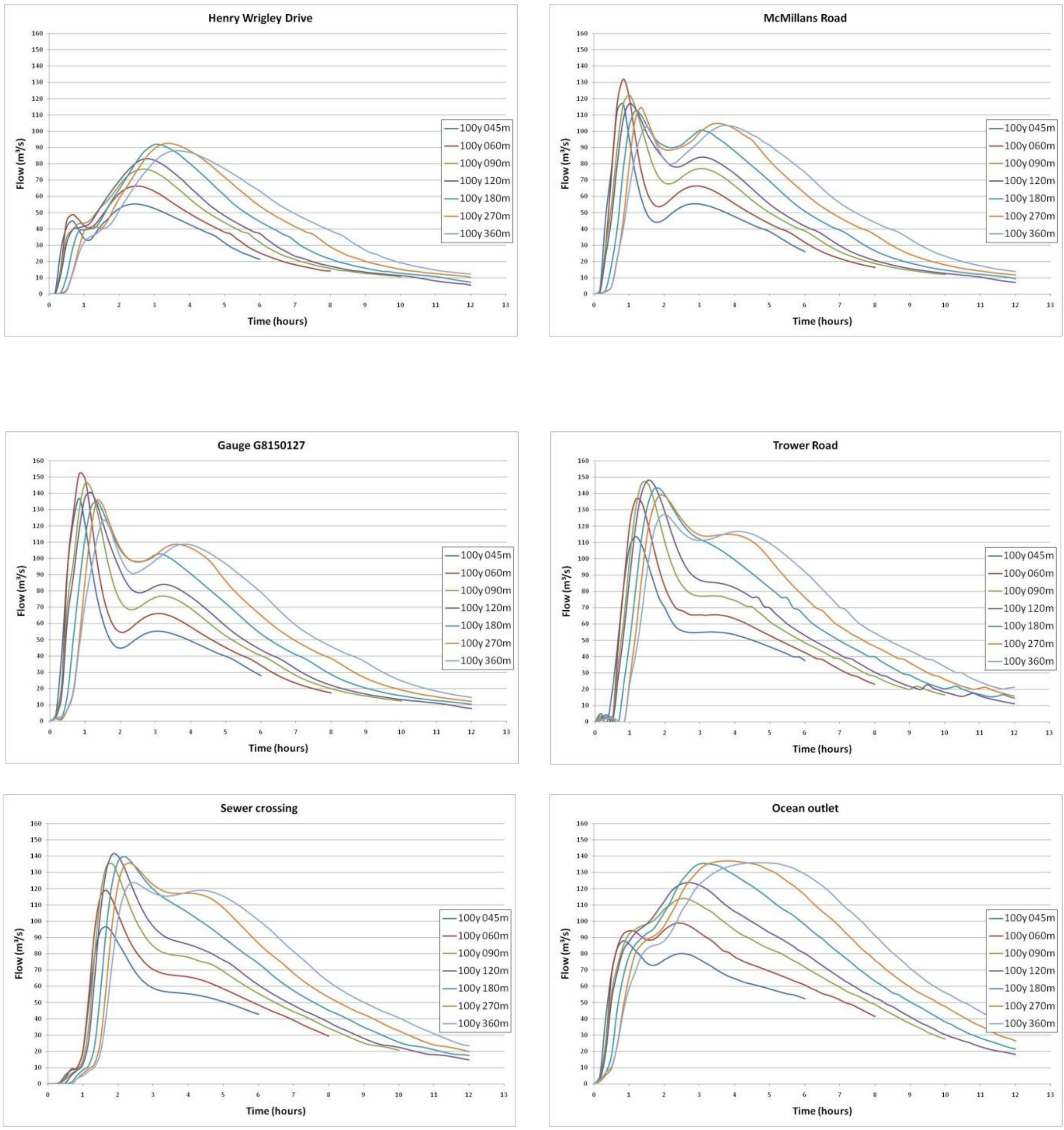
- At Henry Wrigley Drive the critical design flood levels result from the 4.5 hour duration storm. This is due to the flood control weir's impact of attenuating peak flows from the upstream catchment.
- At McMillans Road and the gauging station, critical flooding is from the shorter 1 hour duration storm due to inflows from the fast responding sub catchments between McMillans Road and the flood control weir. This is followed by a second flood peak of a smaller magnitude.
- Critical flooding between Trower Road and the ocean outlet is from the 2 hour to 4.5 hour duration storm events. Flood levels over this length of the creek are controlled by a constriction at the outlet and the amount of floodplain storage downstream of Trower Road.

<u>Floodplain mapping</u>

Floodplain maps are appended to the study report [SKM 2013 a]

The extent of flooding during the Q20 flood event is generally characterised by the following:

- The extent of flooding between the flood control weir and the gauge is generally 150m to 200m in width
- Henry Wrigley Drive remains free from flooding but McMillans Road is overtopped by floodwaters
- Downstream of the gauge there is an expansion of flow into low-lying areas on the left and right overbank resulting in the inundation of existing residential properties on the western side of Rapid Creek Road
- Trower Road is overtopped at the intersection with Rapid Creek Road impacting existing residential properties at the north-west corner of the intersection
- Floodwaters downstream of Trower Road are confined to the creek and mangrove overbank areas and to the constriction at the outlet



- **Figure 51. TUFLOW Q100 hydrographs at selected locations: mean sea level condition**

The extent of flooding during the Q100 flood event is generally characterised by the following:

- The extent of flooding between the flood control weir and the gauge is generally 180m to 230m in width

- Henry Wrigley Drive is overtopped on the northern side of the culverts and there is increased overtopping at McMillans Road
- Between the gauge and Trower Road there is further expansion of floodwaters into the low-lying areas on the left and right overbanks. A breakout of flow on the right overbank near the gauging station causes flooding of an existing rural property. While an increased number of existing residential properties on the western side of Rapid Creek Road are affected
- Trower Road is overtopped at the Rapid Creek Road intersection and a second location approximately 275m to the east (near Freshwater Road)
- Floodwaters downstream of Trower Road are confined to the creek and mangrove overbank areas and to the constriction at the outlet
- Floodwaters from the university open channel catchment threaten a number of existing structures on the university campus

The extent of flooding during the PMF event is generally characterised by the following:

- The extent of flooding between the flood control weir and the gauging station is generally 400m to 450m in width and affects a number of existing developments
- All road crossings are affected by the PMF
- Between the gauge and Trower Road the extent of flooding increases to approximately 700m in width and affects a widespread number of existing properties on the western side of Rapid Creek Road and the eastern side of Freshwater Road
- Downstream of Trower Rd there is inundation of properties adjacent Rapid Creek Road and Lakeside Drive, and increased inundation of the university campus
- At the outlet to the sea there is a breakout of flow to the north of the outlet constriction

Sea levels that formed the downstream boundary conditions for TUFLOW model runs were either:

- Current mean sea level
- Current Highest Astronomical Tide (HAT)
- Current mean sea level plus 1% AEP (1 in 100 year) storm surge
- Year 2100 HAT

The water surface profiles show that the influence of downstream sea level on the extent of flooding is largely in the area downstream of Trower Road.

In some cases there are also minor differences in flood levels immediately upstream of Trower Road but in all cases the flood profiles are identical above chainage 3,500 m, which roughly corresponds to the location of the gauging station G8150127.

Appendix I Selected results of potential flood damages study

The purpose of the flood damages study was to provide a baseline for assessment of any flood mitigation measures considered by the Northern Territory Government for the Rapid Creek floodplain.

Damages estimation for was undertaken as a desktop exercise only: property owners were not approached directly and information on floor levels was not collected by survey.

The AAD is a measure of the potential flood damage occurring every year due to Rapid Creek, averaged over a long period of time. The total potential AAD of the Rapid Creek system is estimated to be in the range $481,000 to $610,000.

The residential component of potential AAD is the area under a residential Potential Damage vs. Probability curve. The NSW Office of Environment and Heritage (OEH) spreadsheet, a widely used tool for calculating residential flood damages in Australia, was used to obtain the residential potential Damage vs. Probability curve. This curve gives the residential potential flood damages for different flood probabilities (Q10, Q20, Q50, Q100, Q200, Q500 and Probable Maximum Flood). This curve was checked for consistency with the actual residential damages estimated for the February 2011 flood.

The total potential AAD was estimated from the residential potential AAD. Non-residential damages were assumed to amount to 20% of residential damages. This was a conservative estimate of the distribution of the total damages, based on the proportion of residential and non-residential damages estimated for the February 2011 event in the second report.

The NPV represents the present day value of all future potential flood damages, which can then be used to calculate benefits and costs of any mitigation options. The NPV of potential flood damages for the Rapid Creek system is estimated to be in the range $10.8 million to $13.7 million, using a discount factor of 4%.

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Appendix J Estimates

i. Levee alongside Rapid Creek Road

ORDER OF COST ESTIMATE

Darwin Region, Rapid Creek, NT, Rapid Creek Flood Mitigation - Flood Levee,

For Department Of Lands, Planning And The Environment
AIS No. : Specification No. : File DB05904

TOTAL PROJECT COST
(All figures include GST)

COMPONENT	QTY	UNIT	RATE	AMOUNT
Contract estimate (see below)				3515173.7
Construction of Flood levee (1.5m high, 1100 m length) near Rapid Creek Rd.				
Escalation On Contract to 02/01/14	5.0	%pa		43376.2
Contingency to allow for uncertainties in the design	25	%		878,793
Construction Contingency	10.0	%		351,517
Rise and Fall On Contract	N/A	%		N/A
SUB-TOTAL				4,800,000
loading for masonry wall construction at northern end				1,200,000
Fees: design				$80,000
Fees: contract admin				$40,000
TOTAL				**$6,120,000**

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ESTIMATE

No.		DESCRIPTION	QTY	UNIT	RATE	AMOUNT	Subtotals
1	Miscellaneous Provisions						122,000.00
	1.01	Mobilisation		Item	50,000.00	50,000.00	
	1.02	Demobilisation		Item	25,000.00	25,000.00	
	1.03	On going costs		Item	25,000.00	25,000.00	
	1.04	As constructed drawings		Item	2,000.00	2,000.00	
	1.05	Project notice boards		Item	10,000.00	10,000.00	
	1.06	Survey		Item	10,000.00	10,000.00	
2	Provision for Traffic			Item	50,000.00	50,000.00	50,000.00
3	Clearing and Grubbing						154,000.00
	3.01	Clearing and Grubbing - including removing vegetation, stripping and stockpiling of topsoil, topsoil respreading, removal of old road surfaces and other obstacles. Assume footprint of levee (10m width) plus 2m either side	15400	m2	10.00	154,000.00	
4	Services						250,000.00
	4.01	Relocation of services		Item	250,000.00	250,000.00	
5	Flood Levee - earthen structure						967,993.72
	5.01	Fill and compact (1.5m average height, 1100m long, assumed crosssectional area of 10.5m2 - 1m top, 10m base, with 1:4 sideslope)	11550	cum	55.00	635,250.00	
	5.02	Trim to batter	13606	m2	5.00	68,031.24	
	5.03	Erosion control - geotextile on both sides of levee)	17647	m2	15.00	264,712.47	
6	Local Millner Drainage						1,810,000.00
	6.01	Install flood gates in purpose built pits to existing drains that carry runoff from Millner into Rapid Creek	12.0	No.	50,000.00	600,000.00	
		Drain alterations consolidate to 8 outlets		allow		250,000.00	
		Pumps and rising mains	8.0	average each	120,000.00	960,000.00	
7	Landscaping						161,179.99
	7.01	New paths over levee, including ramping for disabled access	2.0	No.	10,000.00	20,000.00	
	7.02	Revegation of levee	17647	m2	8.00	141,179.99	
					TOTAL	3,515,174	3,515,174

8	Millner local drainge modifications						
		main drain takes local runoff to D/S Trower Rd					
		excavate, supply, lay backfill incl. appurtenant pits					10,113,746.24
		c'mt 12 to c'mt 11 2 No 1.2 × 0.9 RCBC	102.0	m	2,546.00	259,692.00	
		c'mt 11 to c'mt 10 6 No 1.2 × 0.9 RCBC	100.0	m	3,759.44	375,944.20	
		c'mt 10 to c'mt 9 6 No 1.2 × 0.9 RCBC	103.0	m	3,759.44	387,222.53	
		c'mt 9 to c'mt 8 10 No 1.2 × 0.9 RCBC	104.0	m	12,255.37	1,274,558.48	
		c'mt 8 to c'mt 7 10 No 1.2 × 0.9 RCBC	95.0	m	12,255.37	1,164,260.15	
		c'mt 7 to c'mt 6 10 No 1.2 × 0.9 RCBC	92.0	m	12,255.37	1,127,494.04	
		c'mt 6 to c'mt 5 10 No 1.2 × 0.9 RCBC	88.0	m	12,255.37	1,078,472.56	
		c'mt 5 to c'mt 4 12 No 1.2 × 0.9 RCBC	88.0	m	14,682.78	1,292,084.46	
		c'mt 4 to c'mt 3 12 No 1.2 × 0.9 RCBC	44.0	m	14,682.78	646,042.23	
		c'mt 3 to c'mt 2 12 No 1.2 × 0.9 RCBC	44.0	m	14,682.78	646,042.23	
		c'mt 2 to c'mt 1 12 No 1.2 × 0.9 RCBC	44.0	m	14,682.78	646,042.23	
		c'mt 1 to D/S Trower Rd 12 No 1.2 × 0.9 RCBC	76.0	m	14,682.78	1,115,891.13	
		extend local drains to new main drain					
		allow	1.0	item	100,000.00	100,000.00	
					TOTAL	10,113,746	10,113,746

ii. Detention basins

ORDER OF COST ESTIMATE

Darwin Region, Rapid Creek, NT, ,"MarraraTriangleBasin

For Department Of Lands, Planning And The Environment
AIS No. : Specification No. : File DB05904

TOTAL PROJECT COST
(All figures include GST)

COMPONENT	QTY	UNIT	RATE	AMOUNT
Contract estimate (see below)				2339442.5
Construction of Flood levee (1.5m high, 1100 m length) near Rapid Creek Rd.				
Escalation On Contract to 00/01/00	5.0	%pa		
Contingency to allow for uncertainties in the design	25	%		584,861
Construction Contingency	10.0	%		233,944
Rise and Fall On Contract	N/A	%		N/A
TOTAL				**3,200,000**

ESTIMATE

No.	DESCRIPTION	QTY	UNIT	RATE	AMOUNT	Subtotals
1	Miscellaneous Provisions					**122,000.00**
1.01	Mobilisation		Item	50,000.00	50,000.00	
1.02	Demobilisation		Item	25,000.00	25,000.00	
1.03	On going costs		Item	25,000.00	25,000.00	
1.04	As constructed drawings		Item	2,000.00	2,000.00	
1.05	Project notice boards		Item	10,000.00	10,000.00	
1.06	Survey		Item	10,000.00	10,000.00	
2	Provision for Traffic		Item	5,000.00	5,000.00	**5,000.00**
3	Clearing and Grubbing					**799,150.00**
3.01	Clearing and Grubbing - inlcuding removing vegetation, stripping and stockpiling of topsoil, topsoil respreading, removal of old road surfaces and other obstacles.	79915	m2	10.00	799,150.00	
4	Services					**25,000.00**
4.01	Relocation of minor services		Item	25,000.00	25,000.00	
5	Cut to form basin and push up to bund walls					**1,326,042.50**
5.01	cut to fill and compact	47644	cum	25.00	1,191,100	
5.02	Trim to batter	26989	m2	5.00	134,942.50	
6	Outlet structure					**62,250.00**
6.01	Revetment mattress	315.0	m2	150.00	47,250.00	
	channel to creek - gabion mattresses	100.0	m2	150.00	15,000.00	
				TOTAL	**2,339,443**	**2,339,443**

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ORDER OF COST ESTIMATE

Darwin Region, Rapid Creek, NT, "Mango Orchard Basin

For Department Of Lands, Planning And The Environment
AIS No. : Specification No. : File DB05904

TOTAL PROJECT COST
(All figures include GST)

COMPONENT	QTY	UNIT	RATE	AMOUNT
Contract estimate (see below)				1564940.9
Construction of Flood levee (1.5m high, 1100 m length) near Rapid Creek Rd.				
Escalation On Contract to 00/01/00	5.0	%pa		
Contingency to allow for uncertainties in the design	25	%		391,235
Construction Contingency	10.0	%		156,494
Rise and Fall On Contract	N/A	%		N/A
TOTAL				**2,100,000**

ESTIMATE

No.	DESCRIPTION	QTY	UNIT	RATE	AMOUNT	Subtotals
1	Miscellaneous Provisions					**122,000.00**
1.01	Mobilisation		Item	50,000.00	50,000.00	
1.02	Demobilisation		Item	25,000.00	25,000.00	
1.03	On going costs		Item	25,000.00	25,000.00	
1.04	As constructed drawings		Item	2,000.00	2,000.00	
1.05	Project notice boards		Item	10,000.00	10,000.00	
1.06	Survey		Item	10,000.00	10,000.00	
2	Provision for Traffic		Item	5,000.00	5,000.00	**5,000.00**
3	Clearing and Grubbing					**320,000.00**
3.01	Clearing and Grubbing - inlcuding removing vegetation, stripping and stockpiling of topsoil, topsoil respreading, removal of old road surfaces and other obstacles.	32000	m2	10.00	320,000.00	
4	Services					**25,000.00**
4.01	Relocation of minor services		Item	25,000.00	25,000.00	
5	Cut to form basin and push up to bund walls					**1,045,690.92**
5.01	cut to fill and compact	37859	cum	25.00	946,479	
5.02	Trim to batter	19842	m2	5.00	99,211.75	
6	Outlet structure					**47,250.00**
6.01	Revetment mattress	215.0	m2	150.00	32,250.00	
	channel to creek - gabion mattresses	100.0	m2	150.00	15,000.00	
				TOTAL	**1,564,941**	**1,564,941**

ORDER OF COST ESTIMATE

Darwin Region, Rapid Creek, NT, "DIA land basin

For Department Of Lands, Planning And The Environment
AIS No. : Specification No. : File DB05904

TOTAL PROJECT COST
(All figures include GST)

COMPONENT	QTY	UNIT	RATE	AMOUNT
Contract estimate (see below)				1090156.8
Construction of Flood levee (1.5m high, 1100 m length) near Rapid Creek Rd.				
Escalation On Contract to 00/01/00	5.0	%pa		
Contingency to allow for uncertainties in the design	25	%		272,539
Construction Contingency	10.0	%		109,016
Rise and Fall On Contract	N/A	%		N/A
TOTAL				**1,500,000**

ESTIMATE

No.	DESCRIPTION	QTY	UNIT	RATE	AMOUNT	Subtotals
1	Miscellaneous Provisions					**122,000.00**
1.01	Mobilisation		Item	50,000.00	50,000.00	
1.02	Demobilisation		Item	25,000.00	25,000.00	
1.03	On going costs		Item	25,000.00	25,000.00	
1.04	As constructed drawings		Item	2,000.00	2,000.00	
1.05	Project notice boards		Item	10,000.00	10,000.00	
1.06	Survey		Item	10,000.00	10,000.00	
2	Provision for Traffic		Item	5,000.00	5,000.00	**5,000.00**
3	Clearing and Grubbing					**320,000.00**
3.01	Clearing and Grubbing - inlcuding removing vegetation, stripping and stockpiling of topsoil, topsoil respreading, removal of old road surfaces and other obstacles.	32000	m2	10.00	320,000.00	
4	Services					**25,000.00**
4.01	Relocation of minor services		Item	25,000.00	25,000.00	
5	Cut to form basin and push up to bund walls					**582,906.75**
5.01	cut to fill and compact	20225	cum	25.00	505,613	
5.02	Trim to batter	15459	m2	5.00	77,294.25	
6	Outlet structure					**35,250.00**
6.01	Revetment mattress	135.0	m2	150.00	20,250.00	
	channel to creek - gabion mattresses	100.0	m2	150.00	15,000.00	
				TOTAL	**1,090,157**	**1,090,157**

Sum over three basins proposed:

Marrara Triangle		$3,200,000
Design		$120,000
Contract admin		$40,000
Mango Orchard		$2,100,000
Design		$100,000
Contract admin		$35,000
DIA		$1,500,000
Design		$80,000
Contract admin		$30,000
		$7,205,000

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3. Relief culverts Trower Road

ORDER OF COST ESTIMATE

Darwin Region, Rapid Creek, NT, Rapid Creek Flood Mitigation - Relief Culverts,

For Department Of Lands, Planning And The Environment 6,435,000
AIS No. : Specification No. : File DB05904

TOTAL PROJECT COST
(All figures include GST)

COMPONENT	QTY	UNIT	RATE	AMOUNT
Contract estimate (see below)				3614000.0
Construction of Flood levee (1.5m high, 1100 m length) near Rapid Creek Rd.				
Escalation On Contract to 02/01/14	5.0	%pa		44595.7
Contingency to allow for uncertainties in the design	25	%		903,500
Construction Contingency	10.0	%		361,400
Loading for night work	33.0	%		1,192,620
TOTAL				**6,100,000**
Design	**allow**			**250000**
ract admin	**allow**			**85000**
				6435000

ESTIMATE

No.	DESCRIPTION	QTY	UNIT	RATE	AMOUNT	Subtotals
1	Miscellaneous Provisions					**210,000.00**
1.01	Mobilisation		Item	75,000.00	75,000.00	
1.02	Demobilisation		Item	40,000.00	40,000.00	
1.03	On going costs		Item	50,000.00	50,000.00	
1.04	As constructed drawings		Item	10,000.00	10,000.00	
1.05	Project notice boards		Item	10,000.00	10,000.00	
1.06	Survey		Item	25,000.00	25,000.00	
2	Traffic Management		Item	100,000.00	100,000.00	**100,000.00**
3	Services					**500,000.00**
3.01	Relocate and/or protect existing services		Item	500,000.00	500,000.00	
4	Demolition					
4.01	Remove existing bitumen (Trower Road)	1750.0	m2	4.00	7,000.00	**7,000.00**
5	Earthworks					**100,000.00**
5.01	Excavation for culverts (70m wide x 25m long x 1.3m deep)	2275.0	cum	40.00	91,000.00	
5.02	Backfill around culverts (assume 300 cum)	300.0	cum	30.00	9,000.00	
6	Cast in-situ concrete					**2,475,000.00**
6.01	Culverts (13 new culverts in total - 3m span, 1m high, extending 50m in total either side of existing)					
	a) Base Slab - assume 0.25m thick x 50m width x 25m long	312.5	cum	3,000.00	937,500.00	
	b) Walls - assume 0.25m thick x 14 walls x 1m height x 25m long	87.5	cum	3,000.00	262,500.00	
	c) Top slab - assume 0.3m thk x 50m wide x 25m long	375.0	cum	3,000.00	1,125,000.00	
	d) Wing walls (50 cum assumed)	50.0	cum	3,000.00	150,000.00	
7	Roadworks					**110,000.00**
7.01	Pavement and surfacing - Trower Rd	1750.0	sqm	60.00	105,000.00	
7.02	Reconstruct kerb	100.0	m	50.00	5,000.00	
8	Guard Rails					**49,000.00**
8.01	Install W beam guard rail (70m each side of road)	140.0	m	350.00	49,000.00	
9	Protection works					**63,000.00**
9.01	Geotextile fabric (200m2 assumed)	200.0	m2	15.00	3,000.00	
9.02	Reno Mattress (200m2 assumed)	200.0	m2	300.00	60,000.00	
				TOTAL	**3,614,000**	**3,614,000**

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4 Channel enlargement

ORDER OF COST ESTIMATE

Darwin Region, Rapid Creek, NT, Rapid Creek Flood Mitigation - Channelisation Option,

For Department Of Lands, Planning And The Environment
AIS No. : Specification No. : File DB05904

TOTAL PROJECT COST
(All figures include GST)

COMPONENT	QTY	UNIT	RATE	AMOUNT
Contract estimate (see below)				2455250.0
Construction of Flood levee (1.5m high, 1100 m length) near Rapid Creek Rd.				
Escalation On Contract to 01/01/14	5.0	%pa		29965.8
Contingency to allow for uncertainties in the design	25	%		613,813
Construction Contingency	10.0	%		245,525
Rise and Fall On Contract	N/A	%		N/A
WORKS SUB-TOTALTOTAL				3,300,000
Fees: Design				100,000
Fees: Contract admin				40,000
TOTAL				**3,440,000**

ESTIMATE

No.	DESCRIPTION	QTY	UNIT	RATE	AMOUNT	Subtotals
1	Miscellaneous Provisions					**140,000.00**
1.01	Mobilisation		Item	50,000.00	50,000.00	
1.02	Demobilisation		Item	25,000.00	25,000.00	
1.03	On going costs		Item	25,000.00	25,000.00	
1.04	As constructed drawings		Item	10,000.00	10,000.00	
1.05	Project notice boards		Item	10,000.00	10,000.00	
1.06	Survey		Item	20,000.00	20,000.00	
2	Clearing and Grubbing					**58,800.00**
2.01	Clearing and Grubbing - inlcuding removing vegetation, stripping and stockpiling of topsoil, topsoil respreading, removal of obstacles. Assume area to be cleared is existing bank - 3.5m x 1400m	5880	m2	10.00	58,800.00	
3	Earthworks					**2,197,650.00**
3.01	Excavate channel - assume 5.25m2 area x 1400m length	7350.0	cum	55.00	404,250.00	
3.02	Trim to batter	5880.0	m2	5.00	29,400.00	
3.03	Erosion control - reno mattress on new slope	5880.0	m2	300.00	1,764,000.00	
4	Landscaping					**58,800.00**
4.01	Revegation of new bank	5880	m2	10.00	58,800.00	
				TOTAL	**2,455,250**	**2,455,250**