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Mary's Mount Drainage Corridors Stream Management Guidelines

Report Prepared For
Goulburn City Council

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1.0 INTRODUCTION

1.1. BACKGROUND

Approximately 410 hectares of urban development is planned for Mary's Mount, Goulburn. This area is within the Goulburn Local Government Area and is part of the SCA drinking water catchments defined by SEPP 58.

The Mary's Mount DCP specifies that major overland flow paths shall be set aside as drainage reserves. The drainage reserves are to function as "naturalised" watercourses, achieved by revegetation with native species. These drainage reserves shall:

- Safely convey the 100 year Average Recurrence Interval (ARI) storm event;
- Be resistant to erosion and present no major long term maintenance burden to Council;
- Satisfy some of the public open space requirements of DCP 14; and
- Enhance ecological values and create an aesthetically more pleasing environment with greater opportunities for passive recreation.

Due to the staged manner of development, these Stream Management Guidelines have been prepared to ensure that stream management proceeds in an integrated manner. These guidelines outline creek processes and recommend design approaches to be undertaken during the restoration of drainage corridors in the Mary's Mount subdivision.

This document should be used in conjunction with its sister document, *Mary's Mount Drainage Corridors Vegetation Management Plan*, which provides specifications for vegetation works associated with stream construction.

1.2. SITE LOCATION

These guidelines apply to the designated drainage corridors within the Mary's Mount DCP area (Figure 1.1) which drain to the Wollondilly River. The Wollondilly catchment is a water supply catchment for Sydney, and provides water to many small towns and cities for industry, irrigation and livestock.

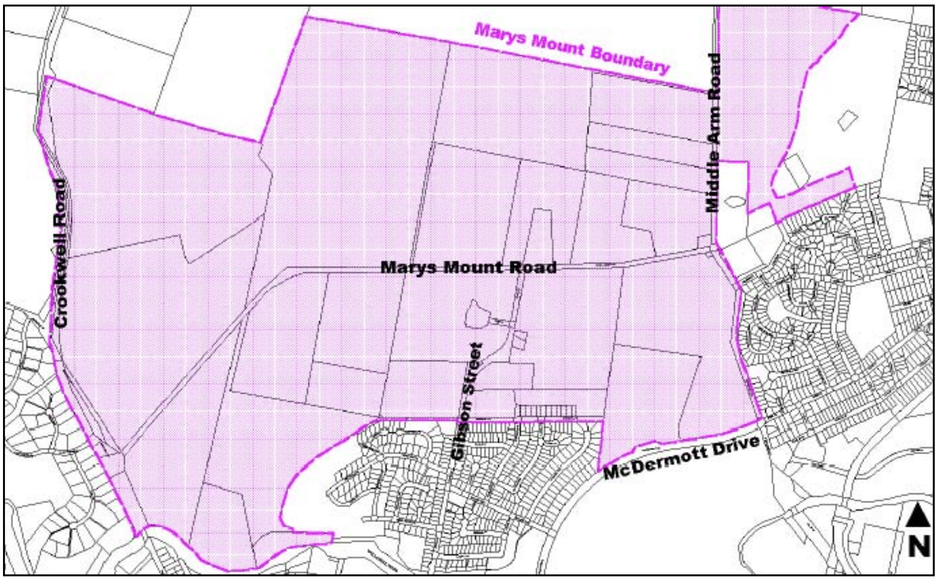

Figure 1.1 Mary's Mount DCP area

1.3. SITE DRAINAGE

The drainage corridors within the DCP area drain in a north to south direction into the Wollondilly River (Drawing M288/P01 Appendix A). The corridors are generally wide and flat at the northern end (Plate 1.1) but become more incised and defined closer to the Wollondilly River (Plate 1.2).

The current flow regime in the upper reaches of the catchment can be described as broad, shallow, sheet flow. However, on the southern side of Mary's Mount Road towards the Wollondilly River, incised low-flow channels have formed within the drainage corridors.

It was noted above that the drainage reserves will be formalised within the Mary's Mount DCP Area to facilitate the safe conveyance of flood flows in natural low maintenance system. Such a system would be heavily vegetated to prevent erosion through the retardation of high velocities.

While the current flow regime has been described above as one with broad sheet flows the widths of flow will be reduced and consequently the depths of flow will be increased. This practice is common when developing green filed sites, to increase the developable yield, with the major difference that in the past, concrete or grassed channels have most often been used without much consideration of natural stream processes or the long term maintenance burden.

The adopted solution for Mary's Mount is a middle-of-road approach which results in an increase in lot yield while simultaneously increasing diversity and natural process and reducing Council's maintenance burden.

Plate 1.1 Broad shallow drainage corridors (upper reaches)

Plate 1.2 Existing incised stream looking towards the Wollondilly River

1.4. REFERENCE DOCUMENTS

These stream management guidelines should be read in conjunction with the following documents (in order of priority);

- *Mary's Mount Drainage Corridors Vegetation Management Plan* (Storm Consulting, 2003)
- *Goulburn City Council Draft Goulburn Development Control Plan No. 14 – Mary's Mount* (Goulburn City Council 2003).
- *Water Sensitive Urban Design Report, Mary's Mount, Goulburn* (Storm Consulting 2003).

The reader should become familiar with the contents of these documents in relation to management of stormwater on the site.

2.0 DEVELOPMENT OF MARY'S MOUNT

Approximately 410 hectares of urban development is planned for Mary's Mount, Goulburn. The Mary's Mount DCP identified the need to maintain a system of major overland flow paths, in accordance with the principles contained in *Australian Rainfall and Runoff* (1987). As a result, drainage corridors have been defined and are to be dedicated to council. These drainage corridors are:

- To be resistant to erosion, and fully stabilised through a process of revegetation;
- To be aesthetically pleasing and be accepted by the community as a public amenity.

The vegetated drainage corridors form part of a larger scheme for water management on the site through the implementation of Water Sensitive Urban Design (WSUD) techniques. These techniques in fact reduce site runoff and the consequent size of conveyance controls.

All development within the Mary's Mount DCP is to be constructed in accordance with the principles of WSUD and in accordance with the report commissioned by Goulburn City Council: "Water Sensitive Urban Design, Mary's Mount Goulburn, by STORM Consulting Pty Ltd, July 2003.

There are legislative requirements outlined in the VMP that are pertinent to stream formalisation works, and include, but are not limited to:

- *Rivers and Foreshores Improvement Act 1948*
- *Native Vegetation Conservation Act 1997*(removal of native or exotic vegetation)
- *Threatened Species Conservation Act 1995*
- *Soil Conservation Act 1938* (works to mitigate soil erosion)

2.1. STORMWATER DRAINAGE CORRIDORS

Drainage corridors must have the capacity to convey overland flow during infrequent storm events up to the 100 year ARI storm event. The actual stream section must be fully contained within the drainage corridor. Minimum corridor widths are specified in the Mary's Mount DCP, Figure 11 (Goulburn City Council 2003). These areas will be dedicated to Council as drainage reserves.

The drainage reserve includes a "buffer zone" that allows for establishment of terrestrial vegetation, which will provide a buffer during possible but unlikely overtopping during extreme flood events. For planning purposes a buffer zone of 5m in width each side of the stream has been adopted (measured above 100 year ARI storm), however the buffer is likely to be greater which will be confirmed by detail hydraulic design.

During the early planning stages of the development it is not known how each developer wishes to develop their respective landholdings. If there is a drainage corridor that occurs within a development, that corridor will need to safely convey the 100 year ARI flow through the corridor, thus leaving all adjacent development free from flooding. The corridors then represent an opportunity for developers to increase their landholding by altering the flow regime from broad sheet flow to narrower but deeper flow.

In summary, there are three possible ways of achieving this outcome. They are:

1. By excavating the bed and banks of the channel.

2. By filling adjacent to a channel so that the existing bed of the channel is unchanged but filling either side of the bed would create a narrower corridor through which flood flows can be conveyed.

3. By a combination of filling and excavation.

These scenarios are explained further below.

2.2. STREAM DEVELOPMENT & OPTIONS

There are many areas at Mary's Mount that currently have "unformed" drainage corridors – ie have a broad sheet flow regime. These areas are likely to require formalisation as a "naturalised" drainage system (trunk drainage corridor) to convey flood flows through the development. It is recommended that this flow can be concentrated in a narrower channel to increase the land yield in the catchments. This formalisation work is to be undertaken by developers when they develop their respective landholdings. The developers will need to fill adjacent to the channels and or excavate the channels to ensure that the lots are constructed above the estimated 100 year ARI water levels.

The alternative is to leave the channels as they are today, and simply revegetate for stability purposes. Each stream section that is formalised is also to be revegetated. Vegetating the entire stream system will ultimately stabilise and protect the system and provide common water quality and environmental benefits. It is also consistent with DCP 14.

The various development options with benefits and consideration when adopted each are documented in Appendix A

2.2.1. Excavation of channel bed

An incised stream would be appropriate when little or no earthworks are planned for the subdivision. Generally this form of construction is suitable when site contours are steeper and the proposed location of the drainage corridor is already situated within a relatively defined drainage channel.

In simple terms, the stream may be formed by excavating to achieve the shape of the desired channel. However, if possible it is encouraged that existing in-stream vegetation and bed features are retained, particularly in the lower reaches of the drainage corridor towards the Wollondilly River where there is rock and established vegetation.

Incised stream sections should be revegetated and protected from erosion consistent with methods outlined in these guidelines and specified in the Mary's Mount Drainage Corridors Vegetation Management Plan (Storm Consulting 2003).

2.2.2. Formalised stream – Filling adjacent to bed

In many cases it will be advantageous to construct the stream by filling to from stream embankments, undertaken in conjunction with earthworks for the subdivision. It is recommended that the works are undertaken in conjunction to ensure integrity of fill and consistency in earthworks. The major advantage of this option is by filling the lots more land will be available for development that will not be prone to flooding.

In this instance it is recommended that earth works that are part of the stream formation be done in accordance with *AS3798 – Guidelines on earthworks for residential development*. This is required to ensure suitable fill and compaction methods and standards are adopted, thereby minimising the potential for erosion.

Again, revegetation and erosion control is essential and should be consistent with methods outlined in these guidelines and specified in the Mary's Mount VMP.

2.2.3. No stream formalisation

There may be some instances at Marys Mount where a developer does not wish to formalise the drainage corridor. This would occur, when for example, a development is situated some distance from a drainage corridor and there is no intention to develop to the limit of the drainage reserve.

Not formalising the stream may cause nuisance flooding within the subdivision and the drainage corridor width (as documented in DCP-14) is not likely to satisfy flood conveyance requirements. In this instance the flood immunity of the development needs to be verified by a qualified Engineer.

In any instance, revegetation of the unformed drainage depressions will still be required to ensure that the creek systems remain stable (resistant to erosion) and have a low maintenance requirement.

2.2.4. Hydraulic assessment

Either of the above options will require hydrology and hydraulic assessment and design by a suitably qualified engineer. Assessment will include consideration of the following;

- Assessment of the flow regime using an acceptable hydrology & hydraulic model(s) to ensure capacity of the stream to safely convey flows. Furthermore, assurance is required that the lots are constructed above the estimated 100 year ARI water level so that lots are not encumbered with a flood prone title.
- Formalised streams, either in fill or cut, will require hydraulic assessment to determine the geometry of the channel ensuring that velocities are within an acceptable limit to minimise erosive forces. This provides guidelines in designing streams.

Details of calculations and modelling must be submitted to Council for review during the development stage.

2.3. RIVERS AND FORESHORES IMPROVEMENT ACT

When any development is in or within 40m of the top of the bank or shores of protected waters or prescribed streams, a permit is required under Part 3A of *the Rivers and Foreshores Improvement Act 1948*. The Development Application will be referred by Council to the Department of Infrastructure, Planning and Natural Resources (DIPNR) who administer the Act.

The *Rivers and Foreshores Improvement Act (R&FI) 1948* applies to protected waters, and includes both natural and artificial water bodies. Part 3A of the R&FI Act also applies to the bank, shore or bed of these water bodies and adjacent land within 40m of the top of banks, which is known as protected land. Part 3A may also apply to land further than 40m from a water body, as determined by DIPNR.

The purpose of Part 3A of the R&FI Act is to control activities and development that that have the potential to cause adverse impacts. These impacts include detrimental effects such as increased erosion, bed lowering, stream diversion, obstructing stream flow, ecological deterioration and long term stability issues. A 3A permit is issued with conditions attached which are specific to the type of activity being undertaken. Part 3A gives DIPNR the authority to order remediation works if it considers an activity has or might damage or adversely affect protected land and waters (DLWC 2000).

In relation to Mary's Mount DCP area, the R&FI Act applies to the stream system situated on the southern side of the Mary's Mount Road. Developers must seek a 3A permit for works within or adjacent to the defined drainage corridors. For details of the relevant areas refer to Drawing enclosed in the Marys Mount Vegetation Management Plan, Appendix A. (Storm, 2003)

Drainage corridors outside the above-mentioned areas, generally in the north of the DCP area, are not subject to the R&FI Act. However, DIPNR (Goulburn Office) should be consulted with in regards to stream design and revegetation, in particular when landowner owners propose to formalise drainage corridors as this can lead to adverse impacts on the surrounding environment if not done correctly. It is recommended that stream designs be submitted to DIPNR for comment prior to commencement of any works.

3.0 STREAM DESIGN

Stream design is particularly important for the Mary's Mount subdivision to safely convey flood flows and provide a "natural" functioning watercourse. A holistic approach is recommended for stream design (see Section 3.1 below), to combine required hydraulic conveyance with environmental, ecological and aesthetic stream attributes.

3.1. STREAM DESIGN PROCESSES

The following table (Table 3.1) illustrates the processes involved in the design of stream sections in the Mary's Mount subdivision. These steps must be undertaken for *all* stream development options, including the option for no stream formalisation.

Table 3.1 Stream design processes

A	***Flow Determination*** - undertake hydrological study to determine flow
B	***Identify drainage corridor width*** as shown in *Goulburn City Council Draft Goulburn Development Control Plan No. 14 – Mary's Mount*
C	***Determine creek cross-section and long-sections*** in accordance with section 3.2 of these *Mary's Mount Drainage Corridors Stream Management Guidelines*
D	Using flow determined from Step A and stream geometry from Step C, ***check the conveyance capacity*** of the stream to ensure that the 100 year ARI storm event flows are contained within the corridor width identified in step B
E	***Adjust and revise stream geometry*** and corridor until velocities and all other factors comply with the requirements of section 3.2 and flow can be safely conveyed within the drainage corridor

3.2. STREAM CHARACTERISTICS

3.2.1. Bank full flow rate

Bankfull flow rate (Q_f) is the amount of water passing through a channel when it is flowing at the top of its banks. Major stream forming activity such as erosion and deposition occur during these regular flooding events. The bankfull flow has a large influence on the geomorphic characteristics of a channel, ie. the planform, bank shape, bed stability and other structures within the channel. Therefore, the bankfull flow must be incorporated into stream design and rehabilitation work. Estimations of bankfull flow rate can be made from the existing channels on the site using

Manning's equation. If estimation of bankfull flow rate is not possible it can be assumed that the 1 in 2 year ARI peak flow at that point is the bankfull flow.

The geometry of a stream is directly related to the bankfull flow rate (Q_f). From the determined bankfull flow rate, the width and depth of the stream can be calculated. Ultimately, the total drainage corridor must convey the 1 in 100 year design storm. Hydraulic modelling and a flood study are required to determine these requirements. Figure 3.1 shows the relationship between bankfull flow and the 1 in 100 year flow within the drainage corridor.

In the case of streams in Mary Mount DCP area, bankfull flow rates will become less defined in the upper reaches of the streams, generally on the northern side of Marys Mount Road.

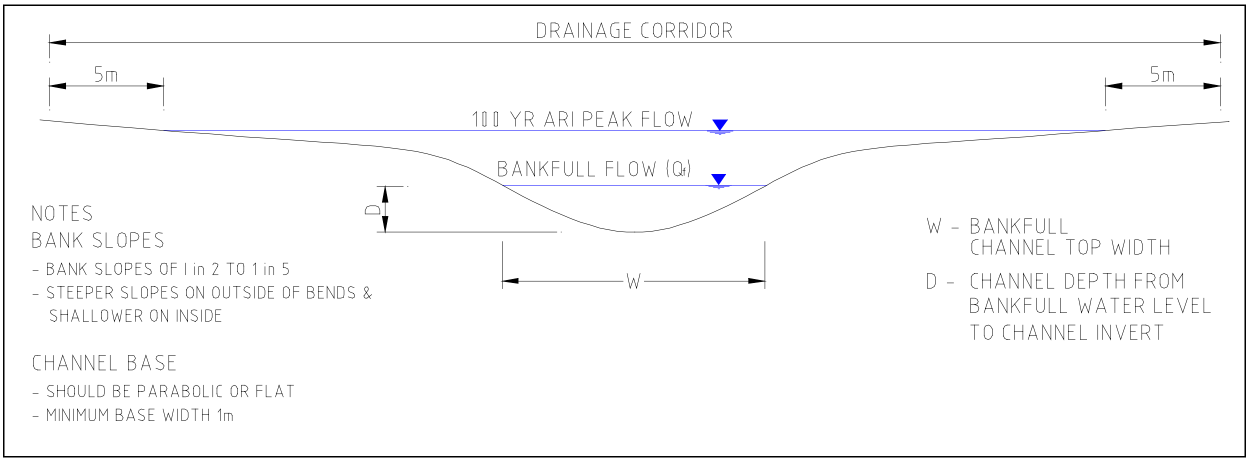

Figure 3.1 Major stream with a low flow channel – typical section

3.2.2. Stream geometry

A detailed flood and hydraulic analysis must be undertaken by proponents to ensure the drainage corridor has the capacity for 1 in 100 year storm event. The stream must be contained within the drainage corridor widths specified in the *Mary's Mount Drainage Corridors Vegetation Management Plan*, (drawing M288/P01, Appendix A).

If it is not possible to convey the flows within the corridor widths then the corridor width would need to be widened to convey the flows within the limits of stable velocities and other factors as defined in this document.

In the case where the bankfull flow is definable (ie. the 1 in 2 year flow rate is measurable and in the order of approximately 100–200 litres/second), the stream section should include a low flow channel (Figure 3.1).

As shown in the figure above, stream width is defined as the stream's width at the top of bank. Stream depth is the elevation difference between bankfull water level and stream invert.

As a guide to determining stream widths and depths, Brisbane City Council (2000) has published a set of design guidelines for natural streams. Table 3.2 below shows the Brisbane-based equations for determining stream geometry, which are recommended for use where bed vegetation is a common feature of the watercourse. The final judgement on stream width and depth is dependent on site conditions and constraints as well as the experience and judgement of the designer.

Table 3.2 Determining stream width and depth for clay-based creek systems with significant sand and gravel bed deposits (BCC 2000).

Bankfull flow rate (Q_f)	Typical bank width W#	Typical depth D#
Q_f < 100 m^3/s	$4.37(Q_f)^{0.373}$	$1.07(Q_f)^{0.224}$
All flows	$4.33\ (Q_f)^{0.5} > W > 1.78\ (Q_f)^{0.5}$	$0.598\ W^{0.6} > D > 0.295\ W^{0.6}$

See Figure 3.1 for dimension details

These widths and depths should be used somewhat critically to ensure that “realistic” stream sections result. A regular trapezoidal stream shape is to be avoided, and instead a varied stream section should be adopted.

It is important that the stream width and depth of a formalised section are integrated with upstream and downstream sections, or that appropriate structures are put in place, particularly where formalised sections are upstream of an uniformalised reach (see Section 5).

3.2.3. Bank stability

Similarly, bank slopes of formalised streams should attempt to blend in with the bank slope immediately upstream and downstream, unless those banks are particularly steep.

Stream banks slopes should be between 1:3 and 1:6 (V:H) with steeper banks on the outside of bends. Bank slope selection should be confirmed by geotechnical investigations. Final bank slope should also consider the type of soil in the bank (either existing or imported fill) and requirements for vegetation and any other constraints of the site.

3.2.4. Roughness

Channel roughness is defined by the material and vegetation lining the bed and banks of the channel. In general the higher the roughness or Manning’s n value, the less hydraulically efficient a channel is. For example, assume two channels of identical shape and slope, one lined with concrete and the other with vegetation. The channel lined with concrete will convey much more water in a given time than a channel that is planted out with grasses and shrubs on the bed and bank.

BCC recommends that the maximum velocity during bankfull flow and 1 in 50 year flood event for a stream with an average Manning’s n roughness of 0.150 is less than 1 m/s to avoid significant vegetation damage.

During the planning stage of the Mary’s Mount project, design of the trunk stormwater system included consideration of volume, velocity and depth in order to safely convey stormwater from the site. <u>The Manning ‘n’ adopted for the streams was 0.15 which allows for mass planting to occur with a low maintenance requirement</u>. This also satisfies riparian corridor requirements. The roughness value above should be used for future stormwater stream designs.

3.2.5. Stream fall

The stream fall is the change in elevation of the stream along the proposed section to be formalised. Any fixed bed features such as bedrock and established vegetation will affect the allowable fall of the streambed.

A streambed slope of between 1 - 2.5 % is recommended for the Mary's Mount drainage corridors. Streams with a lesser slope are acceptable only if dry weather flow is maintained through the low grades. Slopes steeper than three percent are not recommended due to their high erosive potential.

If designers are faced with steeper grades then appropriate drop structures located along the length of the stream can be incorporated to reduce the grade, see Section 4.0. For example, a 100m length of stream at 4% can be reduced to grade of 2.5% by incorporating four drop-structures along its length, each with a drop of 350mm.

3.2.6. Stream meander radius

Streams and rivers do not flow in straight channels but wind across the landscape. Generally they are non-symmetrical in section and hence water moves at different velocities along sections of the stream. Flow velocities are greatest on the outside of bends, which may result in bank erosion at these points. Conversely, flow velocity is lower on the inside bend, resulting in sediment deposition.

It is desirable to introduce stream meanders in stream construction to improve aesthetics and increase habitat and stream diversity. Introducing stream meander also increases the effective length and slope of the stream, and may also alter resistance to flow and the bank full velocity.

Sinuosity describes the curvature of a stream. Minor stream sinuosity (channel length divided by valley length) of between 1.0 and 1.2 is recommended. Note that the sinuosity of the low flow channel within the bed can be different from the sinuosity of the main channel.

Generally, stream design recommends that a template approach is used to determine the meander planform - mimicking the pre-disturbance course or the meander of similarly sized streams in the surrounding catchments.

Developers should avoid the formation of a smooth and repetitive 'sine curve' or straight channel. Instead, an irregular meandering stream and drainage corridor should be adopted. As a guide, the channel should have a non-uniform planform with an average meander wavelength of approximately 10 – 20 times the stream width, this will result in wavelengths for larger in the order of 150 and 300. The meander radius will generally be defined by the overall drainage corridor width, as a guide this should be in order of 10-20 times the stream width, which will generally be in the order of 100 to 200m (denoted as R in Figure 3.2). This is illustrated below in Figure 3.2.

The drainage corridor locations and widths shown on Drawing M288/P01 (STORM, 2003) and DCP-14 are for planning purposes and the designer is encouraged to vary these slightly to introduce sinuosity, so long as the proposed location suits existing site features.

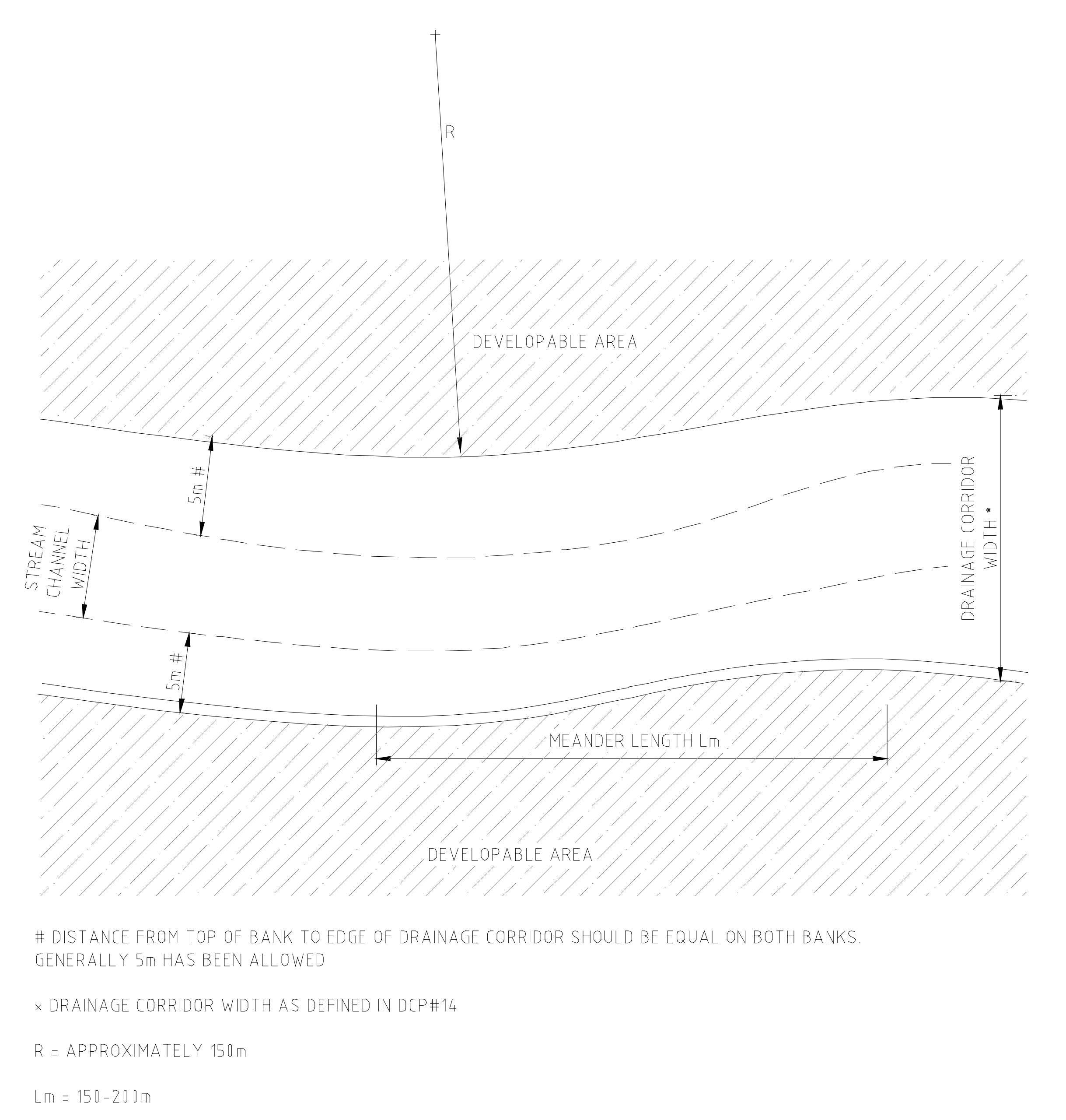

Figure 3.2 Stream meander radius

3.2.7. Incorporating in-stream features

In-stream features such as snags and boulders play an important role. They provide diversity and habitat for aquatic life, and can slow the bankfull velocity, hence reducing the erosive potential of streamflow. While it is recognised that these features have an important function, it is recommended that these features are allowed to develop over time due to natural stream processes.

3.3. STREAM VEGETATION

The vegetation of a stream and its banks has a vital role in overall stream stability and health. Vegetation assists in providing erosion control, bank stability and can significantly influence both the short-term and long-term stability of a watercourse.

Various types of vegetation can provide different effects in terms of erosion control, bank stability and stream processes. For example, aquatic in-stream plants provide good stability in low flow streams by slowing the flow of water and thereby protecting the toe of the stream bank and preventing erosion. Stream vegetation creates stream roughness and resistance to flow. Denser vegetation generally increases the roughness of the stream.

The stability of a dry streambed is governed by the health and density of instream and bank vegetation, which in turn is influenced by the duration and velocity of bankfull flows. Groundcover vegetation, such as *Lomandra* spp., assists in controlling scour of a stream, while deep rooted trees and shrubs anchor the stream bank and prevent landslips associated with undercutting and slumping.

The drainage corridor widths specified in Drawing M288/P01 by STORM Consulting Pty Ltd (refer to *Mary's Mount Drainage Corridors Vegetation Management Plan*) include a minimum five metre buffer zone either side of the stream top of bank. This buffer zone protects streams from adjacent development and allows for creek migration within the corridor. Vegetation also effectively filters sediments and other pollutants from runoff, which is one reason why vegetated streams are preferable.

Vegetation of streams and its associated activities such as weed control and maintenance must be undertaken in accordance with the *Mary's Mount Drainage Corridors Vegetation Management Plan* prepared by STORM Consulting Pty Ltd and should be used in conjunction with these guidelines.

3.4. ROAD CROSSINGS

Road crossings are required in the DCP area where roads (in particular Mary's Mount Road) intersect with the drainage corridors. As for any activity that takes place within an identified protected water body, appropriate permits must be obtained from relevant authorities before any works associated with road crossings commence. Relevant legislation includes but is not limited to, the *Fisheries Management Act 1994* and the *Rivers and Foreshores Improvement Act 1948*.

Culvert crossings are one of the most common forms of road crossings, but have the potential to cause problems in the stream environment. There are a number of factors to consider when designing and constructing a culvert crossing, which are listed below in Table 3.3.

Table 3.3 Culvert crossing recommendations

Potential issue	Recommendations and safeguards
Altering hydraulic conditions	Ensure culvert entrance efficiency is sufficient for expected flows (ie. hydraulic capacity should be equivalent to the bankfull flow rate)
	Shape culvert to match embankment slope and stream alignment
Erosion of stream bed and embankments	Install stilling basins downstream of the culvert outlet to dissipate energy
	Reduce turbulence by matching culvert entrance shape with the slope of the embankment and stream alignment
	Culvert slope to be within recommended grade, usually at a slope equivalent to the stream grade
	Rock armour culvert entrance and exit and their embankments, as well as road embankment
	In cases of severe erosion, a cut-off wall may be necessary
Construction notes	Preferably locate on a straight section of stream
	Approach road should be straight for at least 10 metres either side of the crossing
	Culverts must be long enough to permit construction of stable, erosion-resistant end-wall slopes
	The culvert structure should be keyed in to a sufficient depth to prevent water from eroding the crossing ends
Environmental issues	Culverts must be sensitive to the ecology and geomorphic functions of the stream and wildlife corridors, and where possible integrate with the natural features of the stream and surrounds.

A typical culvert crossing showing protection of the culvert entrance and exit is shown below in Figure 3.3.

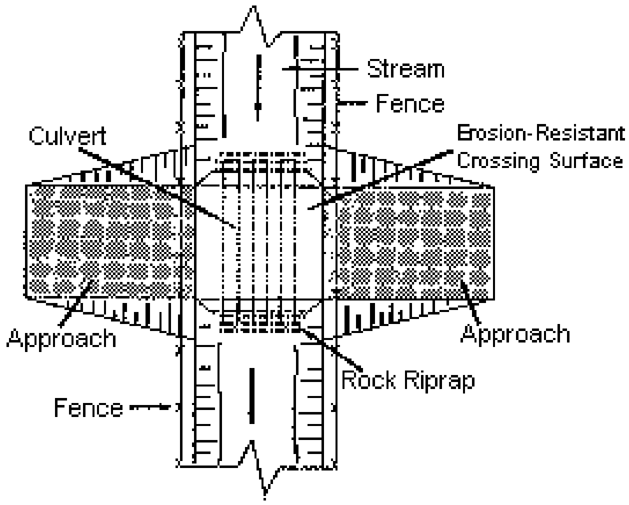

Figure 3.3 Plan view of typical culvert with culvert inlet and outlet protected by riprap

(Source: Ontario Ministry of Agriculture and Food,1992.)

To ensure continuity of corridors created by the revegetation works associated with stream formalisation, it may be necessary to include habitat corridors in the culverts (minimum diameter 300mm). Revegetation of the channel should continue as far as possible to hard structures (ie. The culvert) to maximise continuity of riparian zones.

3.5. WATER QUALITY TREATMENT STRUCTURES

During the course of development, it may be required to install water quality treatment structures and/or stormwater detention devices. These structures should be located outside of the riparian zones and drainage corridors to ensure that treatment of stormwater occurs prior to discharge into the drainage corridors and riparian zones.

4.0 EROSION CONTROL

Watercourses are dynamic systems, continually undergoing change. While erosion in streams is a natural process, urbanisation and other changes to the natural flow regime can exacerbate the erosion that occurs in streambeds and banks.

The drainage corridors in Mary's Mount show signs of bank erosion and gullying which can be addressed during stream formalisation construction phase. However, during stream formalisation and revegetation there is the potential for other kinds of erosion to occur, and so short-term mitigation measures must be put in place to prevent and control erosion. Various recommendations have been suggested to help address the types of erosion likely to be found in the drainage corridors.

4.1. EXISTING EROSION

The existing drainage corridors within the Mary's Mount DCP area exhibit two types of stream erosion:

1. Bank undermining is one kind of erosion - mainly occurring on the outside and downstream end of a bend in the stream. Stream flow is a contributing factor to bank erosion, leading to erosion by undermining and subsequent collapse of bank material (Plate 4.1).

Plate 4.1 Stream bank erosion at Mary's Mount, Goulburn (right hand side, middle)

2. Gully erosion is also evident in the Mary's Mount DCP area - particularly in the western and upstream reaches of the drainage corridors. Extensive runoff from adjacent land may cause bank erosion at the point of entry, creating an erosion head. Headcuts will continue to migrate upstream if untreated, creating gullies (Plate 4.2).

Plate 4.2 An example of gullying in a drainage corridor (Freedom's Reach, Windellema)

It is recommended that bank slopes be appropriately battered to address bank and gully erosion at Mary's Mount (Figure 4.1). Banks which have been battered can be further stabilised by erosion control mats and revegetation. If the erosion is on the outside of the meander bend, further protection such as rock armouring may be required.

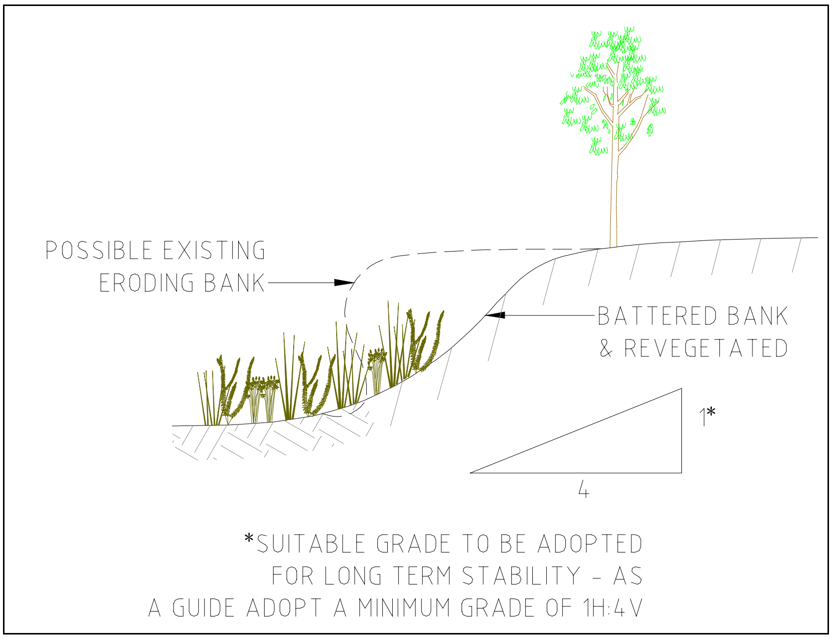

Figure 4.1 Battering and revegetation of banks to address bank erosion

4.2. POTENTIAL STREAM EROSION

While careful stream design and vegetation can minimise the potential for erosion, streambed and bank erosion may eventuate overtime. Potential kinds of erosion include:

- bank erosion and gullying (as discussed in Section 4.1);
- bank slumping; and
- bed erosion.

It is important that suitable erosion control measures are put in place when erosion becomes evident to halt and mitigate erosion and its impacts. Table 4.1 below lists a range of erosion control techniques that could be used to address erosion within drainage corridors. This list is by no means exhaustive and the following table only lists common and effective methods of controlling erosion. Any in-stream hydraulic structures must be designed by qualified consultants in light of site constraints and appropriate permits must be obtained.

Table 4.1 Erosion control measures for drainage corridors

Erosion control measure	Purpose
Drop structures	Grade control and headcut prevention
Timber sills	Grade control and headcut prevention
Chutes	Grade control, headcut prevention, bed protection
Pool and riffle systems	Grade control
Bed control pads	Prevent headcut movement upstream
Bank and bed armouring	Bank and toe protection

Rock drop structures (Plate 4.3) and timber sills (Plate 4.4) used in conjunction with plunge pools can provide erosion control by absorbing steep bed grade and dissipating hydraulic energy. They serve to pass the design flow of the stream from a higher to a lower elevation in a controlled way, allowing a lower grade and a non-erosive velocity to be adopted for the stream section downstream of the structure. Special care in design and construction should be taken to ensure that undermining or outflanking of the structures does not occur. Drop structures and sills are fixed structures that span the stream, and create a fixed step in the stream bed level.

Chutes provide an alternative to sills and drop structures. Chutes are long rock-lined ramps that convey flow down an even gradient, and can also act as a bed control structure. Chutes can also be used to control grade and stabilise an erosion head. Chute geometry and rock size should be matched with the expected flow conditions of the stream so that rock remains stable.

Plate 4.3 Rock weir

Plate 4.4 Timber sills immediately after construction and during flow

A pool and riffle system is a combined approach to erosion, integrating deep pools with riffles to control flow (Plate 4.5 and Plate 4.6). During low flows the water surface profile is stepped, with a flat surface across pools and steep over riffles. In high flow events, the pool riffle system is drowned out, with the water surface profile approximating that of the overall stream gradient. Pools should be sized for given hydraulic conditions.

Plate 4.5 An example of pools and riffles in a stream (Burns Creek, Fairfield)

Plate 4.6 Pool and riffle construction (Restoring the Waters, Fairfield)

Armouring of the bed and stream bank physically protects stream material from the action of stream flow. Armouring protects against the removal of stabilising material from the toe of the bank, and prevents mass failures by collapse and slumping. Bank armouring also assists in controlling erosion from overland flow. In addition to the establishment of dense native vegetation, typical bank protection techniques include rock riprap (Plate 4.7). Vegetation such as logs and branches, which are secured to prevent movement, can also be used. Over time, sediment will be deposited and accumulate between the rocks and brushing, providing a substrate for plants to take root and grow.

Plate 4.7 Rock armouring on stream embankments

4.3. STORMWATER OUTLETS

Stormwater outlets can cause instability and erosion in stream. If the discharge flows cannot safely transition into the receiving stream, armouring and/or an outlet structure may be necessary to prevent erosion. While a good vegetative cover can provide some form of additional protection, other forms of protection may be necessary to reduce the velocity of the stormwater flow to a level that will not cause scour of the receiving stream.

A critical factor in stormwater outlet design is the exit velocity in both the tributary and receiving stream. If possible, the outlet velocity should be lowered by constructing the final length of pipe/channel to a grade that provides the required velocity.

The outlet should be angled in the direction of the main flow of the receiving stream. Angling the outlet results in a smoother flow transition, lowering the potential of scour due to turbulence. An approach angle of 45-60 degrees as measured from the bank is recommended (Figure 4.2).

It is also preferable for the outlet to be at or slightly below the normal water level of the receiving stream, utilising its impact absorbing potential. If this is not possible, the bank of the stream and even the bed at the outlet may require protection (Plate 4.8). The opposite bank and bed may even require protection unless the water is deep enough to protect against scour.

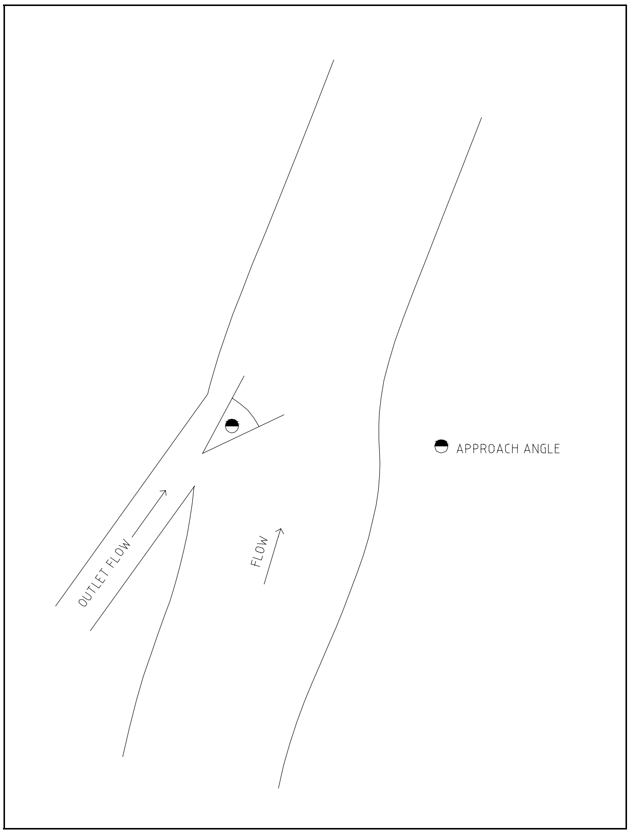

Figure 4.2 Stormwater outlet approach angle (45 to 60 degrees)

Plate 4.8 Stormwater outlet protection, Buffalo Reserve

5.0 INTEGRATION OF FORMALISED STREAMS

5.1. INTRODUCTION

It is recognised that the development of drainage corridors may be undertaken by separate developers and in a staged manner. Therefore it is essential that stream sections be integrated by successive developers to maximise the overall success of the stream works and to ensure the functionality of drainage corridors.

Developers need to ensure that respective sections of formalised stream are connected with existing natural or formed streams. Various development scenarios include the following:

- A developer formalises a stream section where the downstream creek is unformed and in a natural state. A suitable transition structure will be required at property boundary to spread flows. The structure *must* be within the developer's property;

- A developer formalises a stream section and needs to connect with an existing formed stream. The transition structure on the other property will have to be removed and the stream reinstated.

5.2. IMPACTS OF STREAM FORMALISATION

Stream formalisation can impact both upstream and downstream reaches, including:

- Bed erosion in the upstream stream due to increased flow velocities;

- Upstream bank erosion resulting from an increase in bankfull flow rate; and

- Bank erosion in downstream reaches from increased velocities (BCC 2000).

These points are also documented in a table enclosed in Appendix A

5.3. OPTIONS FOR INTEGRATING STREAM SECTIONS

Various solutions exist to integrate formed and natural stream sections. One example includes installing a stilling pond at the downstream end of the works and upstream of an unformed section of stream, thereby allowing water to disperse as it flows over (Figure 5.1 and Plate 5.1).

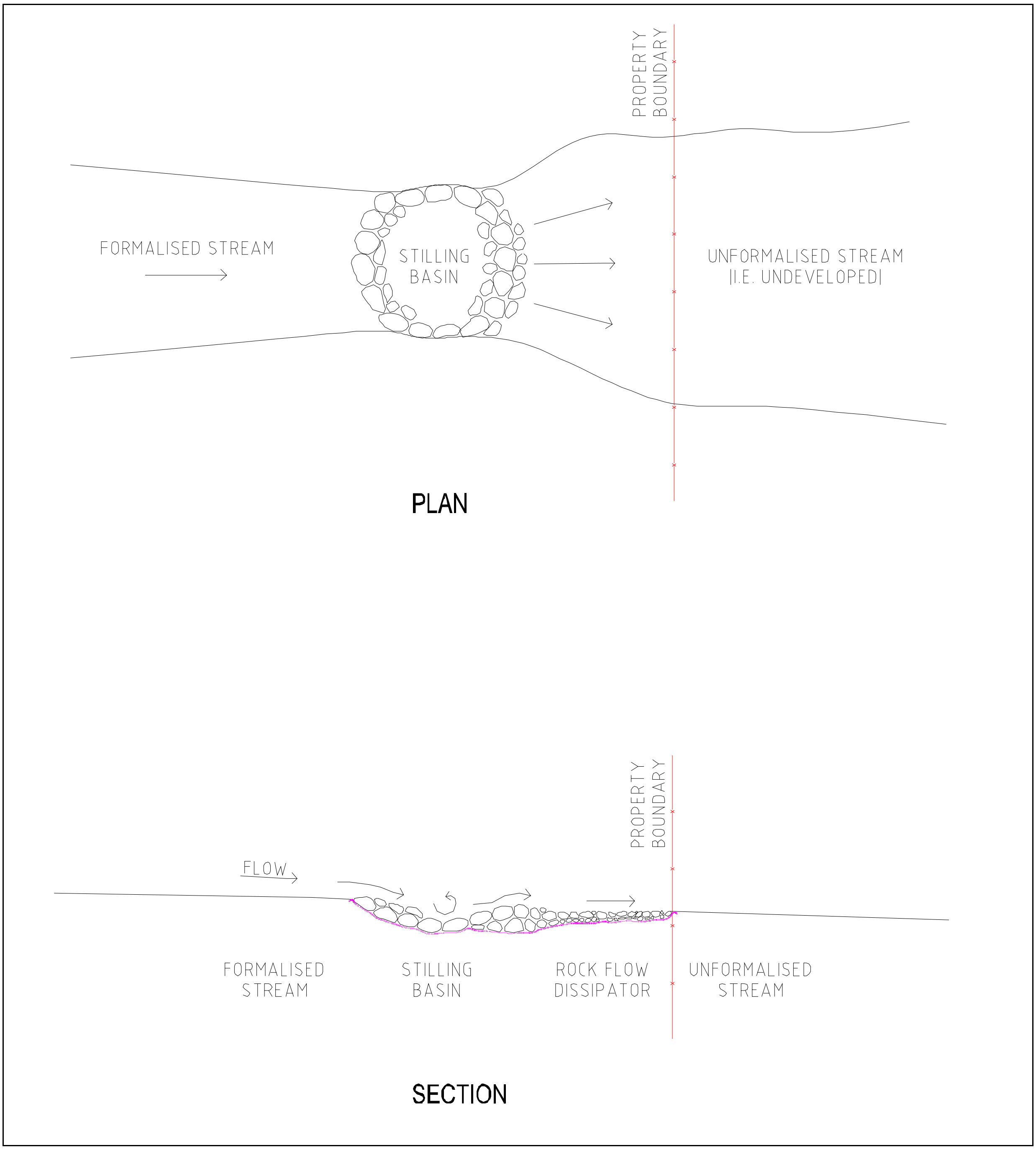

Figure 5.1 An example of using a pool and riffle system to dissipate flows from a formed section of channel

Plate 5.1 Structure used for dissipating flows in a stream, Blair's Gully, Walcha.

6.0 REFERENCES

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A1 DEVELOPMENT SCENARIOS FOR DRAINAGE CORRIDORS

DEVELOPMENT OPTION	BENEFITS	CONSIDERATIONS
Formalise stream (fill base & banks)	• May provide more developable land • In accordance with DCP and STORM's report • Allow disposal of excess fill from development	• Site grading must allow surface drainage to stream • Fill type & suitability for stream works; dispersive, imported sand on clay site … • Certification of imported fill • Sediment & erosion control is critical
Formalise stream (fill banks only)	• May provide more developable land • In accordance with DCP/ STORM's report. • Existing stream bed vegetation and features maintained • Stability for low flows maintained • Allow disposal of excess fill	• Site grading must allow surface drainage to stream • Fill type & suitability for stream works; dispersive, imported sand on clay site … • Certification of imported fill • Sediment & erosion control predominantly for banks
Stream incision	• Reduced disturbance footprint • In accordance with DCP / STORM's report • Appropriate if fill is not available • Assist with surface flow for flatter sites	• Transition (involving land-take) maybe required to meet existing ground levels at property boundaries • Sediment & erosion control critical • Must dispose of excess fill
No stream formalisation (leave as is)	• Revegetation required, providing water quality benefit & habitat • Stability is maintained by existing vegetation • Least cost solution	• Not consistent with DCP / STORM's report • Potential nuisance flooding • Drainage corridor width specified in DCP not likely to satisfy flood conveyance requirements • Generally less land available for development