WATER SENSITIVE URBAN DESIGN

STREAM STABILITY STRATEGIES DISCUSSION PAPER

FINAL

Prepared for the Northern Territory Department of Planning and Infrastructure
GPO Box 2520
Darwin NT 0801

May 2009

This document has been prepared as part of the Darwin Harbour WSUD Strategy, supported by funding from the Australian Government

Australian Government
Department of the Environment, Water, Heritage and the Arts

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Northern Territory Government

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Document Control Sheet	
Report title:	Stream Stability Strategies Discussion Paper
Version:	Final
Author(s):	Peter Gillam
Approved by:	Alexa McAuley
Signed:	
Date:	May 2009
File Location:	W:\Projects 2200s\2208 8005 Darwin region WSUD strategy\Documents and Reports\March 2009
Distribution:	Northern Territory Department of Planning and Infrastructure

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1 INTRODUCTION

Urban development in the Darwin Region is occurring without appropriate management of its impact on the urban water cycle and the health of the region's waterways.

Water Sensitive Urban Design (WSUD) seeks to address the deficiencies in traditional water management practice. The principles of WSUD are to:

- protect and enhancement of natural water systems (creeks and rivers etc.);
- treat urban stormwater to meet water quality objectives for reuse and/or discharge to receiving waters;
- match the natural water runoff regime as closely as possible (where appropriate)
- reduce potable water demand through water efficient fittings and appliances, rainwater harvesting and wastewater reuse;
- minimise wastewater generation and treatment of wastewater to a standard suitable for effluent reuse opportunities and;
- integrate stormwater management into the landscape, creating multiple use corridors that maximise the visual and recreational amenity of urban development.

While the hydrologic impacts of urban development across different climatic zones are variable, it is generally accepted in all climatic zones that urbanisation leads to increased stormwater flow rates and more frequent high flow events. This results in destabilisation of waterways, including increased rates of erosion and altered stream function including impacts to the recycling of nutrients.

Communities in Australian cities and towns are spending resources to reinstate structural and functional features of waterways that have been lost as a result of declining stream stability following urbanisation. In most instances it will be cheaper and easier to protect the stability of a waterway in good condition than to rehabilitate a degraded waterway, highlighting the importance of protecting stream stability from the outset of urban development.

In order to manage the impacts to Darwin Harbour, particularly from new development and re-development areas, the Territory has identified that the implementation of WSUD on all new development zones is critical. To assist in the adoption of WSUD, the Department of Planning and Infrastructure (DPI) in conjunction with Department of Natural Resources, Environment, the Arts and Sport (NRETAS) have secured a grant from the Australian Government to develop a WSUD Strategy for Darwin Harbour. The Strategy is to create an enabling environment to ensure commitment to urban water cycle and stormwater management through the development of a WSUD framework linking policy to locally relevant technical design guidelines, manuals and industry tools.

This discussion paper has been developed as part of the WSUD Strategy for Darwin Harbour.

1.1 Outline of Discussion Paper

This discussion paper brings together information on the current waterway management practices in Australian states and assesses them against the hydrologic climate of Darwin. Changes in the hydrologic cycle of developing catchments are described and key points for management interventions are identified. Possible strategies to protect the stability of waterways are investigated including opportunities to integrate these strategies within the landscape and built form of new suburbs.

This paper investigates the incorporation of stream stability management in Darwin. The paper is presented in the following sections:

Section 2 – summarises the key findings of urbanisation impacts on waterway stability (structure and function).

Section 3 – discusses stormwater management issues that need to be addressed for new developments to ensure waterway stability is provided for.

Section 4 – sets possible objectives to ensure that waterway stability outcomes are achieved for new developments

Section 5 – . explores implementation strategies to meet flow management objectives that ensure waterway stability

Section 6 –presents conclusions and recommendations.

2 BACKGROUND

Climate, geology, topography, channel material and ecosystem processes will cause changes in a waterway over time, but it is possibly a change associated with catchment land uses that produce the most pronounced impacts on a waterway.

Waterways are naturally dynamic systems and the shape and form of a waterway is a result of long term adjustment to the supply of sediment and the size and frequency of flow events.

Following a change in land use within a forested catchment, increased flow rates and more frequent high flow events result in destabilisation of the waterway, including increased rates of erosion and altered stream function. Loss of riparian vegetation associated with the change in land use will exacerbate these impacts on waterway stability.

Eroding stream beds are a significant source of sediment loads to Darwin Harbour. Erosion also reduces the recycling of nutrients within the waterway.

Preserving stream stability offers two major environmental benefits to catchments and receiving waters:

- Ensuring a waterway supports a complex and diverse range of ecology; and
- Reducing sediment and nutrient loads to Darwin Harbour.

These two objectives are linked in that by achieving the former, the latter is guaranteed. However, it is possible to provide a stable channel to an urbanised waterway that is devoid of any of its original character and function, and does not support a functioning ecosystem.

Preserving waterway stability or reinstating stability to actively eroding channels requires an understanding of the predevelopment hydrological processes and sediment loads, under which the waterway evolved, and the mechanisms that prevent erosion in a natural system.

2.1 Hydrology of Undeveloped Catchments in the Northern Territory

Waterways of the Northern Territory experience seasonal flows with flow events commencing months after the onset of the wet season and continuing well into the dry season. Similarly sediment loads flushed from catchments are highly seasonal, coinciding with the peak of the wet season.

Rivers with large catchments and those fed by large groundwater systems tend to be perennial, holding water most of the year and ceasing to flow only near the end of the dry season. Creeks and smaller waterway systems also may be fed by groundwater but tend to be more ephemeral, experiencing longer periods of no flow and occasionally forming disconnected pools.

It is generally accepted that the first wet season runoff from undeveloped catchments occurs around December and January after sufficient wetting up of the catchment. At the commencement of the wet season, in the order of 120-150 mm of rainfall is absorbed by soil stores before the catchment is sufficiently waterlogged to produce surface runoff.

During the peak of the wet season, runoff rates are high with up to 80% of rainfall becoming stream flow. Across the entire season however, in rural areas between 30% (Hatton et al. 1997) and 50% of rainfall becomes stream flow and in Kakadu National Park, as little as 6 to 28% of rainfall becomes stream flow (Townsend and Douglas 2000, Townsend and Douglas 2003).

2.2 Waterway Erosion as a Source of Sediment to Darwin Harbour

Sediment loads from disturbed catchments in the Darwin region derive from both the catchment and the stream itself.

Gravel covering, or lag, is effective at armouring the surface of catchments, but when disturbed by mining or development sediment loads significantly increase. Duggan (1998) reports sediment load export increases by two orders of magnitude. These rates are likely to apply to construction within is known to cause erosion.

Furthermore it is thought that following clearing, the majority of sediment load is not from disturbed surfaces within the catchment but from the stream bed and banks. Dixon, cited in Haig and Townsend (2003) establishes that destabilised streams, resulting from loss of vegetation, produce the majority of sediment from a disturbed area. Analysis of tracer isotopes demonstrated that for a number of land uses, sediment from within a waterway is more likely to be sourced from the waterway bed and banks than the floodplain (Haig and Townsend, 2003).

2.3 Urbanisation and Impacts on Waterway Stability

Following urbanisation, increased hard surfaces, efficient drainage networks and altered land uses bring about changes in hydrology that include the following:

- Runoff becomes significantly less seasonal to the point that creeks experience runoff in the absence of rain as a result of “dry season flows” resulting from outdoor water use (e.g. irrigation and car washing);
- Flow events commence earlier in the wet season due to increased hard surfaces and reduced infiltration rates;
- The frequency of runoff events increases with waterways experiencing between 20 to 30 additional runoff events in a year;
- Flow rates resulting from of frequent events increase dramatically, and creeks receive less groundwater flow;
- The frequency of the stream forming flow increases; and
- Annual runoff volumes can increase by a factor of up to two.

These changes in hydrology significantly increase the erosive energy imparted on a waterway over the year.

Without intervention, a waterway that is not inhibited by bedrock will respond to increased flow rates and volumes by increasing its cross sectional area. The waterway will typically deepen to convey the additional flows. This process, known as incision, generates large volumes of sediment which can be deposited again within slow flowing reaches of the downstream channel, or be discharged to Darwin Harbour. This process of incision can result in the removal or in-filling in of pools and in-stream habitat at the bed of the channel.

Waterways that cannot deepen (due to the presence of bedrock or tidal influence) will undergo rapid widening, washing away banks and riparian vegetation that cannot bind the banks together sufficiently well to resist the higher flows.

A waterway will reach equilibrium once the channel dimensions are sufficient to convey the frequent storm events up to the bank-full flow. The ‘bank-full’ flow is considered to have the greatest influence on the channel cross section, and in South Eastern Australia, is considered to occur twice every three years on average. It is often referred to as the 1.5 year Average Recurrence Interval (ARI) event.

2.4 Riparian Vegetation Communities and Waterway Stability

Riparian vegetation communities are a distinct forest community preferring more shady and wet environments occurring on the banks of waterways. Riparian vegetation is supported by the natural hydrology of the floodplain. Inundation patterns, both flooding and drying, are often important to the survival, flourishing and reproduction of riparian vegetation.

Riparian vegetation protects stream banks from erosion and traps water borne sediments and nutrients within the floodplain.

The highest priority in protecting the stability of a waterway in a developing catchment should lie in preserving channel resilience by protecting the natural riparian vegetation communities.

2.5 Impacts of Changed Hydrology and Fire Patterns on Riparian Vegetation

Changes in the pattern of inundation (i.e. changes in hydrology) can result in a change in vegetation communities. Species numbers may decline due to changed inundation conditions (becoming wetter or dryer), allowing opportunistic species to move in to take over zones that are now favourable to their growth. Incision of channel beds (channel deepening and widening) results in a loss of channel ‘connection’ to the floodplain and less frequent overbank flooding which can be important to the lifecycle of riparian vegetation.

Changes in fire patterns can also produce pronounced changes to a vegetation community affecting species numbers, germination and recovery. Riparian vegetation can recover rapidly after a fire, however an increase in the frequency of burning and intensity of fires can reduce the cover and recovery success of riparian vegetation, allowing fire tolerant species to take over areas once favourable to water-tolerant plants. Furthermore weed species can change the intensity of fires further reducing the success of riparian community recovery. Grasslands and savannahs which can recolonise frequently burnt zones tend to become dominant in frequently burnt areas, however these species have shallow root depths and are not well suited to stabilising waterway banks.

Ongoing erosion of waterway banks can prevent the reestablishment of riparian vegetation by undercutting and washing away establishing plants. Where a creek is undergoing major change it may be necessary to reinstate channel stability with rock armouring to allow vegetation to establish and prevent wash out of banks that have been recently planted.

2.6 Case Study: Mitchell Creek, Palmerston

Mitchell Creek is located on the eastern side of Palmerston, and a large proportion of Palmerston’s new urban development is occurring within the catchment of Mitchell Creek, shown in Figure 1.

Mitchell Creek has undergone significant degradation over the last decade due to urbanisation of half of the catchment, uncontrolled vehicle access, fire and weed invasion. Reaches of the creek channel show signs of continued erosion resulting from altered hydrology and reduced channel resilience (owing to a loss of riparian vegetation). The creek bed is also showing evidence of sediment deposition, from historical erosion within the catchment and sedimentation within the stream channel, resulting in a loss of permanent pool habitat.

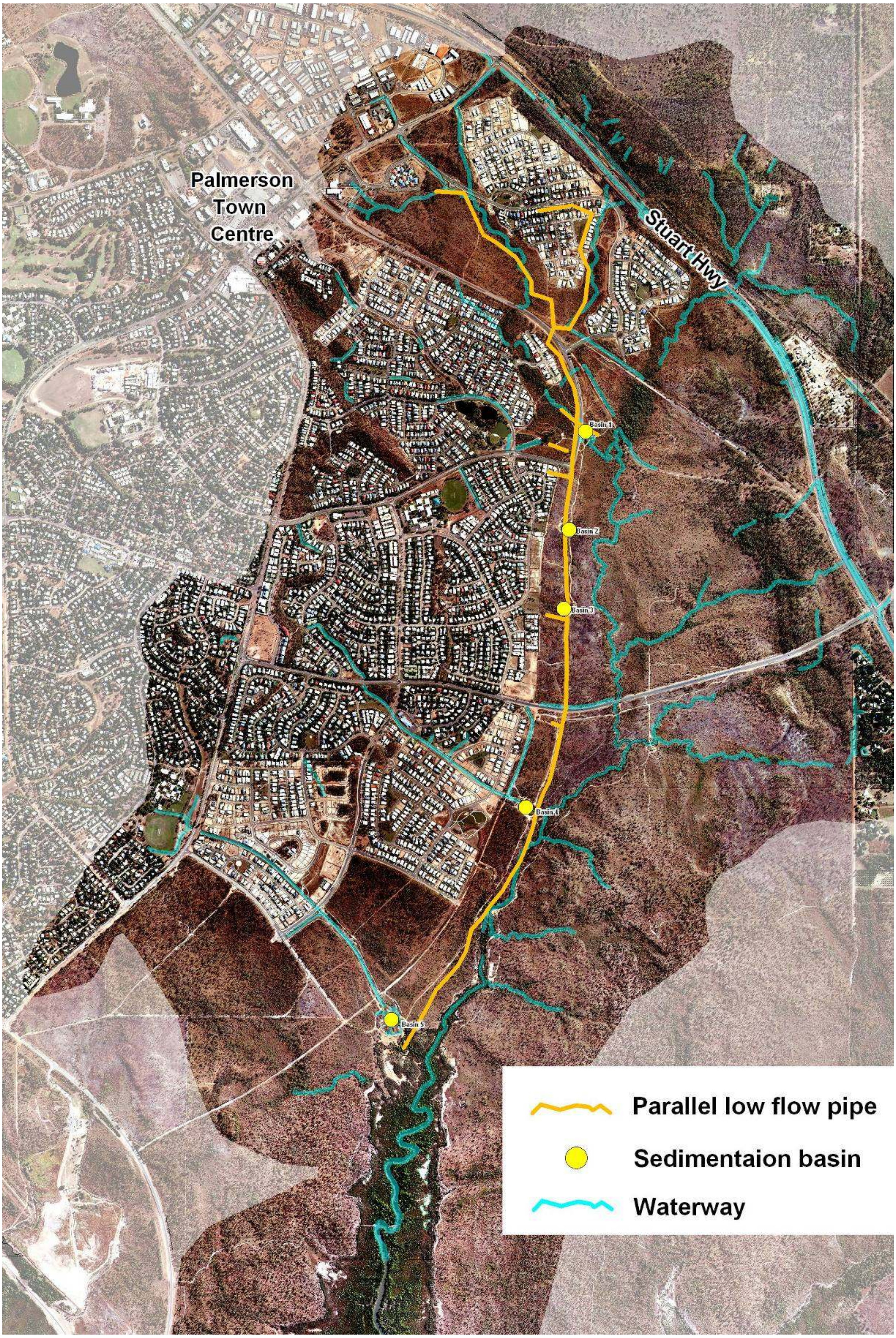

Figure 1: Mitchell Creek catchment, low flow pipe and waterways

The vegetation communities within the riparian corridor are changing in response to human impacts, with a net loss of riparian vegetation and increasing areas of savannah grasslands. Weed species are also encroaching into the corridor.

All the reaches of Mitchell Creek are showing some sign of impact from urban development, with the impacts more pronounced in the creek's lower reaches. As the catchment becomes increasingly urbanised, the channel becomes more unstable with ongoing incision and mass failure of channel banks as a result of undercutting and slumping. In locations the bed of the creek has lowered and uncovered bedrock, which is resisting further lowering and causing the channel to widen. In other locations, the channel is raised as a result of sediment deposition, and this is causing channel widening.

These impacts can be attributed to a combination of the following key factors:

- Loss of riparian vegetation due to fire and subsequent destabilising of creek banks due to loss of riparian root structure. This is discussed further below.

- Altered hydrology resulting in an increase in the frequency and magnitude of erosive flow events.

These factors trigger the following run away effects in the creek channel:

- Rapid adjustment of channel geometry due to increased frequency of erosive flows and weakened channel structure.

- Bank undercutting resulting in further loss of riparian vegetation.

- Disconnection of the floodplain from the channel and altered inundation patterns reducing the suitability of the floodplain as riparian vegetation habitat

The riparian corridor is currently subject to a more frequent and more intense fire regime than that with which it has evolved. Fires occur within the corridor between once and twice a year as a result of accidents or actions to clear paths of vegetation growth. The encroachment of introduced grasses and weed species exposes the riparian corridor to hotter and higher flames than occur from native grass fires. The net effect is a reduction in the recovery potential of the vegetation communities to fire disturbance, particularly riparian communities. This has resulted in an almost complete loss of riparian vegetation along the lower reaches of Mitchell Creek, and colonisation with a more fire tolerant savannah community. Riparian vegetation communities have deep root structures that bind together creek banks creating a stable channel that is resilient to erosion. Savannah species don't offer the same benefit to bank stability and loss of riparian communities has resulted in destabilisation of the channel and allowed the creek channel to widen. While large trees with deep roots are present on the floodplain, they do not exist at a density required to prevent the widening of the creek.

Existing stormwater drainage infrastructure, including the low flow pipe and sedimentation basins, is also exacerbating the effects of urban development on Mitchell Creek.

A low flow pipeline was constructed parallel to the creek to intercept dry weather drainage from the suburbs of Bakewell and Roseberry, and convey high nutrient runoff to the tidal limit, thereby preserving the water quality and the ephemeral nature of the creek. Trunk drainage from subsequent development has been connected to the low flow pipeline, resulting in large flows entering the pipeline during rain events. The pipe is subject to internal damage from high flows and from impacts of off-road vehicles crossing the pipe.

Sedimentation basins were constructed along the creek circa. 1998 to trap sediment in runoff from the existing development. The basins drain to the low flow pipe via hydraulic structures that detain flows arriving directly into the basins. Runoff is released slowly to the low flow pipe, allowing sediment to drop out.

The basins were not sized to manage runoff from subsequent development in the catchment, and their capacity has not been increased to manage runoff from development occurring after 1998. The basins experience significantly greater incoming flow volumes than designed for, and frequently overflow to the creek with little effective sediment removal or flow attenuation (the frequency is to be determined). Lack of maintenance has also compromised the effectiveness of the basins, as sediment has built up within them, reducing their capacity. At some basins the outlet structures have also been eroded. As such, the current level of development in the catchment and existing basin configuration results in the creek exposed to an increased frequency of high intensity flows and erosion forces, as well as sediment loads from the developed areas.

Urban development and vehicle movements across the catchment are sources of weed species and propagules are often present in stormwater, as evident by the presence of weeds in the sedimentation basins and at points where the low flow stormwater pipe discharges or overflows.

Continuous inflows of nutrient rich water to the basins have created ideal conditions for weeds to flourish, and the flow pipe acts as a distribution mechanism for weed propagules. The basins could be more effective at trapping weeds, but minimal weed control in recent years has created effective weed nurseries within the basins, which are potentially increasing the fuel loads within the riparian corridor and intensity of fires when they occur.

3 URBAN WATERWAY STABILITY MANAGEMENT ISSUES

Urbanisation results in significant modification of the natural hydrology of a waterway causing a shift in the equilibrium between the channel form and channel flows.

3.1 Dry Weather Flows

Irrigation and outdoor water use through the dry season is known to generate significant flows within stormwater pipes in Palmerston. This flow rate is significant compared to that coming off a natural catchment in the dry season. Creeks that normally experience a period of no flow may continue to flow year round.

Continually wet areas can allow reed species to establish (Denney and Brock, 1995) that impede flows causing siltation and localised raising of the channel bed which can then lead to bank erosion and channel widening.

3.2 Early Wet Season Flows

As discussed above, urban development results in a shift in seasonality of runoff events, with runoff and stream flows occurring much earlier in the wet season and far more frequently than in an undeveloped catchment. The increase in the number of these flow events is most likely to have the largest impact on waterway stability.

Research by Walsh et al (2004) carried out on streams in Victoria’s Dandenong Ranges identified that following urbanisation, runoff occurred in small to medium rain events that would otherwise not have produced stream flows in a natural catchment. In Victoria these events account for up to 98% of frequent rainfall events in a reference rain year. These events were attributed to the dramatic impacts on stream stability even for catchments with low levels of urbanisation. This is of particular importance in ephemeral and intermittent creeks that rarely experience flow events.

Flows from small to medium rain events are not likely to alter generate large sediment volumes in a single event, but are more likely to impart gradual changes to the base of the channel, potentially resulting in the loss of in-stream pools and other habitats and undercutting banks, resulting in slumping and channel widening.

3.3 Stream Forming Flows

The stream forming flow is an event considered to have the greatest influence on the channel form and alignment. The processes of erosion and deposition are more dynamic during stream forming flows than in lower flow rates. In most streams the stream forming flow is thought to correspond to an event where the stream channel runs full, which is often referred to as ‘bank-full’ flow. At bank full flow in many streams, flow velocities are at their highest. In larger flows, flow velocities tend not to increase substantially, as the flow spreads across the floodplain. Larger flows also occur less frequently; therefore their overall impact on the stream is less significant.

In South Eastern Australia, a common assumption is that the stream forming flow occurs twice every three years on average. The frequency of the stream forming flow will most likely vary across climatic regions, but it is generally agreed that following urban development the predevelopment stream forming flow will occur more frequently resulting in a significantly larger channel that is devoid of its natural character. These changes result in production of sediment loads downstream and modify the types of habitat within the waterway.

3.4 Sediment Loads

An increase in sediment loads supplied to a waterway will shift the equilibrium between sediment deposition and erosion and will bring about channel modifications.

Deposition of sediment from land disturbances, (construction processes, mining or land clearing) or upstream channel erosion, will result in raising of the channel bed in turn leading to widening of the channel. Large flow events may shift such deposits down the channel propagating the same widening process along the waterway.

3.5 Active Erosion

Headward erosion (headcut) and unstable banks represent historical erosion problems that may have occurred as a result of the construction of road crossings, clearing or changes to a waterways hydrologic regime.

Headward erosion begins when something occurs in a waterway to lower the invert of the channel at a particular location (e.g. construction of a road crossing). Where there is a drop from natural to lower invert levels, the flow velocity increases and scouring occurs. Scouring lowers the channel to match the downstream levels, and the drop moves gradually upstream.

Unstable banks may occur due to scour and erosion and/or loss of riparian vegetation.

These erosion problems can be a source of sediment that creates problems further downstream by altering a waterway’s sediment load, as discussed in the section above.

4 STREAM STABILITY OBJECTIVES

Table 1 outlines some broad goals and objectives for protecting stream stability downstream of urban areas. These objectives are proposed to address the issues identified in Section 3 and avoid problems similar to those which have been experienced at Mitchell Creek, Palmerston.

Table 1: Stream stability objectives for the Darwin Region

Goals	Objectives
Improved channel stability	• Prevent ongoing erosion within waterways • Protect and reinstate riparian vegetation communities • Protect the connectivity between channel and floodplain
Maintain natural sediment supply rates and channel equilibrium	• Control sediment loads from catchment during construction • Reduce sediment loads during developed phase, to meet WSUD objectives (80% retention of total suspended solids load)
Preserve dry season flow regimes	• Reduce anthropogenic base flows generated from lawn watering, car washing, leaking mains etc.
Preserve wet season flow regimes	• Attenuate runoff during frequent storm events • Reduce the early onset of wet season flows • Preserve the predevelopment frequency and duration of stream forming flows

Section 5 outlines suggested strategies for meeting these goals and objectives.

5 STRATEGIES FOR MEETING STREAM STABILITY OBJECTIVES

Stream channels may begin to erode immediately following changes in the natural hydrologic regime or sediment supply, and timely intervention is imperative to minimise the likelihood of flow on effects. Historical changes in land use such as agriculture, mining or forestry may have resulted in loss of riparian vegetation or increased runoff and waterways may respond to these historical changes over decades.

Management interventions for preventing impacts on stream stability or arresting active erosion are typically of two kinds:

- Actions within the catchment, such as capturing sediment and implementing hydrologic controls to mitigate the impacts of development on the hydrologic cycle, thereby relying on natural channel resilience provided by riparian communities.

- Actions within the waterway itself, such as revegetation, rock armouring and channel shaping will provide stability to actively eroding channels and provide improved resilience to increased flows from a developing catchment.

A range of actions in both these categories are summarised in Table 2. In general, the strategies for improving channel stability focus on the waterway itself, while the others focus on the catchment.

Table 2: Strategies for meeting the stream stability goals

Goals	Strategies
Improved channel stability	• Carry out in-stream works including channel shaping, channel armouring, bank revegetation and provision of grade control structures at erosion points. • Preserve the natural fire regime (i.e. the frequency of burning) • Preserve burn heights and burn intensity through weed control
Maintain natural sediment supply rates and channel equilibrium	• Stabilise disturbed areas in the catchment with vegetation and sediment control • Direct stormwater to sedimentation basins during construction periods • Treat stormwater from completed development with swales, wetlands and bioretention systems
Preserve dry season flow regimes	• Use low flow bypasses around sensitive waterway reaches • Encourage losses through infiltration to groundwater • Encourage losses through evapotranspiration within suitably designed wetlands • Intercept in harvesting and reuse schemes
Preserve wet season flow regimes	• Attenuate runoff rates through stormwater treatment systems such as wetlands and bioretention systems • Construct detention basins to attenuate flows from frequent events (e.g. up to the 5 or 10 year ARI storm) from development

Strategies to meet the first two goals are well documented in other literature and are not discussed further in this document. The following sections explore strategies to meet the final two goals (preserving dry season and wet season flow regimes) in more detail. Hydrologic modelling has been undertaken to better understand natural wet season flow regimes and to establish potential options for preserving key attributes of the wet season hydrology after urban development occurs.

5.1 Preserving Dry Season Flow Regimes

Dry weather flows from urban catchments are difficult to quantify due to the variability of factors determining how much runoff is generated and how much is captured and delivered by stormwater pipes. Due to high nutrient rates, it is of great benefit to total waterway health that these flows be intercepted and prevented from entering waterways.

Capture and reuse through a stormwater harvesting strategy presents the best balance of environmental outcomes given the benefits to potable water use reduction. Treated flows can be used for irrigation of open space and playing fields, however the quantum of harvested water needs to be determined before the feasibility of these systems can be assessed.

Diverting stormwater around ephemeral creeks, as has been done on Mitchell Creek Palmerston, is effective but is expensive to construct, requires significant infrastructure through riparian areas and can become expensive and difficult to properly maintain. A study being undertaken concurrently is looking at the benefits of such systems.

Infiltration strategies offer a promising solution, but the effectiveness of this strategy is highly dependent on the presence of suitable underlying soils, and is ineffective during periods when the groundwater table is high.

5.2 Preserving Wet Season Flow Regimes

Hydrologic management through the use of stormwater treatment systems and dedicated detention structures will ensure that post development hydrology of a waterway in a developing catchment is within the range that will avoid erosion and undercutting of the surrounding vegetation.

Strategies to manage the impacts of urbanisation on stream hydrology (and therefore stream stability) were explored using hydrologic models.

Modelling enables quantification of the detention storages required to meet the goals proposed in Table 1 and reiterated in Table 2.

A range of flow management strategies have been explored that draw on common practices from around Australia. Hydrological parameters have been quantified for the Darwin Region using hydrologic modelling of hypothetical catchments

MUSIC modelling has been undertaken to simulate continual time series of rainfall and runoff processes by approximating the hydrologic processes of soil saturation, runoff and groundwater flow. MUSIC modelling results have been calibrated against published runoff rates for the Top End. MUSIC modelling is industry standard software commonly used for sizing stormwater treatment devices such as wetlands and bioretention basins. MUSIC uses the hydrologic algorithms from Hydsim which is also a commonly used rainfall and runoff model in Australia.

RORB modelling has been undertaken to simulate design storm rainfall and runoff processes with parameters taken from previous studies on Mitchell Creek, Palmerston (GHD, 1995). RORB models were developed to investigate the size of detention basin structures required to restore predevelopment flows from a catchment.

5.2.1 Overview of Modelling Process

The hydrologic modelling undertaken for this discussion paper involved the following steps:

- **Predevelopment Model Establishment** – two predevelopment models were constructed to establish the predevelopment hydrology of a catchment:
    - A MUSIC model was set up, based on a continuous time series of rainfall data (1987-1996) and monthly evaporation data (both from the Darwin Airport meteorological station). This model was used to estimate typical annual runoff volumes from a catchment and the frequency of runoff during the wet season.

  - A RORB model was set up to simulate design storm events. Rainfall intensity and frequency data for the region was adopted in accordance with Australian Rainfall and Runoff (1987). This model was used to estimate the peak flows from the catchment associated with different recurrence interval storms (1, 2, 5 and 10 year ARI storms).

Both of these models were applied to a hypothetical catchment in Palmerston with typical parameters for the area.

- **Model Calibration** –predevelopment model outputs were compared to published values. Runoff rates were compared to published values for the Kakadu National Park. Little gauged catchment data was available in Palmerston for a local model calibration.

- **Developed Model Establishment -** the predevelopment models were adjusted to reflect landuse changes following establishment of a new subdivision where hard surfaces account for approximately 50% of the catchment area and drainage is collected within piped stormwater systems. Dry weather flows from these catchments are extremely difficult to predict as they are based on highly variable human practices. Dry weather flows have been estimated based on infield observations at Palmerston.

- **Testing Stormwater Management Strategies** – A range of bioretention, wetland and infiltration strategies were tested using MUSIC modelling to assess the effectiveness in meeting hydrologic objectives. RORB modelling was used to size detention requirements in addition to that provided by wetlands and bioretention systems.

5.2.2 Model Calibration and Discussion of Results

A summary of MUSIC results for the predevelopment and developed catchment are presented in Table 3**Error! Reference source not found.**.

Table 3: Summary of hydrologic modelling results for a 10 ha hypothetical catchment in Palmerston

Scenario	Mean Annual Runoff Volume (ML/yr)*	Runoff Coefficient	1yr	2yr	5yr	5yr
Predevelopment	55.5	33%	1.0	1.2	1.8	2.2
Developed (50% impervious)	107.6	63%	1.9	2.9	3.8	4.3

*Annual rainfall 1699 mm

The predevelopment MUSIC model yields a runoff coefficient comparable to a value of 30% for undeveloped catchments (Hatton et al. 1997).

There is a commonly held perception that in large storm events in the Darwin Region, post development peak flows do not increase significantly compared to the predevelopment scenario. However the RORB model predicted that design storm flows would double at the downstream extent of a developed catchment. These flow rates reflect discharge from a developed catchment to a creek and do not account for any attenuation that may occur within the creek itself.

A partial series analysis was undertaken on the 10 years of MUSIC results to extract peak flows for various recurrence intervals and compare them to the RORB model results. The results compare well, indicating that although only calibrated to a small data set, the MUSIC model produces runoff rates in accordance with long established hydrologic procedures in Australian Rainfall and Runoff. The comparison is presented in Table 4. Note that as the MUSIC model was only run for 10 years, the peak flow results from MUSIC are more reliable for the lower ARIs.

Table 4: A comparison of hydrologic model predictions for a hypothetical 10 ha catchment in Palmerston

	Peak flows (m^3/s)			
ARI	**1yr**	**2yr**	**5yr**	**10yr**
10 ha un developed catchment (0% impervious)				
MUSIC	-	2.3	3.7	4.3
RORB	1.0	1.2	1.8	2.2
10 ha developed catchment				
MUSIC	1.8	2.7	3.7	4.3
RORB	1.9	2.9	3.8	4.3

The MUSIC and RORB models do not agree on the relative increase in flows from a developed catchment for 1 and 2 year events. The RORB modelling predicts a doubling in flow rates for the 1 and 2 year ARI events. The MUSIC model predicts significantly lower flow rates for the frequent events than the RORB model.

The difference in model results may be attributed to differences in the structure and function of each modelling package. RORB is best suited to estimating flood flows based on the probability of extreme rainfall and runoff conditions. The model is typically used in flood risk applications, but is well suited to sizing stormwater detention structures. MUSIC on the other hand is preferred for analysis of long term simulations than discrete rainfall events.

The differences in flow predictions highlight the need for calibrated and validated models.

MUSIC modelling results are presented below in the form of a continuous hydrograph for a typical early wet season in Figure 2.

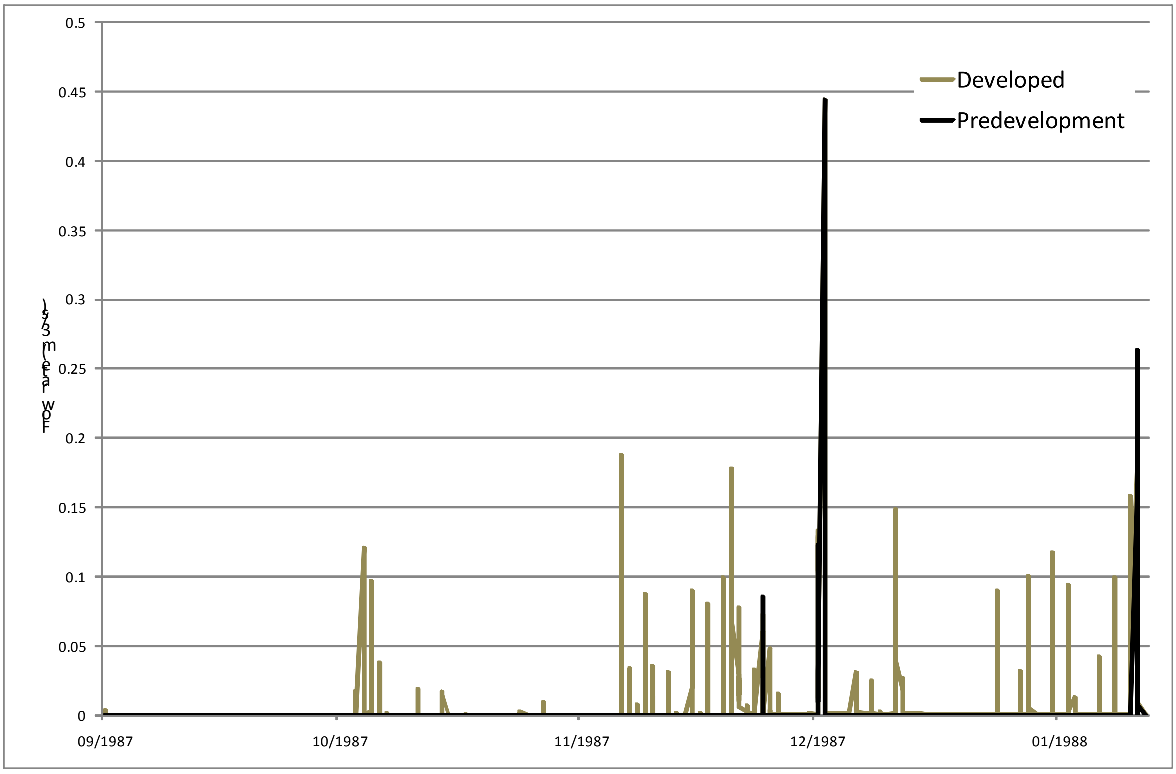

Figure 2: Early wet season flows for a 10 ha hypothetical catchment

The MUSIC modelling time series predicts that the frequency of runoff from a developed catchment will increase dramatically. The introduction of impervious surfaces in a catchment dramatically increases the number of runoff events. MUSIC modelling indicates that this is approximately 20 to 30 additional runoff events in a wet season, which will have a significant cumulative impact on the waterway.

Within a developed catchment runoff is shown to occur during each rain event, while runoff from the predevelopment catchment only occurs once the catchment is saturated.

5.2.3 Runoff attenuation in stormwater treatment systems

Runoff from frequent rain events at the start of the wet season can be controlled through the provision of detention. Most stormwater treatment systems provide some degree of stormwater detention, particularly for frequent flows. Therefore the use of wetland and bioretention stormwater treatment systems as recommended for new developments in the Darwin Region (as part of the WSUD Strategy) will provide additional benefits to preserving stream stability by mimicking the processes within a natural catchment.

These systems are sized to treat runoff resulting from frequent storm events meet best practice treatment objectives as defined by a 45% reduction in Total Nitrogen (TN), 60 % reduction in Total Phosphorous (TP) and 80% in Total Suspended Solids (TSS).

A ‘best practice’ wetland footprint is proportional to approximately 6% of the feeding catchment, which captures runoff in an “extended detention” zone that drains over a notional 72 hour period. Wetlands will water levels will draw down over a dry period, which must be filled before the wetland discharges. This volume will go some of the way of removing runoff during the early wet season.

A bioretention system sized to achieve best practice stormwater pollutant reduction is proportional to 2.5% of the feeding catchment. Bioretention systems also include an extended detention zone. Bioretention systems drain over a period of hours and do not attenuate flows as much as wetlands.

For a 10 ha hypothetical catchment, it has been estimated that typical wetland and bioretention systems will provide temporary storage in the extended detention zone of 21 and 4.5 m^3/ha respectively.

The difference in the frequency of runoff events is illustrated by a continuous runoff hydrograph predicted by MUSIC modelling in Figure 3. Again, the early and mid wet season in 1987 is presented.

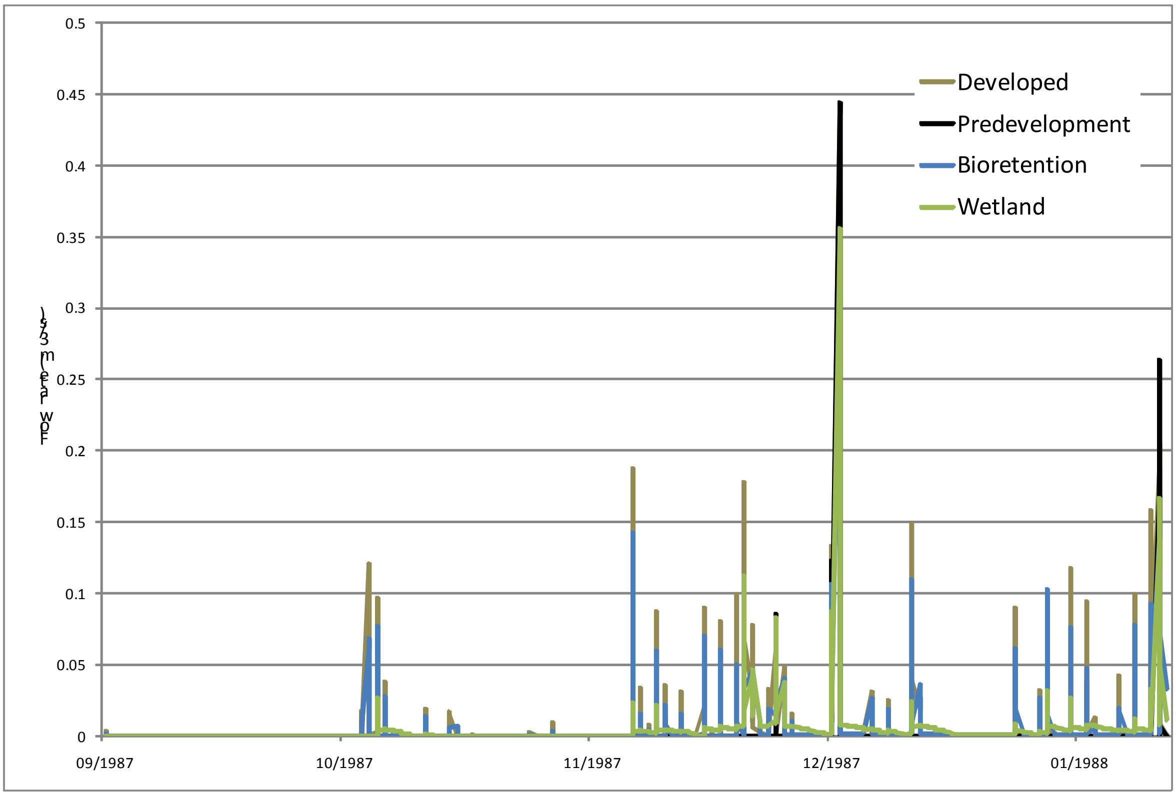

Figure 3: Impacts of wetland and bioretention on post development hydrology for a 10 ha hypothetical catchment

The wetland and bioretention systems reduce the magnitude of frequent runoff events, but do not entirely prevent runoff entering the waterway.

The wetland is shown to be effective by reducing the runoff rate to approximately a third of the incoming flow rate.

The bioretention system is shown to be less effective, but reduces the peak flow rate by half.

Both systems will produce significant reductions in the long term erosive energies that a creek is exposed to.

The systems could be improved with the addition of infiltration basins that allow treated runoff to infiltrate to the groundwater system below.

The run off values in Figure 3 were ranked and plotted as a cumulative frequency plot, showing the probability of a certain flow rate for each of the scenarios presented above. The 99 percentile flow is equivalent to the most intense rainfall event in a year, and can be compared to the 1-year ARI event. Figure 4 presents the changes in runoff patterns and the 99 percentile flow rate for each scenario.

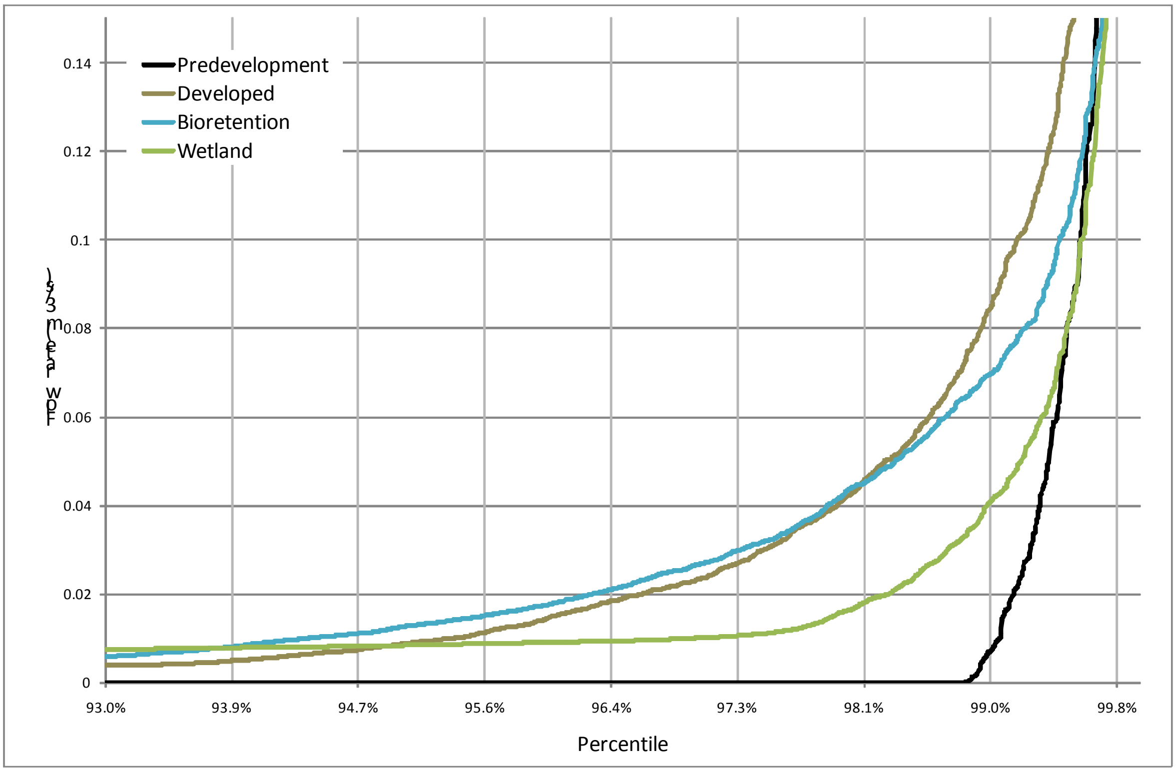

Figure 4: Impacts of wetland and bioretention on post development hydrology for a 10 ha hypothetical catchment

Figure 4 shows that both wetland and bioretention systems have a benefit in terms of reducing the magnitude of flow events, however the bioretention system only results in a small change from the basic post development scenario with no attenuation. The bioretention and wetland systems will reduce the ‘flashy’ nature of post development runoff, which will assist in reducing high velocities and erosion. Both types of treatment system slowly release flows producing a drawn out hydrograph, which dominates the left hand side of Figure 4.

5.2.4 Runoff attenuation in dedicated detention storages

Table 4 above showed the relative increase in storm flow following development. Additional storage beyond that provided by a wetland or bioretention system is required to provide the attenuation of design storms to ensure that post development runoff rates do not increase, and that the frequency of bank full discharge also does not increase.

A RORB model of a single detention basin was developed to determine the storage volume and outlet configuration required to closely match post development peak flow rates to predevelopment flow rates for the same recurrence interval.

Model results are presented below in Table 5 for a 10 hectare catchment that is 50% hard surface and drains to a single detention basin with a pipe outlet and spillway. The basin has been sized to attenuate each design storm with a single outlet and represents a simple solution.

Table 5: RORB model results for detention basin sizing

ARI (years)	Pre-development flows (m^3/s)	Developed flows (m^3/s)	Basin outflows (m^3/s)	Outlet	Basin Storage (m^3)
1yr	1.0	1.9	1.2	Pipe flow	1,585
2yr	1.2	2.9	1.3	Pipe flow	2,450
5yr	1.8	3.8	1.6	Pipe and weir	3,425
10yr	2.2	4.3	1.9	Pipe and weir	3,970

The basin outflows closely match the predevelopment flow rates from the 10 ha catchment, and could be more closely matched with optimisation of the outlet configuration.

For this hypothetical catchment, detention storage is required at a rate of 400 m^3/ha to ensure that the frequency of the 10 year ARI predevelopment flow is not increased.

These results will be validated against a study currently being undertaken for Mitchell Creek, which will determine the predevelopment bank full flow for different reaches in the catchment.

Storage volume rates for other catchments may differ depending on catchment slope, length and other factors.

6 SUMMARY AND RECOMMENDATIONS

Stream stability is a significant issue downstream of urban areas. Three principal influences on stream stability are:

- Hydrology (flow regimes in the wet and dry seasons)
- Sediment loads from the catchment
- Condition of riparian vegetation

Urban development has impacts on all of these factors. Hydrology is affected by the increase in impervious surfaces; sediment loads are increased by activities in the catchment in both construction and developed phases; and riparian vegetation is affected by fire regimes. Riparian vegetation is also impacted by changes in hydrology and deterioration in stream stability, so that positive feedback occurs and impacts gradually escalate if left unmanaged.

Methods to manage stream stability include physical works to stabilise waterways, as well as actions within the catchment to manage sediment loads and restore key aspects of the predevelopment hydrology.

This discussion paper included a section focused on strategies to restore predevelopment hydrology. The hydrological impacts of urban development in the Darwin Region can be summarised as follows:

- During the dry season, outdoor water use delivers dry season flows into waterways. Streams which were ephemeral before development can flow year-round.
- During the wet season, impervious surfaces and stormwater infrastructure deliver runoff very efficiently into downstream waterways. This results in:
    - More frequent runoff, particularly early in the wet season, before the catchment is saturated
    - Higher peak flows from storm events
    - A greater overall runoff volume

Peak flows can be addressed with conventional stormwater management measures, namely detention systems. This paper presented the results of some preliminary hydrologic modelling showing how much detention would be required to restore predevelopment peak flows in the 1-10 year ARI events. Stormwater treatment systems can provide a portion of these detention requirements.

To more fully address stream stability, other management measures are also required, to address a broader range of the impacts of urban development. These strategies may include the following:

- Strategies which improve channel stability (improving resilience to urban impacts):
    - Carry out in-stream works including channel shaping, channel armouring, bank revegetation and provision of grade control structures at erosion points.
    - Preserve the natural fire regime (i.e. the frequency of burning)
    - Preserve burn heights and burn intensity through weed control
- Strategies which reduce sediment loads from urban catchments:
    - Stabilise disturbed areas in the catchment with vegetation and sediment control

    - Direct stormwater to sedimentation basins during construction periods
    - Treat stormwater from completed development with swales, wetlands and bioretention systems
- Strategies which address changes in post-development hydrology:
    - Use low flow bypasses around sensitive waterway reaches
    - Encourage losses through infiltration to groundwater
    - Encourage losses through evapotranspiration within suitably designed wetlands
    - Intercept in harvesting and reuse schemes

To further the understanding of stream stability in the Darwin Region, as well as the means of ameliorating the impact of urban development on scour, erosion and degradation of in-stream habitat, it is recommended to undertake a geomorphologic assessment case study. The assessment would analyse an existing waterway and the potential impacts of future development, and formulate management options to protect the waterway from degradation.

The assessment would involve hydraulic and hydrologic analyses to quantify hydraulic parameters in the reach and relate those to processes observed in the field. The analysis would involve:

- Development of HEC-RAS hydraulic models of the subject reach for pre-development and post-development hydrology.
- Analysis of data collected for existing streams which are unaffected by development
- Bed grade analysis of the subject reach to assess its current stability and the implications for stability under the post-development hydrology
- Assessment of velocity and stream power distribution through the subject reach under current and future hydrology. Hydraulic parameters in the subject reach should be compared to stability thresholds developed from similar sand bed streams
- Comparison of observed areas of erosion and deposition with model output and prediction of likely channel response under post-development hydrology using the bed grade and stream power analysis.

The assessment would also include identification of threats to the waterway and allow appropriate management interventions to be investigated. Potential management options to be assessed would include stormwater detention, flow spreaders and in-stream protection works.

This assessment has been proposed for Mitchell Creek in Palmerston. New urban development in the Mitchell Creek catchment also offers an opportunity to put catchment management strategies into practice to protect stream stability.

7 REFERENCES

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