Swales
(incorporating Buffer Strips)

Chapter 2

2.1 Introduction

Vegetated swales are used to convey stormwater in lieu of, or with, underground stormwater drainage systems, and to provide removal of coarse and medium sediments. They are commonly combined with buffer strips and bioretention systems (refer Chapter 3 - Bioretention Swales). Swales utilise overland flow and mild slopes to convey water slowly downstream. They provide a means of disconnecting impervious areas from downstream waterways, assisting in protecting waterways from damage by frequent storm events, by reducing flow velocity compared with piped systems.

The interaction between stormwater flow and vegetation within swale systems facilitates pollutant settlement and retention. Even swales with relatively low vegetation height (such as mown grass) can achieve significant sediment deposition rates provided flows are well distributed across the full width of the swale and the longitudinal grade of the swale is kept low enough (typically less than 4 % grade) to maintain slower flow conditions.

Swales alone cannot provide sufficient treatment to meet current stormwater treatment/ water quality objectives, but can provide an important pretreatment function for other WSUD measures in a treatment train enabling water quality objectives to be met. Swales are particularly good at coarse sediment removal as a pretreatment for tertiary treatment systems such as wetlands and bioretention basins.

A typical sketch of a swale at-grade crossing is shown in Figure 2-1.

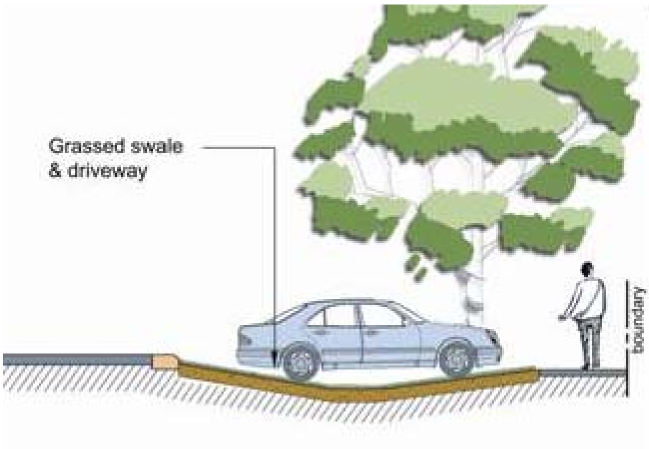


Figure 2-1: Typical Arrangement of a Swale “at-grade” Driveway Crossing

Buffer strips (or buffers) are areas of vegetation through which runoff passes while travelling to a discharge point. They reduce sediment loads by passing a shallow depth of flow through vegetation and rely upon well distributed sheet flow. Vegetation tends to slow velocities and coarse sediments are retained. With their requirement for uniformly distributed flow, buffer strips are suited to treatment of road runoff in situations where road runoff is discharged via flush kerbs or through regular kerb ‘cut-outs’. In these situations, buffer strips can form part of a roadside swale system, that is, the swale batter that receives the distributed inflows from the adjoining road pavement. The coverage of buffer strips in this chapter is limited to their application as part of a roadside swale system only. The reader is referred to *Australian Runoff Quality* (Engineers Australia 2006) for additional discussion on buffer strip design and for worked examples.

2.2 Design Considerations for Swales

2.2.1 Landscape Design

Swales may be located within parkland areas, easements, carparks or along roadway corridors within footpaths or centre medians. Landscape design of swales and buffer strips along the road edge can assist in defining the boundary of road or street corridors as well as enhancing landscape character. It is important that the landscape design of swales and buffers addresses stormwater quality objectives whilst also incorporating landscape functions. As such, it is important that swales and buffers are carefully designed to integrate with the surrounding landscape character. It is also necessary to adequately address potential aesthetics issues such as weeds and sustaining perennial plants during the dry season. Further discussion on landscape design considerations is provided in Section 2.4.

2.2.2 Hydraulic Design

Typically, swales are applicable for smaller scale contributing catchments up to 1-2 ha as larger than this, flow depths and velocities are such that the water quality improvement function of the swale and its long-term function may be compromised. For water quality improvement, swales need only focus on ensuring frequent storm flows (typically up to the 3 month ARI (Average Recurrence Interval) flow) are conveyed within the swale profile. In most cases, however, a swale will also be required to provide a flow conveyance function as part of a minor drainage and/or major drainage system. In particular, swales located within road reserves must also allow for safe use of adjoining roadway, footpaths and bike paths by providing sufficient conveyance capacity to satisfy current engineering infrastructure design requirements (as defined by Townsville City Council development guidelines). In some cases, flows will encroach onto the road surface to acceptable levels. It may also be necessary to augment the capacity of the swale with underground stormwater drainage to satisfy the road drainage criteria. This can be achieved by locating overflow pits (field inlet pits) along the invert of the swale that discharge into an underground stormwater drainage. Careful attention should be given to the design of overflow pits to ensure issues of public safety (particularly when raised grates are being used) and aesthetic amenity are taken into account.

The longitudinal slope of a swale is another important hydraulic design consideration. Swales generally operate best with longitudinal slopes of between 1 % and 4 %. Slopes milder than this can become waterlogged and have stagnant ponding, however, the use of subsoil drains (in accordance with local government standard drawings) beneath the invert of the swale can alleviate this problem by providing a pathway for drainage of any small depressions that may form along the swale. For longitudinal slopes steeper than 4 %, check banks (e.g. small rock walls) along the invert of the swale, or equivalent measures, can help to distribute flows evenly across the swales, as well as reduce velocities and potential for scour. Check dams are typically low level (e.g. 100 mm) rock weirs that are constructed across the base of a swale. It is also important to protect the vegetation immediately downstream of check dams. Rock pitching can be used to avoid erosion.

A rule of thumb for locating check dams is for the crest of a downstream check dam to be at 4 % grade from 100 mm below the toe of an upstream check dam (refer Figure 2-2). The impact of check dams on the hydraulic capacity of the swale must be assessed as part of the design process.

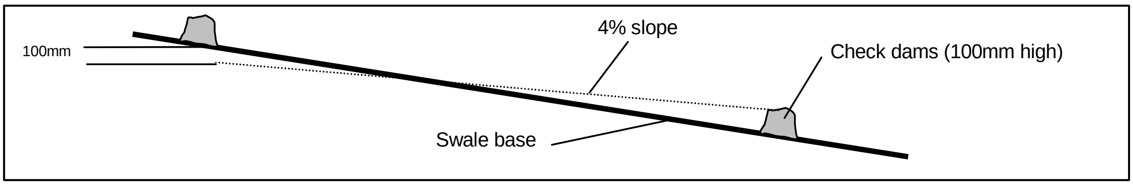


Figure 2-2: Location of Check Dams in Swales

It is important to ensure velocities within swales are kept low (preferably less than 0.5 m/s for minor flood flows and not more than 2.0 m/s for major flood flows) to avoid scouring of collected pollutants and vegetation. When located within road reserves, swales can be subjected to velocities associated with major flood flows (50-100 year ARI) being conveyed along the road corridor. Therefore, appropriate checks need to be undertaken on the resultant velocities within the swale to ensure the maximum velocity within the swale does not exceed 2.0 m/s. Similar checks should also be undertaken to assess depth x velocity within the swale, at crossings and adjacent to pedestrian and bicycle pathways and on road carriage ways to ensure public safety criteria are satisfied. These are:

- depth x velocity < 0.6 m^2/s for low risk locations and 0.4 m^2/s for high risk locations as defined in QUDM.
- maximum flow depth on driveway crossings and on road carriage ways = 0.3 m.

Minimum freeboard of 0.3 m and the 50 year Ari flood level in the swale to floor levels on structures and entrances to underground car parks.

2.2.3 Vegetation Types

Swales can use a variety of vegetation types including turf, sedges and tufted grasses. Vegetation is required to cover the whole width of the swale, be capable of withstanding design flows and be of sufficient density to prevent preferred flow paths and scour of deposited sediments.

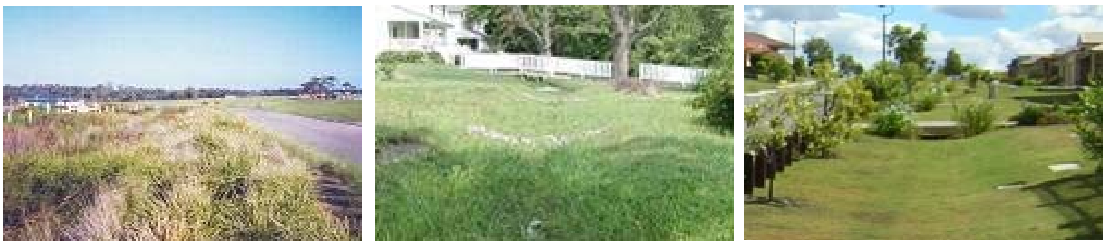


Plate 2-1: Swale systems: heavily vegetated (left), use of check dams (centre), grass swale with elevated crossings (right)

Turf swales are commonly used in residential areas and can appear as a typical road footpath. Turf swales should be mown and well maintained in order for the swale to operate effectively over the long term. Denser vegetated swales can offer improved sediment retention by slowing flows more and providing vegetation enhanced sedimentation for deeper flows. However, densely vegetated swales have higher hydraulic roughness and therefore require a larger area and/ or more frequent use of swale field inlet pits to convey flows compared to turf swales. Densely vegetated swales can become features of the urban landscape and once established, require minimal maintenance and are hardy enough to withstand large flows. To maintain aesthetics, supplemental irrigation may be required to sustain dense perennial vegetation which is also important for long term weed management.

Section 2.4 of this chapter and Appendix A provide more specific guidance on the selection of appropriate vegetation for swales and buffers.

2.2.4 Driveway Crossings

A key consideration when designing swales along roadways is the requirement for provision of driveway crossings (or crossovers). Driveway crossings can be ‘at-grade’ or ‘elevated’. ‘At-grade’ crossings follow the profile of the swale (e.g. like a ford), while ‘elevated’ crossings are raised above the invert of the swale (e.g. like a bridge deck or culvert).

Crossings constructed 'at-grade' reduce the maximum allowable swale batter slopes to approximately 1 in 9 to ensure vehicles can traverse the crossing without bottoming out. This means the swale will have a shallow profile thus reducing its flow conveyance capacity. 'At-grade' crossings are typically cheaper to construct than elevated crossings, however they need to be constructed at the same time as the swale to avoid damaging the swale. This imposes a fixed driveway location on each allotment, which can potentially constrain future house layouts. 'At-grade' crossings are best suited to developments where the spacing between crossings is typically more than 15 m. Local government standard drawings may provide guidance on appropriate driveway construction.

Plate 2-2: At-grade (left) under construction with trees yet to be established, pre-constructed 'at-grade' (centre) and elevated driveway crossings to allow vehicle access across swales

'Elevated' crossings are not appropriate in all street applications; however, where appropriate, they can be designed as streetscape features. They also provide an opportunity for locating check dams (to distribute flows) or to provide temporary ponding above a bioretention system (refer Chapter 3 – Bioretention Swales). A major limitation with 'elevated' crossings can be their high life cycle costs compared to 'at-grade' crossings (particularly in dense urban developments) due to the need for on-going maintenance. Safety concerns with traffic movement adjacent to 'elevated' crossings and the potential for blockages of small culvert systems beneath the crossing are other possible limitations. These limitations can be overcome by careful design through the use of spanning crossings rather than using small culverts and through the use of durable decking materials in place of treated timber.

2.2.5 Traffic Controls

Another design consideration is keeping traffic and building materials off swales (particularly during the building phase of a development). If swales are used for parking then the topsoil will be compacted and the swale vegetation may be damaged beyond its ability to regenerate naturally. In addition, vehicles driving on swales can cause ruts along the swale that can create preferential flow paths that will diminish the swale's water quality treatment performance as well as creating depressions that can retain water and potentially become mosquito breeding sites.

To prevent vehicles driving on swales and inadvertent placement of building materials, it is necessary to consider appropriate traffic control solutions as part of the swale design. These can include planting the swale with dense vegetation that will discourage the movement of vehicles onto the swale or, if dense vegetation cannot be used, providing physical barriers such as kerb and channel (with breaks to allow distributed water entry to the swale) or bollards and/ or street tree planting.

Kerb and channel should be used at all corners, intersections, cul-de-sac heads and at traffic calming devices to ensure correct driving path is taken. For all of these applications, the kerb and channel is to extend 5 m beyond tangent points. The transition from barrier or lay back type kerb to flush kerbs and vice versa is to be done in a way that avoids creation of low points that cause ponding onto the road pavement.

Where road edge guide posts or 'bollards' are used, consideration should be given to intermixing mature tree plantings with the bollards to break the visual monotony created by a continuous row of bollards. Bollards should comply with relevant local government specifications.

2.2.6 Roof Water Discharge

Roof runoff can contain a range of stormwater pollutants including nitrogen washed from the atmosphere during rainfall events. Rainfall is consistently the major source of nitrogen in urban stormwater runoff (Duncan 1995) and inorganic nitrogen concentrations in rainfall often exceed the threshold level for algal blooms

(Weibel *et al*. 1966). Roof water should therefore be discharged onto the surface of the swale for subsequent conveyance and treatment by the swale (and downstream treatment measures) before being discharged to receiving aquatic environments. Depending on the depth of the roof water drainage system and the finished levels of the swale, this may require the use of a small surcharge pit located within the invert of the swale to allow the roof water to surcharge to the swale. Any residual water in the surcharge pit can be discharged to the underlying subsoil drainage by providing perforations in the base and sides of the surcharge pit. If a surcharge pit is used, an inspection chamber along the roof water drainage line is to be provided within the property boundary. Surcharge pits are discussed further in Section 2.3.4.3.

Roof water should only be directly connected to an underground stormwater drainage system if an appropriate level of stormwater treatment is provided along (or at the outfall of) the pipe drainage system.

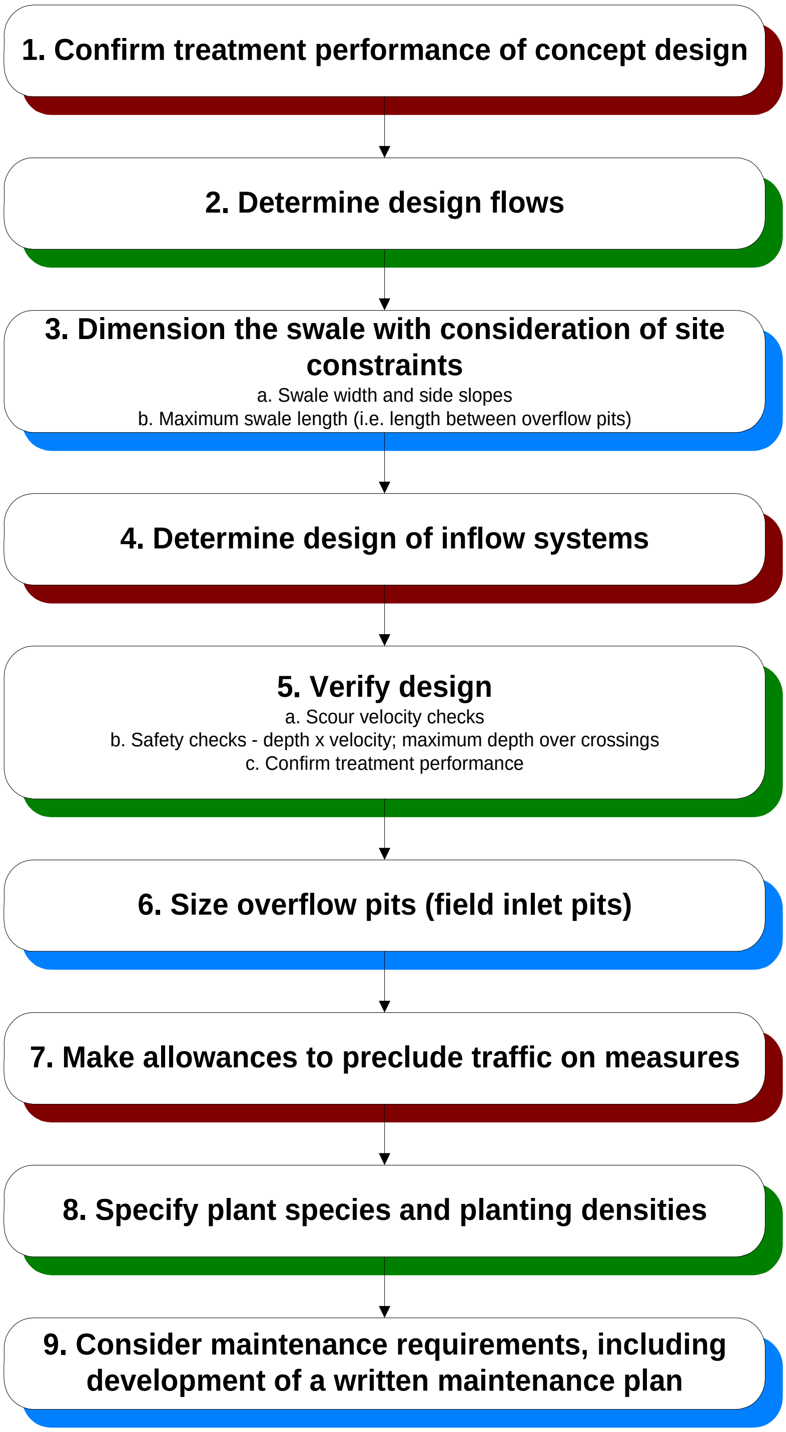
2.2.7 Services

Swales located within standard road reserves are to have services located within the services corridors in accordance with local government requirements. Sewers located beneath swales are to be fully welded polyethylene pipes with rodding points. Care should be taken to ensure the service conduits do not compromise the performance of the swale. Consideration will also need to be given to access to services for ongoing maintenance without the need to regularly disrupt or replace the swale.

2.3 Swale Design Process

The design process for swales involves in the first instance designing the swale to meet flow conveyance requirements and then ensuring the swale has the necessary design features to optimise its stormwater quality treatment performance.

The key design steps are:



Each of these design steps is discussed in the following sections. A worked example illustrating application of the design process on a case study site is presented in Section 2.9.

2.3.1 Step 1: Confirm Treatment Performance of Concept Design

Before commencing detailed design, the designer should first undertake a preliminary check to confirm the swale outlined on the concept design is adequate to deliver the level of stormwater quality improvement inferred within the concept design documentation. This assessment should be undertaken by a WSUD specialist and can be achieved by modelling expected treatment performance in an appropriate quantitative modelling program. Where possible, this modelling should be based on local rainfall data, the proposed configuration of the system, and based on local stormwater treatment performance data.

It should be noted that swales should form part of the stormwater 'treatment train' as they will not achieve contemporary load-based objectives on their own. Therefore, other stormwater quality best management practices should be incorporated into the surrounding catchment to augment the stormwater treatment performance of any proposed swale system.

2.3.2 Step 2: Determine Design Flows

Two design flows are required to be estimated for the design of a swale, particularly where they are designed within a road reserve. These are to size the swale for conveyance of flows rather than treatment:

- minor flood flow (2 year ARI) to allow minor floods to be safely conveyed. For commercial and industrial areas the design flow requirement for minor flows is a 5 year ARI event.
- major flood flow (50 year ARI) to check flow velocities, velocity depth criteria, conveyance within road reserve, and freeboard to adjoining property.

Queensland Urban Drainage Manual (QUDM) identifies the Rational Method as the procedure most commonly used to estimate peak flows from small catchments in Queensland. Catchment areas delivering flow to swales are typically small, therefore the Rational Method is recognized as an appropriate method to use in the determination of peak design flows.

2.3.3 Step 3: Dimension the Swale with Consideration of Site Constraints

Factors to consider are:

- Maximum contributing catchment area (<1-2ha)
- allowable width given the proposed road reserve and/ or urban layout
- how flows will be delivered into a swale (e.g. cover requirements for pipes or kerb details)
- vegetation height
- longitudinal slope
- maximum side slopes and base width
- provision of crossings
- requirements of QUDM and Townsville City Council requirements.

Depending on which of the above characteristics are fixed, other variables may be adjusted to derive the optimal swale dimensions for the given site conditions. The following sections outline some considerations in relation to configuring a swale.

2.3.3.1 Swale Width and Side Slopes

The maximum width of swale is usually determined from an urban layout and at the concept design stage. Where the swale width is not constrained by an urban layout (e.g. when located within a large open space area), then the width of the swale may be selected based on consideration of landscape objectives, maximum side slopes for ease of maintenance and public safety, hydraulic capacity required to convey the desired design flow, and treatment performance requirements. The maximum swale width needs to be identified early in the design process as it dictates the remaining steps in the swale design process.

Selection of an appropriate side slope for swales located in parks, easements or median strips is heavily dependant on site constraints, and swale side slopes are typically between 1 in 10 and 1 in 4.

For swales located adjacent to roads, side slopes will typically be dictated by the driveway crossing. Where there are no driveway crossings then the maximum swale side slopes will be established from ease of maintenance and public safety considerations. Where 'elevated' crossings are used, swale side slopes would typically be between 1 in 6 and 1 in 4. 'Elevated' crossings will require provision for drainage under the crossings with a culvert or similar. Where 'at grade' crossings are used, swale side slopes are typically 1 in 9. The selection of crossing type should be made in consultation with urban and landscape designers. Local government design requirements or standard drawings for driveway construction should be consulted.

2.3.3.2 Maximum Length of a Swale

Provided the water quality function of the swale is met, the maximum length of a swale is the distance along a swale before an overflow pit (field inlet pit) is required to drain the swale to an underground stormwater drainage system.

The maximum length of a swale located within parkland areas and easements is calculated as the distance along the swale to the point where the flow in the swale from the contributing catchment (for the specific design flood frequency) exceeds the bank full capacity of the swale. For example, if the swale is to convey the minor flood flow without overflowing, then the maximum swale length would be determined as the distance along the swale to the point where the minor flood flow from the contributing catchment is equivalent to the bank full flow capacity of the swale (bank full flow capacity is determined using Manning's equation as discussed below).

The maximum length of a swale located along a roadway is calculated as the distance along the swale to the point where flow on the adjoining road pavement (or road reserve) no longer complies with local government road design standards (for both the minor and major flood flows) as defined by the Townsville City Council's development guidelines and/or QUDM.

2.3.3.3 Swale Capacity – Manning's Equation and Selection of Manning's *n*

Manning's equation is used to calculate the flow capacity of a swale. This allows the flow rate and flood levels to be determined for variations in swale dimensions, vegetation type and longitudinal grade. Manning's equation is given by:

$$Q = \frac{A \cdot R^{2/3} \cdot S^{1/2}}{n} \qquad \text{Equation 2.1}$$

Where: Q = flow in swale (m^3/s)

A = cross section area (m^2)

R = hydraulic radius (m)

S = channel slope (m/m)

n = roughness factor (Manning's n)

Manning's n is a critical variable in the Manning's equation relating to roughness of the channel. It varies with flow depth, channel dimensions and the vegetation type. For constructed swale systems, recommended values are between 0.15 and 0.3 for flow depths shallower than the vegetation height (preferable for treatment) and significantly lower for flows with depth greater than the vegetation (e.g. 0.03 – 0.05 at more than twice the vegetation depth i.e. 50-100 year ARI). It is considered reasonable for Manning's n to have a maximum at the vegetation height and then to sharply reduce as depths increase. Figure 2-3 shows a plot of Manning's n versus flow depth for a grass swale with longitudinal grade of 5 %. It is reasonable to expect the shape of the Manning's n relation with flow depth to be consistent with other swale configurations, with the vegetation height at the boundary between low flows and intermediate flows (Figure 2-3) on the top axis of the diagram. The bottom axis of the plot has been modified from Barling and Moore (1993) to express flow depth as a percentage of vegetation height.

Further discussion on selecting an appropriate Manning's n for a swale is provided in Appendix E of the MUSIC User Guide (CRCCH 2005).

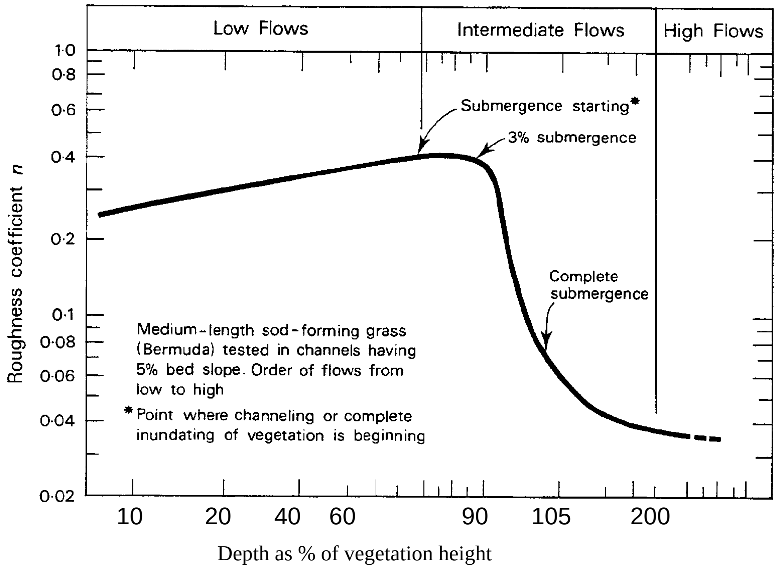


Figure 2-3: Impact of Flow Depth on Hydraulic Roughness (adapted from Barling & Moore (1993))

2.3.4 Step 4: Determine Design of Inflow Systems

Inflows to swales can be via distributed runoff (e.g. from flush kerbs along a road) or point outlets such as pipe culverts. Combinations of these two inflow pathways can also be used.

2.3.4.1 Distributed Inflow

An advantage of flows entering a swale system in a distributed manner (i.e. entering perpendicular to the direction of the swale) is that flow depths are kept as shallow sheet flow, which maximises contact with the swale vegetation on the batter receiving the distributed inflows. This swale batter is often referred to as a buffer. The function of the buffer is to ensure there is dense vegetation growth, flow depths are shallow (below the vegetation height) and erosion is avoided. The buffer provides good pretreatment (i.e. significant coarse sediment removal) prior to flows being conveyed along the swale.

Distributed inflows can be achieved either by having a flush kerb or by using kerbs with regular breaks in them to allow for even flows across the buffer surface.

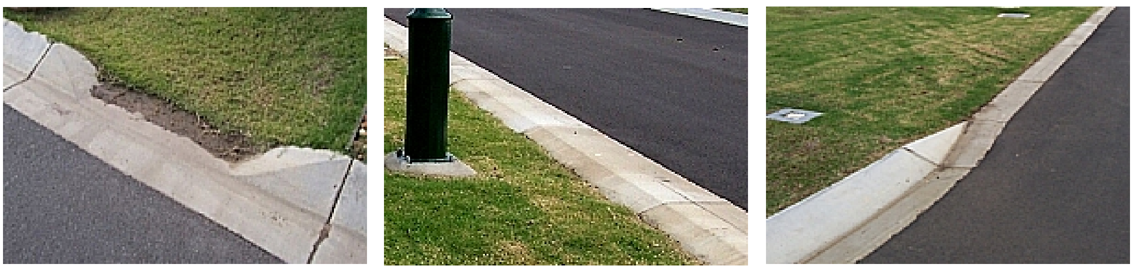


Plate 2-3: Kerb arrangements to promote distributed flow into swales

2.3.4.2 Buffer Requirements

No specific design rules exist for designing buffer systems, however there are several design guides that are to be applied to ensure buffers operate to improve water quality and provide a pretreatment role. Key design parameters of buffer systems are:

- providing distributed flows onto a buffer (potentially spreading stormwater flows to achieve this)
- avoiding rilling or channelled flows
- maintaining flow depths less than vegetation heights (this may require flow spreaders, or check dams)

- minimising the slope of buffer, best if slopes can be kept below 5 %, however buffers can still perform well with slopes up to 20 % provided flows are well distributed. The steeper the buffer the more likely flow spreaders will be required to avoid rill erosion.

Maintenance of buffers is required to remove accumulated sediment and debris therefore access is important. Sediments will accumulate mostly immediately downstream of the pavement surface and then progressively further downstream as sediment builds up.

It is important to ensure coarse sediments accumulate off the road surface at the start of the buffer. Figure 2-4 (left) shows sediment accumulating on a street surface where the vegetation is the same level or slightly higher than the road. To avoid this accumulation, a flush kerb with an arris should be used that sets the top of the vegetation 60 mm below edge of pavement. This requires the finished topsoil surface of the swale (i.e. before turf is placed) to be approximately 100 mm below the edge of pavement level. This allows sediments to accumulate off any trafficable surface.

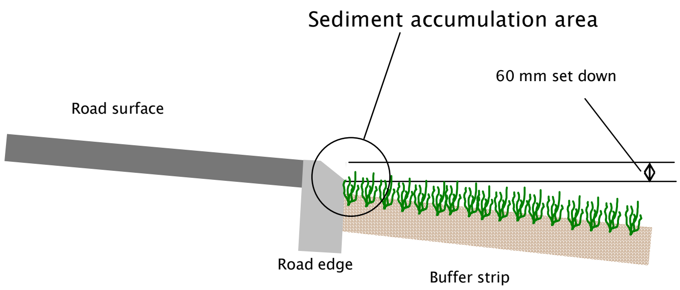


Figure 2-4: Flush kerb without set-down, showing sediment accumulation on road (left) and flush kerb with 60 mm set-down to allow sediment to flow into the vegetated area (right).

2.3.4.3 Concentrated Inflow

Concentrated inflows to a swale can be in the form of a concentrated overland flow or a discharge from a pipe drainage system (e.g. allotment drainage line). For all concentrated inflows, energy dissipation at the inflow location is an important consideration to minimise any erosion potential. This can usually be achieved with rock benching and/ or dense vegetation.

The most common constraint on pipe systems discharging to swales is bringing the pipe flows to the surface of a swale. In situations where the swale geometry does not permit the pipe to achieve ‘free’ discharge to the surface of the swale, a ‘surcharge’ pit may need to be used. Surcharge pits should be designed so that they are as shallow as possible and have pervious bases to avoid long term ponding in the pits (this may require under-drains to ensure it drains, depending on local soil conditions). The pits need to be accessible so that any build up of coarse sediment and debris can be monitored and removed if necessary.

Figure 2-5 shows an example of a typical surcharge pit discharging into a swale. It is noted that surcharge pits are generally not considered good practice (due to additional maintenance issues and mosquito breeding potential) and should therefore be avoided where possible.

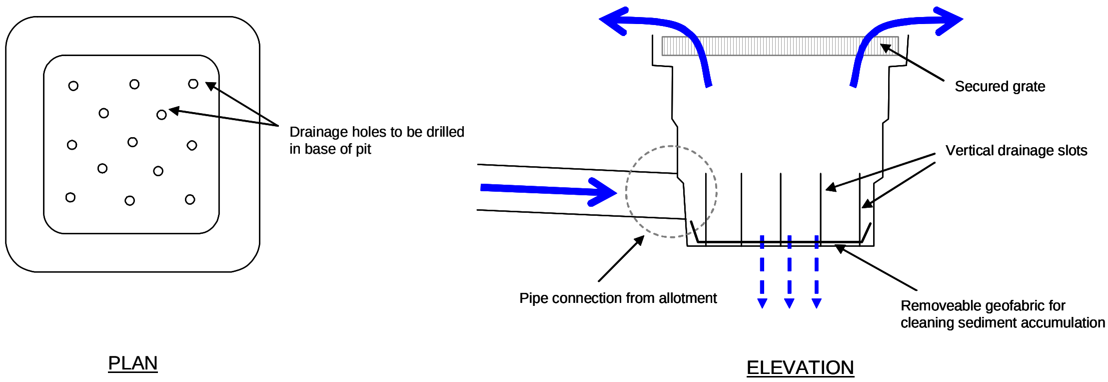


Figure 2-5: Example of Surcharge Pit for Discharging Concentrated Runoff into a Swale

Surcharge pits are most frequently used when allotment runoff is required to cross a road into a swale on the opposite side of the road or for allotment and roof runoff discharging into shallow profile swales. Where allotment runoff needs to cross under a road to discharge into a swale it is preferable to combine the runoff from more than one allotment to reduce the number of crossings required under the road pavement.

2.3.5 Step 5: Verify Design

2.3.5.1 Vegetation Scour Velocity Check

Potential scour velocities are checked by applying Manning's equation to the swale design to ensure the following criteria are met:

- less than 0.5 m/s for minor flood (2 year ARI) discharge
- less than 2.0 m/s and typically less than 1.0 m/s for major flood (50 year ARI) discharge.

2.3.5.2 Velocity and Depth Check – Safety

As swales are generally accessible by the public it is important to check that depth x velocity within the swale, at crossings and adjacent to pedestrian and bicycle pathways satisfies the following public safety criteria:

- depth x velocity of < 0.4 m^2/s is not exceeded for all flows up to the major design event, as defined in QUDM.
- maximum flow depth on driveway crossings and on road carriage ways = 0.3 m.

2.3.5.3 Confirm Treatment Performance

If the previous two checks are satisfactory then the swale design is adequate from a conveyance function perspective and it is now necessary to reconfirm the treatment performance of the swale by reference back to the information presented in Section 2.3.1.

2.3.6 Step 6: Size Overflow Pits (Field Inlet Pits)

To size a swale field inlet pit, two checks should be made to test for either drowned or free flowing conditions. A broad crested weir equation can be used to determine the length of weir required (assuming free flowing conditions) and an orifice equation used to estimate the area between openings required in the grate cover (assuming drowned outlet conditions). The larger of the two pit configurations should be adopted (as per Section 7.05 QUDM). In addition a blockage factor is to be used, that assumes the field inlet is 50 % blocked.

For free overfall conditions (weir equation):

$$Q_{weir} = B \cdot C_w \cdot L \cdot h^{3/2}$$ Equation 2.2

Where Q_{weir} = flow over weir (pit) (m^3/s)

B = blockage factor (0.5)

C_w = weir coefficient (1.66)

L = length of weir (m)

h = depth of water above weir crest (m)

Once the length of weir is calculated, a standard sized pit can be selected with a perimeter at least the same length of the required weir length.

For drowned outlet conditions (orifice equation):

$$Q_{orifice} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h}$$ Equation 2.3

Where $Q_{orifice}$ = flow into drowned pit (m^3/s)

B = blockage factor (0.5)

C_d = discharge coefficient (0.6)

A = total area of orifice (openings) (m^2)

g = 9.80665 m/s^2

h = depth of water above centre of orifice (m)

When designing grated field inlet pits reference should be made to the procedure described in QUDM Section 7.05.4 (DNRW, IPWEA & BCC 1998) and Townsville City Council's development guidelines.

2.3.7 Step 7: Make Allowances to Preclude Traffic on Measures

Refer to Section 2.2.5 for discussion on traffic control options.

2.3.8 Step 8: Specify Plant Species and Planting Densities

Refer to Section 2.4 and Appendix A for advice on selecting suitable plant species for swales in the Coastal Dry Tropics. Consultation with landscape architects is recommended when selecting vegetation to ensure the treatment system compliments the landscape of the area.

2.3.9 Step 9: Consider Maintenance Requirements

Consider how maintenance is to be performed on the swale (e.g. how and where is access available, where is litter likely to collect etc.). A specific maintenance plan and schedule should be developed for the swale, either as part of a maintenance plan for the whole treatment train, or for each individual asset. Guidance on maintenance plans is provided in Section 2.6.

2.3.10 Design Calculation Summary

The following design calculation table can be used to summarise the design data and calculation results from the design process.

SWALES – DESIGN CALCULATION SUMMARY SHEET

	Calculation Task		CALCULATION SUMMARY	
			Outcome	Check
	Catchment Characteristics			
		Catchment Area	ha	
		Catchment Land Use (i.e. residential, Commercial etc.)		
		Catchment Slope	%	
	Conceptual Design			
		Swale Top Width	m	
		Swale Length	m	
		Swale Location (road reserve/ park/other)		
		Road Reserve Width	m	
1	Confirm Treatment Performance of Concept Design			
		Swale Area	m^2	
		TSS Removal	%	
		TP Removal	%	
		TN Removal	%	
2	Determine Design Flows			
	Time of concentration refer to *Handbook for Drainage: Design Criteria* (TCC 2004) / QUDM		minutes	
	Identify Rainfall intensities			
		Minor Storm ($I_{2\ year\ ARI}$)	mm/hr	
		Major Storm ($I_{50\ year\ ARI}$)	mm/hr	
	Design Runoff Coefficient			
		Minor Storm ($C_{2\ year\ ARI}$)		
		Major Storm ($C_{50\ year\ ARI}$)		
	Peak Design Flows			
		Minor Storm (2 year ARI)	m^3/s	
		Major Storm (50 year ARI)	m^3/s	
3	Dimension the Swale			
	Swale Width and Side Slopes			
		Base Width	m	
		Side Slopes – 1 in		
		Longitudinal Slope	%	
		Vegetation Height	mm	
	Maximum Length of Swale			
		Manning's *n*		
		Swale Capacity		
		Maximum Length of Swale		
4	Design Inflow Systems			
		Swale Kerb Type		
		60 mm set down to Buffer/ Swale Vegetation	Yes/ No	
		Adequate Erosion and Scour Protection (where required)		
5	Verification Checks			
		Velocity for 2 year ARI flow (< 0.25 - 0.5 m/s)	m/s	
		Velocity for 50 year ARI flow (< 2 m/s)	m/s	
		Velocity x Depth for 50 year ARI (< 0.4 m^2/s)	m^2/s	
		Depth of Flow over Driveway Crossing for 50 year ARI (< 0.3 m)	m	
		Treatment Performance consistent with Step 1		
6	Size Overflow Pits (Field Inlet Pits)			
		System to convey minor floods (2 year ARI)	L x W	

2.3.10.1 Typical Design Parameters

The Table 2-1 provides typical values for a number of key swale design parameters.

Table 2-1: Typical Design Parameters

Design Parameter	Typical Values
Swale longitudinal slope	1 % to 4 %
Swale side slope (for areas not requiring access, e.g. parks, easements, median strips)	1 in 4 to 1 in 10
Swale side slope for trafficability (for footpaths with 'at-grade' crossings)	Maximum 1 in 9
Swale side slope (elevated driveway crossings)	1 in 4 to 1 in 10
Manning's *n* (with flow depth less than vegetation height) (Refer Figure 2-3)	0.15 to 0.3
Manning's n (with flow depth greater than vegetation height)	0.03 to 0.05
Maximum velocity to prevent scour in minor event (e.g. Q_2)	0.25 - 0.5 m/s
Maximum velocity for $Q_{50\text{-}100}$	1.0 - 2.0 m/s

2.4 Landscape Design Notes

2.4.1 Introduction

The design and installation of swales as part of the water sensitive urban design strategy is as much a landscape based solution as it is an engineering solution. Swales can be successfully integrated into a landscape such that both the functional stormwater objectives and landscape aesthetics and amenity are achieved.

2.4.2 Objectives

Landscape design of swales and buffer strips require the following four key objectives to meet WSUD strategies:

- Integrated planning and design of swale and buffer strips within the built and landscape environments
- Ensure surface treatments for swales and buffer strips address the stormwater quality objectives whilst enhancing the overall natural landscape. This includes requirements for maintaining dense perennial vegetation throughout the dry season to maintain aesthetics and to minimise weed growth.
- Allow for Crime Prevention through Environmental Design (CPTED) principals to be incorporated into swale and buffer strip design and siting.
- Create landscape amenity opportunities that enhances the community and environmental needs such as shade, habitat creation, screening, view framing and visual aesthetics

2.4.3 Context and Site Analysis

Comprehensive site analysis should inform the landscape design as well as road layouts, civil works and maintenance requirements. Existing site factors such as roads, driveways, buildings, landforms, soils, plants, microclimates, services and views should be considered. For further guidance refer to the *South East Queensland WSUD Conceptual Design Guidelines* (Healthy Waterways Partnership, 2008)

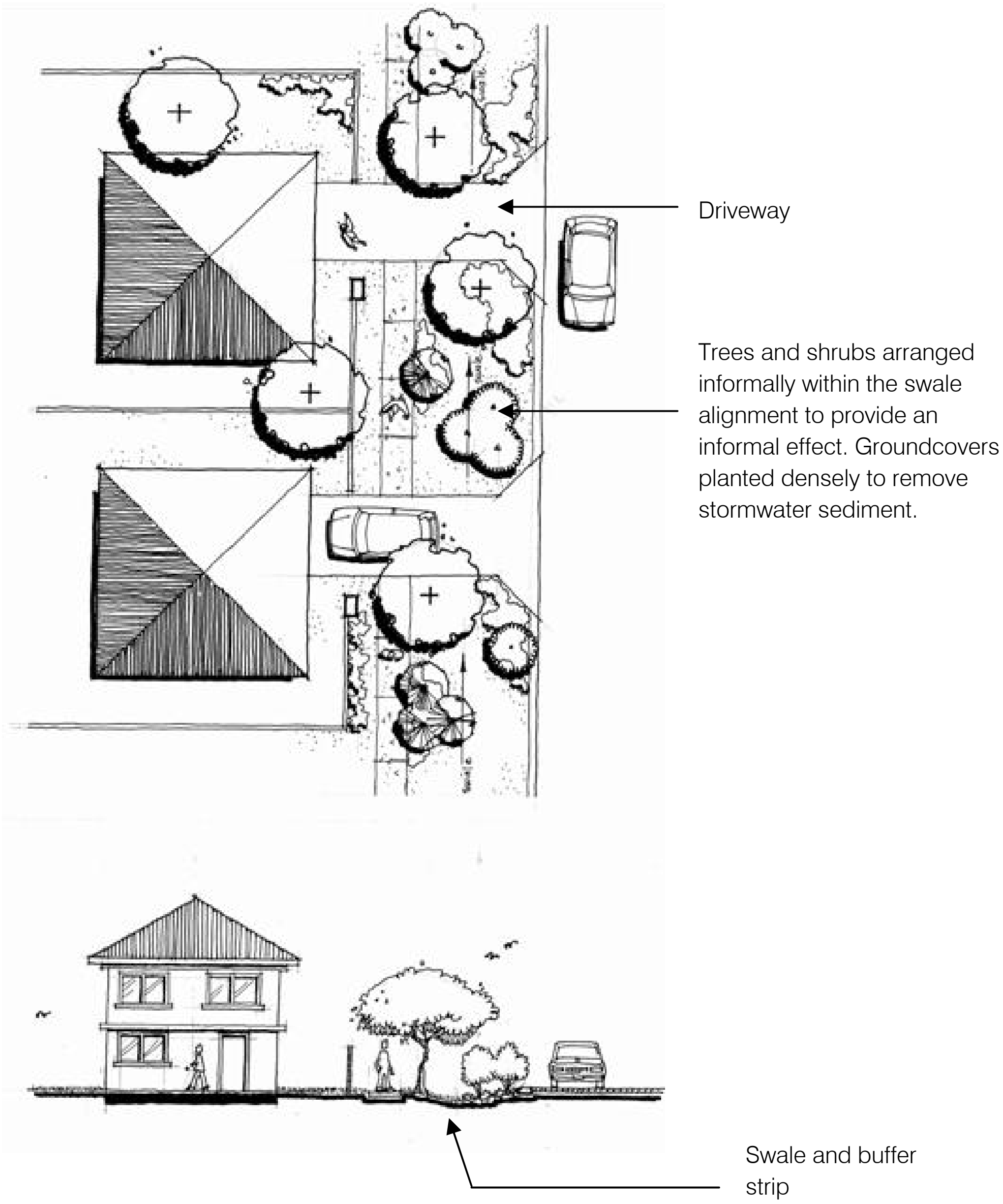
When designing for swales as part of the WSUD strategy, the overall concept layout needs to consider possible road profiles and cross-sections, building and lot layout, possible open space and recreational parks and existing natural landforms. Often things like slope and soil type will also determine which swale type and swale location will be the most effective.

Careful site analysis and integrated design with engineers, landscape architects and urban designers will ensure swales meet functional and aesthetic outcomes. A balanced approach to alignments between roads, footpaths and lot boundaries will be required early in the concept design of new developments to ensure swales are effective in both stormwater quality objectives and built environment arrangements. This is similar to concept planning for parks and open space where a balance is required between useable recreation space and WSUD requirements.

2.4.4 Streetscape Swales and Buffer Strips

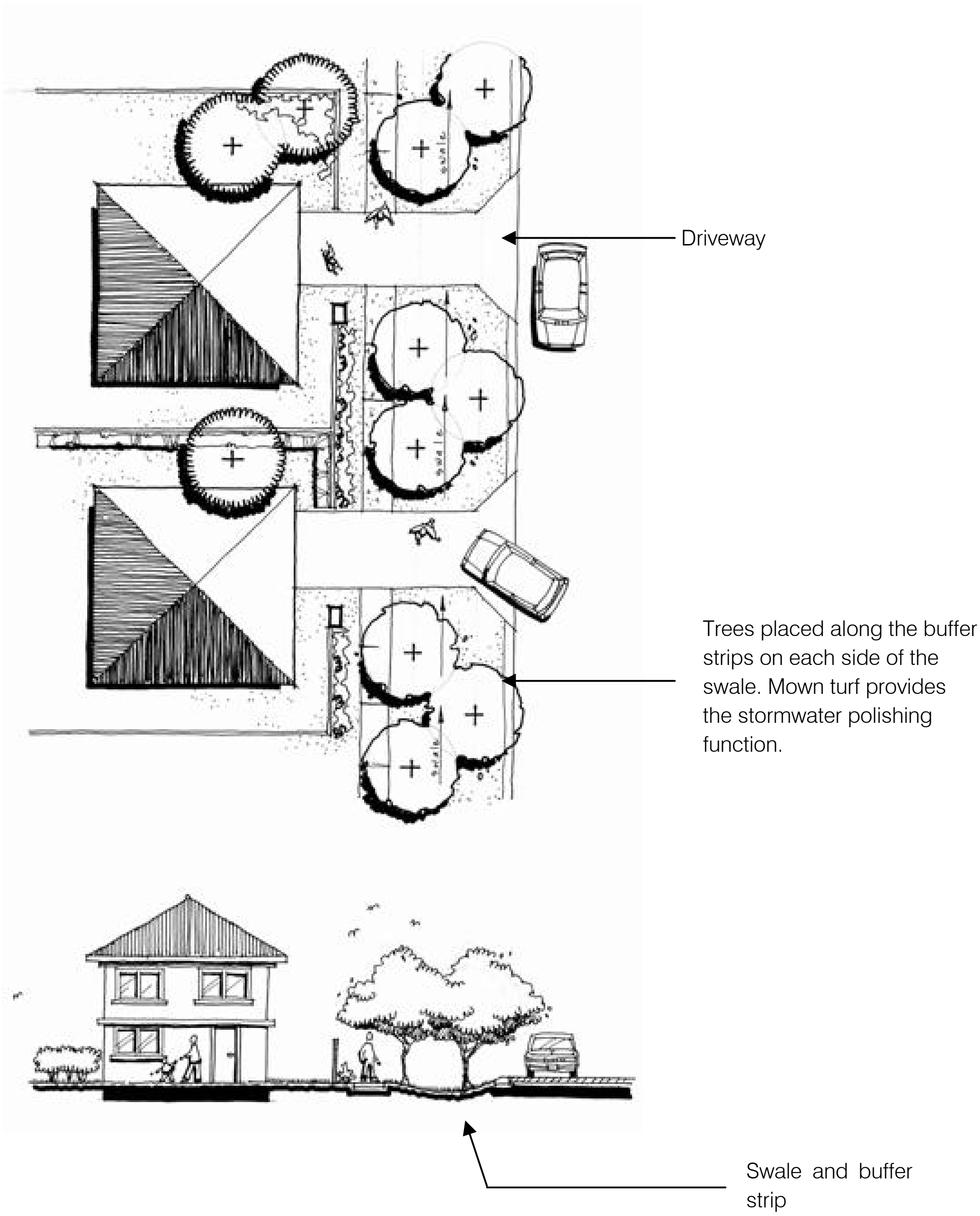
2.4.4.1 Residential Streets

When using swales in road spaces it is important to understand how the swale landscape can be used to define the visual road space. Creative landscape treatments may be possible given that the swale and buffer strip system will typically be a minimum of 4 m in width. Design responses may range from informal 'natural' planting layouts to regimented avenues of trees along each external and internal edge of the swale/ buffer system. Figure 2-6 and Figure 2-7 illustrate potential planting layouts.



Note: Landscape design is subject to Townsville City Council Development and CPTED Guidelines, site line safety requirements and standard service allocations detailed in this document.

Figure 2-6: Possible 'natural' planting layout for residential swales



Note: Landscape design is subject to Townsville City Council Development and CPTED Guidelines, site line safety requirements and standard service allocations detailed in this document.

Figure 2-7: Possible Avenue Planting for Residential Swales

Swales can be incorporated into a typical streetscape landscape using either a central splitter median or using one or both sides of the road verge. Generally, the central median swale will provide a greater landscaped amenity, allowing planting and shade trees to enhance the streetscape more effectively, whilst verges remain constraint free. This swale configuration is however confined to roads requiring larger corridors for increased traffic.

In smaller minor roads, one side of the road can have a swale landscape to capture stormwater runoff from road pavements and house lots. To enhance the visual road space, creative landscape treatments to driveway cross-overs, general planting and invert treatments should be used. It is important in this swale arrangement that services and footpaths that are standard for road verges, have been planned and located to avoid clashes of function. Designs should obtain advice and approval from Townsville City Council for placement of swales and services.

Swale surface treatments are generally divided into a turfed or a vegetated (planting) finish to the invert. When detailing a turf swale, consideration should be given to the impact of mowing on batters and the generally damp invert. This can be minimised by using different turf species that require less maintenance and respond to wet environments.

Vegetated swales can provide a relatively maintenance free finish if the planting and invert treatment are designed well. Key considerations when detailing are type and size of inorganic mulch, density and types of plantings, locations of trees and shrubs, type of garden (mowing) edges to turf areas that allows unimpeded movement of stormwater flow and overall alignment of swale invert within the streetscape. Placement of trees and shrubs should not impede the maintenance and mowing of the swale. Due to the sever dry periods in the Coastal Dry Tropics, vegetated swales must have supplemental irrigatation to ensure dense perennial vegetation can be sustained to maintain aesthetics, stormwater treatment capacity and to minimise weed growth.

Figure 2-8 and Figure 2-9 illustrate the potential different treatments based on typical minor road configurations.

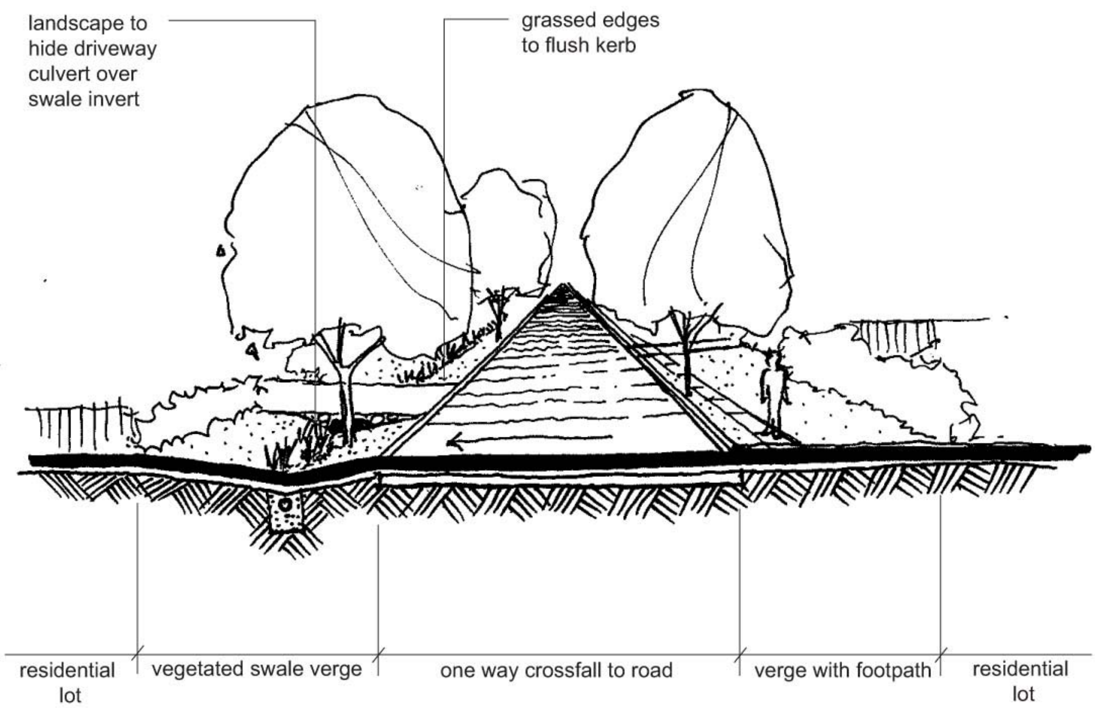


Figure 2-8: Landscape treatment of vegetated swale on single side of road

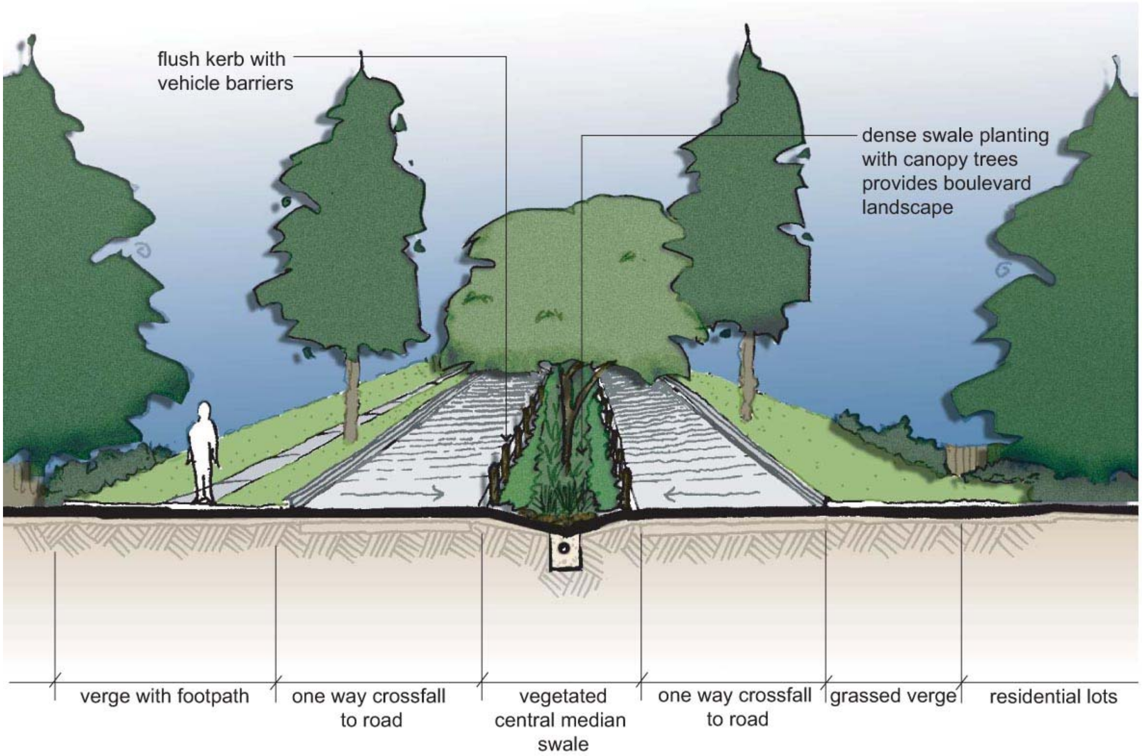


Figure 2-9: Landscape treatment of a vegetated swale in central median

2.4.4.2 Civic and Urban Spaces

With increasing population growth, functional urban design is required to create more robust spaces that meet current environmental and social needs. Often constrained by existing infrastructure, landscape treatments of swales can have a dual role of providing functional stormwater quality objectives whilst creating landscapes that enhance the communities‘ perception of water sensitive urban design.

Within civic and other highly urbanized spaces, use of hard useable edges to swales and planting strategies can be used to create an aesthetic landscape that meets recreational uses and promotes water sensitive urban design. This is illustrated in Figure 2-10.

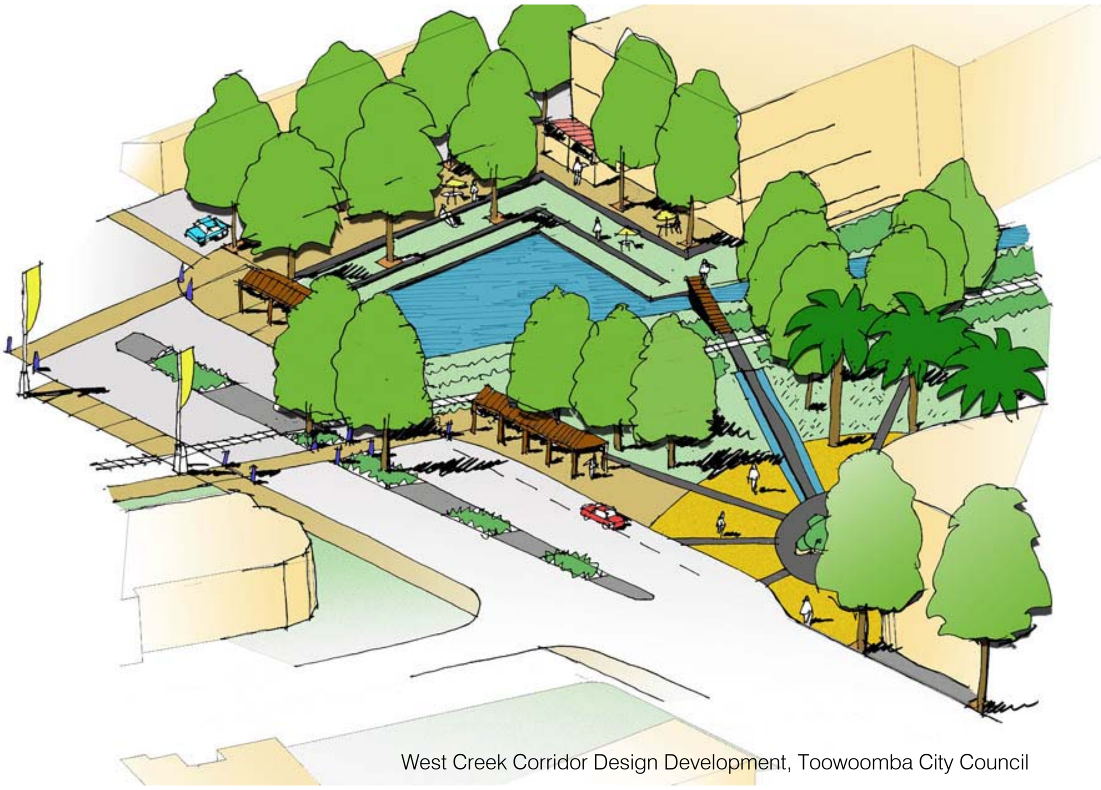


Figure 2-10: Typical urban treatment to swales

2.4.4.3 Open Space Swales (and buffer strips)

Design and siting of parks/open space swales allows for greater flexibility in sectional profile, treatments and alignments. It is important however for careful landscape planning, to ensure that spaces and function of particular recreational uses (either passive or active) are not encumbered by stormwater management devices including swales.

Swales and buffer strips can form convenient edges to pathway networks, frame recreational areas, create habitat adjacent to existing waterways/vegetation and provide landscape interest. Important issues to consider as part of the open space landscape design is maintenance access and CPTED principles which are further discussed in following sections.

2.4.5 Appropriate Plant Selection

Planting for swale/ buffer strip systems may consist of up to four vegetation types:

- groundcovers for sediment removal and erosion protection (required element)
- shrubbery for screening, glare reduction, character, and other values
- street trees for shading, character and other landscape values
- existing vegetation.

Where the landscape design includes canopy layers, more shade tolerant species should be selected for the groundcover layer. Trees and shrubs should also be managed so that the groundcover layer is not out-competed. If this does occur, replacement planting and possible thinning of the upper vegetation layers may be required to ensure the pollutant removal capacity of the groundcover is maintained.

2.4.5.1 Trees

Trees for swale systems to streets should conform to the relevant local council's landscape guidelines.

Open space swale planting of trees should take into account existing vegetation species, soil types, be able to grow under conditions associated with periodic inundation and allow for open canopies to promote groundcover growth. While Appendix A provides guidance on plant species selection, it is not intended as an exhaustive list and designers should ensure that the proposed planting schedule is suitable for the specific site.

2.4.5.2 Shrubs

Shrubs provide an important role in allowing for visual screening and borders, and should compliment the design and siting of the swale and buffer strip. Some species are outlined in Appendix A that are useful in urban and residential landscapes, however it should be noted that these lists are guides only. Other species and cultivars may be appropriate given the surrounding natural and/ or built environment of the swale.

While Appendix A provides guidance on plant species selection, it is not intended as an exhaustive list and designers should ensure that the proposed planting schedule is suitable for the specific site. Reference to the local government's landscape strategy or plant selection guidelines may provide guidance on choosing suitable shrub and tree species.

2.4.5.3 Groundcovers

Groundcovers provide the main functional component in meeting the stormwater objectives for removing sediment, aiding nutrient uptake and pollutant removal capacity. In selecting appropriate groundcover species the following considerations need to be addressed:

- density of planting
- species tolerance to high or low flows
- leaf surface density
- use of local endemic species.

Appendix A provides guidance on selecting suitable plant (including turf) species and cultivars that remove sediment and deliver the desired stormwater quality objectives. A table of recommended species (Table A.1) is also provided. In general, vegetation should possess:

- a high leaf surface density within the design treatment depth to aid efficient stormwater treatment
- a uniform distribution of vegetative material to prevent stormwater flows from meandering between plants.

2.4.5.4 Existing Vegetation

Existing vegetation, such as remnant native trees, within the swale/ buffer strip alignment may be nominated for retention. In this case, the swale will need to be diverted or piped to avoid the vegetation's critical root zone (equivalent to 0.5 m beyond the vegetation's drip line).

2.4.6 Safety

Swales and buffer strips within streetscapes and parks need to be generally consistent with public safety requirements for new developments. These include reasonable batter profiles for edges, providing adequate barriers to median swales for vehicle/pedestrian safety and safe vertical heights from driveways to intersecting swale inverts.

2.4.6.1 Crime Prevention Through Environmental Design (CPTED)

Landscape design of swales and buffer strips need to accommodate the standard principles of informal surveillance, reducing concealment areas by providing open visible areas as required. Regular clear sight lines between local roads and footpaths/properties, which can be facilitated by vegetation lower than 1 metre or clear trunked trees above 1.6 metres. Refer to Townsville City Council CPTED guideline where available.

2.4.6.2 Traffic Sightlines

Where landscaping for swales and buffer strips in road verges and medians are located in critical sightline corridors as required for traffic visibility, the standard rules apply to vegetation heights. Refer to *Road Landscape Manual* (DMR 1997) for guidance.

2.5 Construction and Establishment

This section provides general advice for the construction and establishment of swales and key issues to be considered to ensure their successful establishment and operation. Some of the issues raised have been discussed in other sections of this chapter and are reiterated here to emphasise their importance based on observations from construction projects around Australia.

2.5.1 Staged Construction and Establishment Approach

It is important to note that swale systems, like most WSUD elements that employ vegetation based treatment processes, require approximately two growing seasons (i.e. two years) before the vegetation in the systems has reached its design condition (i.e. height and density). In the context of a large development site and associated construction and building works, delivering swales and establishing vegetation can be a challenging task. Swales require a construction and establishment approach to ensure the system establishes in accordance with its design intent. The following sections outline a recommended staged construction and establishment methodology for swales (from Leinster, 2006).

2.5.1.1 Construction and Establishment Challenges

There exist a number of challenges that must be appropriately considered to ensure successful construction and establishment of swales. These challenges are best described in the context of the typical phases in the development of a Greenfield or Infill development, namely the Subdivision Construction Phase and the Building Phase (see Figure 2-11).

- *Subdivision* Construction - Involves the civil works required to create the landforms associated with a development and install the related services (roads, water, sewerage, power etc.) followed by the landscape works to create the softscape, streetscape and parkscape features. The risks to successful construction and establishment of swales during this phase of work are generally related to the construction activities which can generate large sediment loads in runoff which can smother vegetation and construction traffic and other works can result in damage to the swales. Importantly, all works undertaken during *Subdivision* Construction are normally ‘controlled’ through the principle contractor and site manager. This means the risks described above can be readily managed through appropriate guidance and supervision.
- Building Phase - Once the *Subdivision* Construction works are complete and the development plans are sealed then the Building Phase can commence (i.e. construction of the houses or built form). This phase of development is effectively ‘uncontrolled’ due to the number of building contractors and sub-contractors present on any given allotment. For this reason the Allotment Building Phase represents the greatest risk to the successful establishment of swales.

2.5.2 Staged Construction and Establishment Method

To overcome the challenges associated within delivering swales a Staged Construction and Establishment Method should be adopted (see Figure 2-11):

- Stage 1: Functional Installation - Construction of the functional elements of the swale at the end of *Subdivision* Construction (i.e. during landscape works) and the installation of temporary protective measures. For example, temporary protection of swales can been achieved by using a temporary arrangement of a suitable geofabric covered with shallow topsoil (e.g. 50 mm) and instant turf (laid perpendicular to flow path).
- Stage 2: Sediment and Erosion Control – During the Building Phase the temporary protective measures preserve the functional infrastructure of the swales against damage whilst also allowing for flow conveyance to sediment control devices throughout the building phase to protect downstream aquatic ecosystems.

- Stage 3: Operational Establishment - At the completion of the Building Phase, the temporary measures protecting the functional elements of the swales can be removed along with all accumulated sediment and the system re-profiled and planted in accordance with the design and planting schedule.

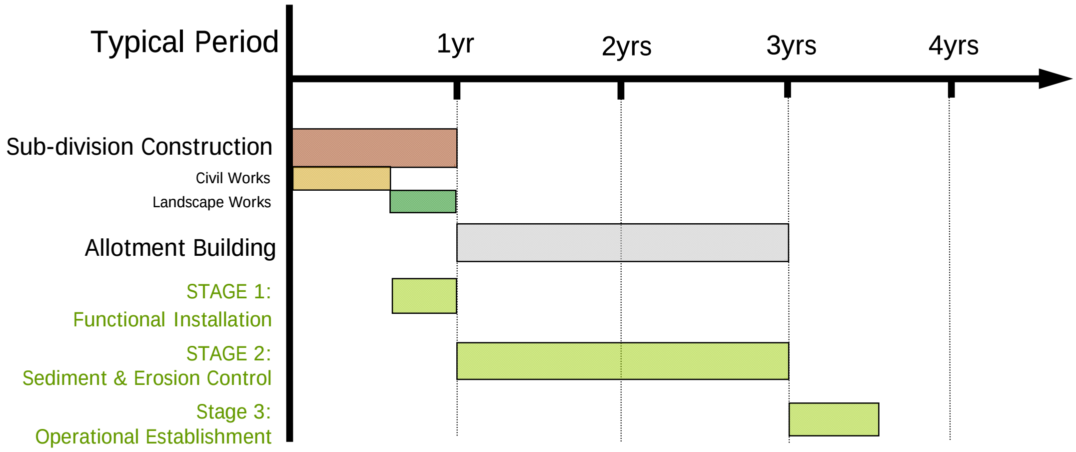


Figure 2-11: Staged Construction and Establishment Method

2.5.2.1 Functional Installation

Protection of the swale during the building phase is important as uncontrolled building site runoff can cause excessive sedimentation and introduce weeds and litter to the swale. As a result, reprofiling and replanting of the swale may be required following the building phase. To avoid this, it is recommended that a staged implementation approach be employed by using, in lieu of the final swale planting, a temporary arrangement of a suitable geofabric covered with shallow topsoil (e.g. 50 mm) and instant turf (laid perpendicular to flow path). This will allow the swale to function as a temporary erosion and sediment control facility throughout the building phase. At the completion of the building phase these temporary measures should be removed with all accumulated sediment and the swale reprofiled (if necessary) and planted in accordance with the proposed swale design. It may be possible to reuse the instant turf as part of the final planting if this is consistent with the proposed landscape design. Townsville City Council may not accept assets that are not performing to design specification (e.g. blocked with construction sediment).

Ensure traffic and deliveries do not access swales during construction. Traffic can compact the soil and cause preferential flow paths, while deliveries can smother vegetation. Washdown wastes (e.g. concrete) can disturb vegetation and cause uneven slopes along a swale. Swales should be fenced off during building phase and controls implemented to avoid washdown of wastes.

2.5.2.2 Sediment and Erosion Control

The temporary protective layers should be left in place through the allotment building phase to ensure sediment laden waters do not smother the swale vegetation. Silt fences should be placed around the boundary of the swale to exclude silt and act as a barrier to restrict vehicular and other access.

In addition to regular maintenance (outlined in Section 2.6) it is good practice to check the operation of inlet erosion protection measures following the first few rainfall events. It is important to check for these early in the systems life, to avoid continuing problems. Should problems occur in these events the erosion protection should be enhanced.

Where flush kerbs are to be used, a set-down from the pavement surface to the vegetation should be adopted. This allows a location for sediments to accumulate that is off the road pavement surface. Generally a set down from the kerb of 60 mm to the top of vegetation (if turf) is adequate. Therefore, total set down to the base soil is approximately 100 mm (with turf on top of base soil).

2.5.2.3 Operational Establishment

At the completion of the Allotment Building Phase the temporary measures (i.e. geofabric and turf) are removed with all accumulated sediment and the swale re-profiled and planted in accordance with the proposed landscape design. Establishment of the vegetation to design condition can require more than two growing seasons, depending on the vegetation types, during which regular watering and removal of weeds will be required.

2.5.3 Horticultural Topsoils for Swales (and Buffer Strips)

Soil management for plants should aim to optimise nutrient and soil-water delivery to the plants' root hairs. During the swale construction process, topsoil is to be stripped and stockpiled for possible reuse as a plant growth medium. The quality of the local topsoil should be tested to determine the soils suitability for reuse as a plant growth medium. In situ soils are likely to have changed from its pre-European native state due to prior land uses such as farming and industry. Remediation may be necessary to improve the soils capacity to support plant growth and to suit the intended plant species. Soils applied must also be free from significant weed seed banks as labour intensive weeding can incur large costs in the initial plant establishment phase. On some sites, topsoils may be non-existent and material will need to be imported.

The installation of horticultural soils should follow environmental best practices and include:

- preparation of soil survey reports including maps and test results at the design phase
- stripping and stockpiling of existing site topsoils prior to commencement of civil works
- deep ripping of subsoils using a non-inversion plough
- reapplication of stockpiled topsoils and, if necessary, remedial works to suit the intended plant species
- addition where necessary, of imported topsoils (certified to AS 4419-2003).

The following minimum topsoil depths are required:

- 150 mm for turf species
- 300 mm for groundcovers and small shrubs
- 450 mm for large shrubs
- 600 mm for trees.

2.5.4 Sourcing Swale Vegetation

Notifying nurseries early for contract growing is essential to ensure the specified species are available in the required numbers and of adequate maturity in time for swale planting. When this is not done and the planting specification is compromised, because of sourcing difficulties, poor vegetation establishment and increased initial maintenance costs may occur.

The species listed in Table A.1 (Appendix A) are generally available commercially from local native plant nurseries. Availability is, however, dependent upon many factors including demand, season and seed availability. To ensure the planting specification can be accommodated, the minimum recommended lead time for ordering is 3-6 months. This generally allows adequate time for plants to be grown to the required size. The following sizes are recommended as the minimum:

- Viro Tubes 50 mm wide x 85 mm deep
- 50 mm Tubes 50 mm wide x 75 mm deep
- Native Tubes 50 mm wide x 125 mm deep

2.5.5 Vegetation Establishment

To ensure successful plant establishment the following measures are recommended in addition to regular general maintenance as outlined in Section 2.6.

2.5.5.1 Timing for Planting

October and November are considered the most ideal time to plant vegetation in treatment elements. This allows for adequate establishment/ root growth before the heavy summer rainfall period but also allows the plants to go through a growth period soon after planting resulting in quicker establishment. Planting late in the year also avoids the dry winter months, reducing maintenance costs associated with watering. Construction planning and phasing should endeavour to correspond with suitable planting months wherever possible. In some circumstances it may be appropriate to leave temporary planting in place (if this is used to protect the swale during the building phase, e.g. turf over geofabric), and then remove this at a suitable time to allow the final swale planting to occur at the preferred time of year.

2.5.5.2 Weed Control

Conventional surface mulching of swale systems with organic material like tanbark, should not be undertaken. Most organic mulch floats and runoff typically causes this material to be washed away with a risk of causing drain blockage. To combat weed invasion and reduce costly maintenance requirements for weed removal, high planting density rates should be adopted. Suitable biodegradable erosion control matting or a heavy application of seedless hydro-mulch can also be applied to swale batters (where appropriate) for short term erosion and weed control.

2.5.5.3 Watering

Regular watering of swale vegetation is essential for successful establishment and healthy growth. The frequency of watering to achieve successful plant establishment is dependent upon rainfall, maturity of planting stock and the water holding capacity of the soil. However, the following watering program is generally adequate but should be adjusted (increased) to suit the site conditions:

- Week 1-2 3 visits/ week
- Week 3-6 2 visits/ week
- Week 7-12 1 visit/ week

After this initial three month period, watering may still be required, particularly during the first winter (dry period). Watering requirements to sustain healthy vegetation should be determined during ongoing maintenance site visits.

2.6 Maintenance Requirements

Swale treatment relies upon good vegetation establishment and therefore ensuring adequate vegetation growth is the key maintenance objective. In addition, they have a flood conveyance role that needs to be maintained to ensure adequate flood protection for local properties.

The most intensive period of maintenance is during the plant establishment period (first two years) when weed removal and replanting may be required. It is also the time when large loads of sediments may impact on plant growth, particularly in developing catchments with an inadequate level of erosion and sediment control.

The potential for rilling and erosion along a swale needs to be carefully monitored, particularly during establishment stages of the system. Other components of the system that will require careful consideration are the inlet points (if the system does not have distributed inflows) and surcharge pits. The inlets can be prone to scour and build up of litter and occasional litter removal and potential replanting may be required.

Swale field inlet pits also require routine inspections to ensure structural integrity and that they are free of blockages with debris.

Typical maintenance of swale elements will involve:

- Routine inspection of the swale profile to identify any areas of obvious increased sediment deposition, scouring of the swale invert from storm flows, rill erosion of the swale batters from lateral inflows or damage to the swale profile from vehicles.
- Routine inspection of inlet points (if the swale does not have distributed inflows), surcharge pits and field inlet pits to identify any areas of scour, litter build up and blockages.

- Removal of sediment where it is impeding the conveyance of the swale and/ or smothering the swale vegetation and if necessary reprofiling of the swale and revegetating to original design specification.
- Repairing damage to the swale profile resulting from scour, rill erosion or vehicle damage.
- Clearing of blockages to inlet or outlets.
- Regular watering/ irrigation of vegetation until plants are established and actively growing (see Section 2.5.5.3).
- Mowing of turf or slashing of vegetation (if required) to preserve the optimal design height for the vegetation.
- Removal and management of invasive weeds (see Section 2.5.5.2).
- Removal of plants that have died (from any cause) and replacement with plants of equivalent size and species as detailed in the plant schedule.
- Pruning to remove dead or diseased vegetation material and to stimulate new growth.
- Litter and debris removal.
- Vegetation pest monitoring and control.

Inspections are also recommended following large storm events to check for scour. All maintenance activities must be specified in a maintenance plan (and associated maintenance inspection forms) to be developed as part of the design procedure. Maintenance personnel and asset managers will use this plan to ensure the swales continue to function as designed. Maintenance plans and forms must address the following:

- inspection frequency
- maintenance frequency
- data collection/ storage requirements (i.e. during inspections)
- detailed cleanout procedures (main element of the plans) including:
  - equipment needs
  - maintenance techniques
  - occupational health and safety
  - public safety
  - environmental management considerations
  - disposal requirements (of material removed)
  - access issues
  - stakeholder notification requirements
  - data collection requirements (if any)
- design details

An example operation and maintenance inspection form is provided in the checking tools provided in Section 2.7.

2.7 Checking Tools

This section provides checking aids for designers and Council development assessment officers. Section 2.5 also provides general advice for the construction and establishment of swales and key issues to be considered to ensure their successful establishment and operation based on observations from construction projects around Australia.

The following checking tools are provided:

- Design Assessment Checklist

- Construction Inspection Checklist (during and post)
- Operation and Maintenance Inspection Form
- Asset Transfer Checklist (following 'on-maintenance' period).

2.7.1 Design Assessment Checklist

The checklist on page 2-32 presents the key design features that are to be reviewed when assessing a design of a swale. These considerations include configuration, safety, maintenance and operational issues that need to be addressed during the design phase. If an item receives a 'N' when reviewing the design, referral is made back to the design procedure to determine the impact of the omission or error. In addition to the checklist, a proposed design is to have all necessary permits for installation. Development assessment officers from Townsville City Council will require that all relevant permits be in place prior to accepting the design.

2.7.2 Construction Checklist

The checklist on page 2-33 presents the key items to be reviewed when inspecting the swale during and at the completion of construction. The checklist is to be used by construction site Superintendants and Townsville City Council compliance inspectors to ensure all the elements of the swale have been constructed in accordance with the design. If an item receives an 'N' in Satisfactory criteria then appropriate actions must be specified and delivered to rectify the construction issue before final inspection sign-off is given.

2.7.3 Operation and Maintenance Inspection Form

The form on page 2-34 should be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time. Inspections should occur every 1 to 6 months depending on the size and complexity of the swale system, and the stage of development (i.e. inspections should be more frequent during building phase).

2.7.4 Asset Transfer Checklist

Land ownership and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design should clearly identify the asset owner and who is responsible for its maintenance. The proposed owner should be responsible for performing the asset transfer checklist. For details on asset transfer to council, contact Townsville City Council. The table on page 2-35 provides an indicative asset transfer checklist.

SWALE DESIGN ASSESSMENT CHECKLIST

Asset I.D.		DA No.:	
Swale Location:			
Hydraulics:	Minor Flood (m^3/s):	Major Flood (m^3/s):	
Area:	Catchment Area (ha):	Swale Area (m^2):	

TREATMENT	Y	N
Treatment performance verified?		
INFLOW SYSTEMS	**Y**	**N**
Inlet flows appropriately distributed?		
Swale/ buffer vegetation set down of at least 60 mm below kerb invert incorporated?		
Energy dissipation (rock protection) provided at inlet points to the swale?		
SWALE CONFIGURATION/ CONVEYANCE	**Y**	**N**
Longitudinal slope of invert >1% and <4%?		
Manning's n selected appropriate for proposed vegetation type?		
Overall flow conveyance system sufficient for design flood event?		
Maximum flood conveyance width is compliant with QUDM?		
Overflow pits provided where flow capacity exceeded?		
Velocities within swale cells will not cause scour?		
Maximum ponding depth and velocity will not impact on public safety (V x d < 0.4 m/s)?		
Maintenance access provided to invert of conveyance channel?		
LANDSCAPE	**Y**	**N**
Plant species selected can tolerate periodic inundation and design velocities?		
Planting design conforms with acceptable sight line and safety requirements?		
Street trees conform to, Section 3.4.31 of the Land Development Guidelines?		
Top soils are a minimum depth of 300mm for plants and 100 mm for turf?		
Existing trees in good condition are investigated for retention?		
Swale and buffer strip landscape design integrates with surrounding natural and/ or built environment?		

OTHER NOTES

SWALE CONSTRUCTION INSPECTION CHECKLIST			
Asset I.D.:		Inspected by:	
Site:		Date:	
		Time:	
Constructed By:		Weather:	
		Contact during visit:	

Items Inspected	Checked		Satisfactory		Items Inspected	Checked		Satisfactory	
	Y	N	Y	N		Y	N	Y	N
DURING CONSTRUCTION & ESTABLISHMENT									
A. FUNCTIONAL INSTALLATION					Structural Components				
Preliminary Works					13. Location and levels of pits as designed				
1. Erosion/ sediment control plan adopted					14. Safety protection provided				
2. Traffic control measures					15. Location of check dams as designed				
3. Location same as plans					16. Swale crossings located/ built as designed				
4. Site protection from existing flows					17. Pipe joints/ connections as designed				
5. Critical root zones (0.5 m beyond drip line) of nominated trees are protected					18. Concrete and reinforcement as designed				
					19. Inlets appropriately installed				
Earthworks					20. Inlet erosion protection installed				
6. Existing topsoil is stockpiled for reuse					21. Set down to correct level for flush kerbs				
7. Level bed of swale					B. EROSION AND SEDIMENT CONTROL				
8. Batter slopes as plans					22. Silt fences and traffic control in place				
9. Longitudinal slope in design range					23. Stabilisation immediately following earthworks				
10. Provision of sub-soil drainage for mild slopes (<1%)					C. OPERATIONAL ESTABLISHMENT				
11. Compaction process as designed					Vegetation				
12. Appropriate topsoil on swale					24. Test and ameliorate topsoil, if required				
					25. Planting as designed (species/ densities)				
					26. Weed removal and watering as required				
FINAL INSPECTION									
1. Confirm levels of inlets and outlets					6. Check for uneven settling of soil				
2. Traffic control in place					7. Inlet erosion protection working				
3. Confirm structural element sizes					8. Maintenance access provided				
4. Check batter slopes					9. Construction sediment removed				
5. Vegetation as designed					10. Evidence of local surface ponding				

COMMENTS ON INSPECTION
ACTIONS REQUIRED:
Inspection officer signature:

SWALE (AND BUFFER) MAINTENANCE CHECKLIST			
Asset I.D.:			
Inspection Frequency:	1 to 6 monthly	Date of Visit:	
Location:			
Description:			
Site Visit by:			

INSPECTION ITEMS	Y	N	ACTION REQUIRED (DETAILS)
Sediment accumulation at inflow points?			
Litter within swale?			
Erosion at inlet or other key structures (eg crossovers)?			
Traffic damage present?			
Evidence of dumping (e.g. building waste)?			
Vegetation condition satisfactory (density, weeds etc)?			
Replanting required?			
Mowing required?			
Sediment accumulation at outlets?			
Clogging of drainage points (sediment or debris)?			
Evidence of ponding?			
Set down from kerb still present?			
Soil additives or amendments required?			
Pruning and/ or removal of dead or diseased vegetation required?			
COMMENTS			

ASSET TRANSFER CHECKLIST		
Asset Description:		
Asset I.D.:		
Asset Location:		
Construction by:		
'On-maintenance' Period:		
TREATMENT	Y	N
System appears to be working as designed visually?		
No obvious signs of under-performance?		
MAINTENANCE	Y	N
Maintenance plans and indicative maintenance costs provided for each asset?		
Vegetation establishment period completed (2 years)?		
Inspection and maintenance undertaken as per maintenance plan?		
Inspection and maintenance forms provided?		
Asset inspected for defects?		
ASSET INFORMATION	Y	N
Design Assessment Checklist provided?		
As constructed plans provided?		
Copies of all required permits (both construction and operational) submitted?		
Proprietary information provided (if applicable)?		
Digital files (e.g. drawings, survey, models) provided?		
Asset listed on asset register or database?		
COMMENTS		

2.8 Engineering Drawings and Standards

Townsville City Council should be consulted to source standard drawings applicable to swales. These drawings may provide example swale dimensions for a number of different road reserve configurations.

If no standard drawings exist for the local government area, Brisbane City Council standard drawings applicable to swales (UMS 151-154, UMS 157 and UMS 158) may be used as reference standards for swale design. BCC Standard drawings are available online at:

http://www.brisbane.qld.gov.au/planning-building/planning-building-rules/standard-drawings/index.htm

2.9 Swale Worked Example

As part of a high density residential development in the Townsville region, runoff from allotments and street surfaces is to be treated in vegetated swale systems where practical. This worked example describes the detailed design of two different swale systems located in the road reserve of a local road network within the residential estate. The conceptual configuration of the swale is presented in Figure 2-12. The layout of the catchment and swales (Swale 1 is 75 m long and Swale 2 is 35 m long) is presented in Figure 2-13.

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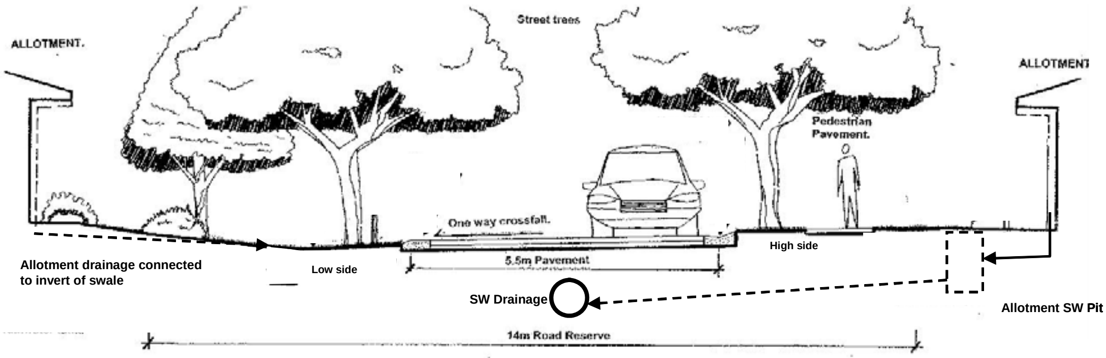

Figure 2-12: Conceptual Configuration of a Swale

Plate 2-4: Typical sections for Swale 1 (left) and Swale 2 (right)(Note that Swale 1 also requires provision for traffic control and Swale 2 requires provision for pedestrians)

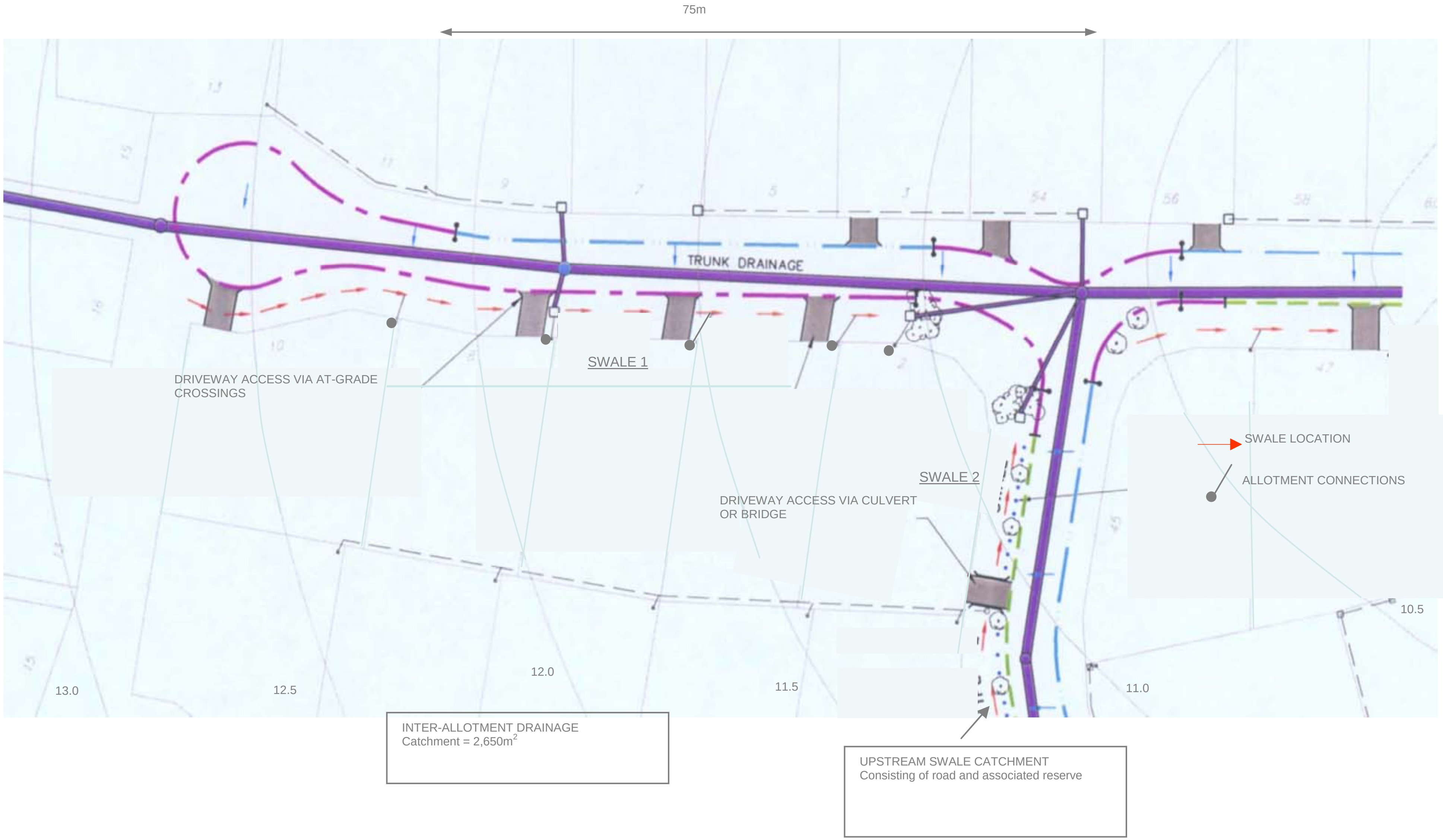

Figure 2-13: Typical Layout for Swale Worked Example

A stormwater management concept design for the development recommended these systems (Swale 1 and Swale 2) as part of a treatment train. The site comprises a network of residential allotments served by a 15 m local road reserve within which the swale systems are to be located. The streets will have a one way cross fall (to the high side) with flush kerbs to allow for distributed flows into the swale systems across a buffer zone. The intention is for turf swale systems in most cases, however, the development is located within a bushland setting so the project landscape architect has indicated that densely planted native tufted vegetation (e.g. sedges to 300 mm) should be investigated for Swale 2.

The contributing catchment area to Swale 1 includes 35 m deep allotments on one side and the road reserve. In this case runoff from allotments on the opposite side of the road is to be treated using on site treatment facilities and will discharge via allotment drainage to the piped stormwater drainage system under the road pavement. Access to the allotments draining to the swale will be via an at-grade crossover requiring maximum batter slope for the swale of 1 in 9 (11 %).

Swale 2 is to accept runoff from a small road reserve catchment plus a relatively large inter-allotment catchment which discharges just upstream of a driveway cross over. Flows will enter the swale and be conveyed under a raised driveway crossover via a conventional stormwater culvert and back into the swale system with appropriate erosion control.

For both systems (Swale 1 and Swale 2), the road reserve comprises a 7.5 m wide road pavement surface, 3.5 m footpath reserve on the opposite to the swale and a 4.0 m swale and services easement.

Minor and major flood events are to be conveyed within the swale/ road corridor in accordance with Townsville City Council development guidelines. The top width of both swales is fixed (at 4.0 m) and there will be a maximum catchment area the swale can accommodate, beyond which an underground pipe may be required to augment the conveyance capacity of the swale and road system.

Design Objectives

The design criteria for the swale systems are to:

- Convey all flows associated with minor (2 year, as defined by Council's guidelines) and major (50 year, as defined by Council's guidelines) storm events within the swale/ road system.
- Ensure flow velocities do not result in scour.
- Ensure public safety, in particular vehicle an d pedestrian safety.
- Promote sedimentation of coarse particles through the edge of the swale by providing for an even flow distribution and areas for sediment accumulation.
- Provide traffic management measures that will preclude traffic damage (or parking) within the buffer or swale (e.g. bollards or parking bays).
- Integration of the swale and buffer strip landscape design with the surrounding natural and/ or built environment.
- Provision of driveway access to lots given side slope limits.

Site Characteristics

Swale 1:

Catchment area	1,987 m^2	(lots)
	638 m^2	(roads and concrete footpath)
	255 m^2	(swale and services easement)
	2,880 m^2	(total catchment)
Landuse/ surface type	residential lots, roads/ concrete footpaths, swale and service easement	
Overland flow slope:	total main flow path length = 80 m	
	slope = 2 %	
Soil type:	clay	

Fraction impervious:	lots f_i = 0.7	
	roads/ footpath f_i = 1.00	
	swale/ service easement f_i = 0.10	

Swale 2:

Catchment area	1,325 m^2	(lots)
	500 m^2	(roads and concrete footpath)
	200 m^2	(swale and services easement)
	2,025 m^2	(total)
Landuse/ surface type	residential lots, roads/ concrete footpaths, swale and service easement	
Overland flow slope:	total main flow path length = 30 m	
	slope = 2 %	
Soil type:	clay	
Fraction impervious:	lots f_i = 0.7	
	roads/ footpath f_i = 1.00	
	swale/ service easement f_i = 0.10	

2.9.1 Step 1: Confirm Treatment Performance of Concept Design

The earlier conceptual design of the stormwater treatment system required of this project included appropriate quantitative modelling to ensure that stormwater discharges from the site comply with the relevant water quality objectives (WQOs). It is noted that subsequent additional treatment elements will be required (e.g. wetlands, bioretention systems) in order to enable WQO compliance.

Modelling of treatment performance shows the swale configuration can be expected to achieve load reductions of 85%, 55% and 14% of TSS, TP and TN respectively. The swales are approximately 10% of the contributing catchment areas, however the swale design is also responding to hydraulic capacity, landscape outcomes and access requirements (i.e. 'at-grade' driveway crossings) within the development.

2.9.2 Step 2: Determine Design Flows

With a small residential catchment, the Rational Method is recommended to estimate peak flow rates and the minor system design event is the 2 year *ARI (Stormwater Drainage Design Specification D5*, TCC 2002*).* The steps in determining peak flow rates for the minor and major design events using the Rational Method is outlined in the calculations below.

2.9.2.1 Major and Minor Design Flows

Time of concentration (t_c)

Approach:

The time of concentration is estimated assuming overland flow across the allotments and along the swale.

From procedures documented in QUDM the overland sheet flow component should be limited to 50 m in length and determined using the Kinematic Wave Equation:

$t = 6.94\ (L.n^*)^{0.6}/I^{0.4}\ S^{0.3}$

Where t = overland sheet flow travel time (mins)

L = overland sheet flow path length (m)

n* = surface roughness/retardance coefficient

I = rainfall intensity (mm/hr)

S = slope of surface (m/m)

In urban areas, QUDM notes that sheet flow will typically be between 20 to 50 m, after which the flow will become concentrated against fences, gardens or walls or intercepted by minor channel or piped drainage (from QUDM). Therefore when calculating remaining overland flow travel times, it is recommended that stream velocities in Table 4.06.5 of QUDM be used.

<u>Swale 1</u>

Assuming: Predominant slope = 2%

Overland sheet flow component = 50 m

Overland channel flow component = 30 m

Flow path is predominately lawn, with a typical n* = 0.25 (QUDM)

2 year ARI:

$t_{sheet\ flow}$ $= 6.94\ (50 \times 0.25)^{0.6} / (98.5^{0.4} \times 0.02^{0.3})$

$= 16$ mins

Iterations will need to be repeated until $t_{sheet\ flow}$ matches 2 year ARI rainfall intensity on the IFD chart for that duration, as shown in the above calculation. Note that IFD data will need to be determined in line with the *Handbook for Drainage: Design Criteria* (TCC 2004).

$t_{channel\ flow}$ $= (30m / 0.7m/s) / 60s/min$

$= 1$ min

t_c $= t_{sheet\ flow} + t_{channel\ flow}$

$= 17$ mins

50 year ARI:

$t_{sheet\ flow}$ $= 6.94\ (50 \times 0.25)^{0.6} / (235^{.4} \times 0.02^{0.3})$

$= 11$ mins

Iterations will need to be repeated until $t_{sheet\ flow}$ matches the 50 year ARI rainfall intensity on the IFD chart for that duration, as shown in the above calculation.

$t_{channel\ flow}$ $= (30m / 0.7m/s) / 60s/min$

$= 1$ min

t_c $= t_{sheet\ flow} + t_{channel\ flow}$

$= 12$ mins

<u>Swale 2</u>

Assuming: Predominant slope = 2%

Overland sheet flow = 30m

Flow path is predominately lawn, with a typical n* = 0.25 (QUDM)

2 year ARI:

t_c $= 6.94\ (30 \times 0.25)^{0.6} / (115^{0.4} \times 0.02^{0.3})$

$= 11$ mins

Repeat iterations until $t_{sheet\ flow}$ matches the 2 year ARI rainfall intensity on IFD chart for that duration.

50 year ARI:

t_c $= 6.94\ (30 \times 0.25)^{0.6} / (265^{0.4} \times 0.02^{0.3})$

$= 8$ mins

Repeat iterations until $t_{sheet\ flow}$ matches the 50 year ARI rainfall intensity on IFD chart for that duration.

Design rainfall intensities

Table 2-2: Summary of Design Rainfall Intensities

Swale	2 year t_c	2 year Rainfall Intensity	50 year t_c	50 year Rainfall Intensity
Swale 1	17 mins	96.1 mm/hr	12 mins	227 mm/hr
Swale 2	11 mins	115 mm/hr	8 mins	265 mm/hr

Design runoff coefficient

Apply the rational formula method outlined in QUDM using runoff coefficients as specified by the *Stormwater Drainage Design Specification D5* (TCC, 2002).

Assuming the Development Category is High Density (fraction impervious 0.9, ${}^{1}I_{10}$= 80.6): Using QUDM table 4.05.3 yields C_{10} = 0.88

Applying the relevant frequency factors from QUDM table 4.05.2:

C_2 = 0.88 x 0.85 = 0.75

C_{50} = 0.85 x 1.15 = 0.98

Peak design flows

As it is a small catchment apply the Rational Method.

Q = CIA/360

Swale 1:

Q_2 = 0.00278 x 0.75 x 96.1 x 0.288 = 0.058 m^3/s

Q_{50} = 0.00278 x 0.98 x 227 x 0.288 = 0.178 m^3/s

Swale 2:

Q_2 = 0.00278 x 0.75 x 115 x 0.2025 = 0.049 m^3/s

Q_{50} = 0.00278 x 0.98 x 265 x 0.2025 = 0.146 m^3/s

2.9.3 Step 3: Configuring the Swale

2.9.3.1 Swale Width and Side Slopes

To facilitate at-grade driveway crossings the following cross section is proposed:

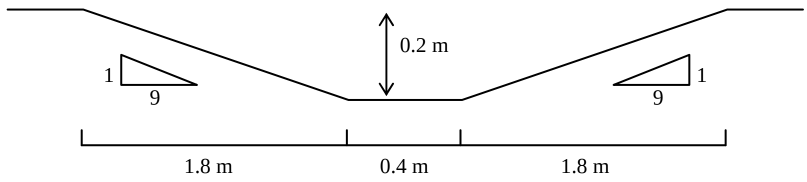

Figure 2-14: Swale Width and Side Slopes cross section

2.9.3.2 Maximum Length of Swale

To determine the maximum length of both swales (i.e. the maximum length before an overflow pit (field entry pit) is required, the 'bank full' capacity of the swale is estimated to establish how much (if any) of the minor flood and major flood flow may need to be conveyed by the road. The worked example firstly considers the swale capacity using a grass surface with a vegetation height of 50 mm. An extension of the worked example is to investigate the consequence of using 300 mm high vegetation (e.g. sedges) instead of grass in Swale 2.

A range of Manning's *n* values are selected for different flow depths appropriate for grass. It is firstly assumed that at bank full capacity, the flow height will be well above the vegetation height in the swale and therefore Manning's n will be quite low (refer to Figure 2-3). A figure of 0.04 is adopted (flow depth will need to be checked to ensure it is above the vegetation).

- adopt slope 2 % (stated longitudinal slope)
- Manning's n = 0.04 (at 0.2 m depth)
- side slopes 1(v):9(h).

Using Equation 2.1: $$Q = \frac{A \;\; R^{2/3} \;\; S^{1/2}}{n}$$

Q_{cap} = 0.357 m^3/s >> Q_2 (0.058 m^3/s and 0.048 m^3/s for Swale 1 and 2 respectively)

The nominated swale (determined from the landscape design) has sufficient capacity to convey the required peak 2 year ARI flow (Q_2) without any requirement for flow on the adjacent road or for an additional piped drainage system. The capacity of the swale (Q_{cap} = 0.357 m^3/s) is also sufficient to convey the entire peak 50 year ARI flow (Q_{50}) of 0.178 m^3/s (swale 1) and 0.146 m^3/s (swale 2) without requiring flow to be conveyed on the adjacent road and footpath. Therefore, the maximum permissible length of swale for both Swale 1 and Swale 2 is clearly much longer than the 'actual' length of each swale (i.e. Swale 1 = 75 m and Swale 2 = 35 m) and as such no overflow pits are required and no checks are required to confirm compliance with the road drainage standards for minor and major floods as defined in Townsville City Council development guidelines.

To confirm the Manning's *n* assumptions used in the above calculations, Manning's *n* is varied according to the flow depth relating to the vegetation height. This can be performed simply in a spreadsheet application. The values adopted here are shown in Table 2-3.

Table 2-3: Manning's *n* and Flow Capacity Variation with Flow Depth – Turf

Flow Depth (m)	Manning's *n*	Flow Rate (m^3/s)
0.025	0.3	0.001
0.05	0.1	0.006
0.1	0.05	0.056
0.11	0.05	0.069
0.12	0.05	0.085
0.13	0.05	0.102
0.14	0.05	0.121
0.15	0.04	0.179
0.2	0.04	0.356

From the table of Manning's equation output (Table 2-3), it can be seen that the boundary layer effect created by the turf significantly decreases between a flow depth of 0.025 m and 0.1 m with Manning's n decreasing from 0.3 to 0.05. This is due to the weight of the water flowing over the grass causing it to 'yield over' creating a 'smoother' surface with less resistance to flow. Once the water depth has reached three times the vegetation height (0.15 m), the Manning's n roughness coefficient has been further reduced to 0.04. The use of Manning's n = 0.04 for the calculation of the 'bank full' capacity of the swale is validated by Table 2-3 which also shows the 2 year ARI peak flows in Swale 1 and Swale 2 would have a flow depth of approximately 0.1m, and the 50 year ARI peak flows in both Swale 1 and 2 would have a flow depth of approximately 0.15 m.

The flow depths of both the minor (0.1 m) and major (0.15 m) event flows are less than the depth of the swale (0.2m), indicating that all flow is contained within the swales. Usually the swale should be sized so that in a major event the road accommodates some of the flow in line with flow width depth requirements outlined in the local Council's development guidelines. However these dimensions are used to facilitate at grade driveway crossings (refer to Figure 2-14).

Based on this result, the maximum permissible length of swale is also much longer than the 'actual' length of Swale 2 (i.e. 35 m) and as such no overflow pits are required except for at the downstream end of the swale to facilitate discharge to the trunk underground stormwater drainage system (see Section 2.3.6 for design of overflow pits).

For the purposes of this worked example, the capacity of Swale 2 is also estimated when using 300 mm high vegetation (e.g. sedges). The higher vegetation will increase the roughness of the swale (as flow depths will be below the vegetation height) and therefore a higher Manning's n should be adopted.

Table 2-4 below presents the adopted Manning's n values and the corresponding flow capacity of the swale for different flow depths using 300mm high vegetation (sedges).

Table 2-4: Manning's *n* and Flow Capacity Variation with Flow Depth – Sedges

Flow Depth (m)	Manning's *n*	Flow Rate (m^3/s)
0.025	0.3	0.001
0.05	0.3	0.002
0.1	0.3	0.009
0.11	0.3	0.012
0.13	0.3	0.017
0.14	0.3	0.020
0.15	0.3	0.024
0.18	0.3	0.037
0.2	0.3	0.048

Table 2-4 shows that the current dimension of Swale 2 is not capable of conveying the 2 year ARI (Q2) discharge for the higher vegetation. In this case, if the designer wishes to use sedges in the swale, additional hydraulic calculations will be required to determine the maximum length of swale to ensure that the swale and adjacent roadway can convey the 2 and 50 year ARI events, in accordance with the requirements of the local council's development guidelines.

Regardless of the above, this worked example continues using the grass option for Swale 2.

2.9.4 Step 4 Design Inflow Systems

There are two ways for flows to reach the swale, either directly from the road surface or from allotments via an underground 100 mm pipe.

Direct runoff from the road enters the swale via a buffer (the grass edge of the swale). The pavement surface is set 60 mm higher than the top of the swale batter (i.e. the top of the vegetation) and has a taper that will allow sediments to accumulate in the first section of the buffer, off the road pavement surface.

Flows from allotments will discharge into the base of the swale and localised erosion protection is provided with grouted rock at the outlet point of the pipe.

2.9.5 Step 5: Verification Checks

2.9.5.1 Vegetation scour velocity checks

Velocity checks are performed to ensure vegetation is protected from erosion at high flow rates. 2 year and 50 year ARI flow velocities are checked and need to be kept below 0.5 m/s and 2.0 m/s respectively.

Velocities are estimated using Manning's equation. Velocities are checked at the downstream end of each swale:

Swale 1 and Swale 2:

Flow depth, $d_{2\,year} = 0.10$ m

Velocity, $V_{2\,year} = 0.43$ m/s < 0.5 m/s therefore OK

$D_{50\,year} = 0.15$ m

$V_{50\,year} = 0.54$ m/s < 2.0 m/s therefore OK

2.9.5.2 Velocity and Depth Checks - Safety

Given both Swale 1 and 2 can convey their respective 50 year ARI design flows the maximum velocity-depth product will therefore be at the most downstream end of each swale.

At the bottom of both Swale 1 and Swale 2:

$V = 0.54$ m/s, $d = 0.15$ m; therefore $V \times d = 0.081 < 0.4$, therefore OK.

Both swales will have flows passing over driveway crossings and the maximum depth of flow in Swale 1 and 2 for the 50 year ARI event is only 0.15 m (refer to Table 2-3) which is much less than the maximum allowable 0.3 m.

2.9.5.3 Confirm Treatment Performance

As there has been no requirement to alter the swale geometry established for Swales 1 and 2 in Step 3, the same treatment performance identified in Step 1 still applies. Where modifications to the swale geometry occur during the previous design steps, a check of the new configuration with procedures identified in Step 1 is required to ensure treatment performance is adequate.

2.9.6 Step 6: Size Overflow Pits

As determined in Step 3, both Swale 1 and Swale 2 have sufficient capacity to convey up to the 2 year ARI event from their respective catchments and as such do not require the use of overflow pits. However, the case study requires an overflow pit to be provided at the downstream end of both Swale 1 and 2 to facilitate discharge to the trunk underground stormwater drainage system.

The trunk minor drainage system is a 2 year ARI system and therefore the overflow pits at the downstream end of Swales 1 and 2 need to be sized to discharge the peak 2 year ARI flow from each swale. The calculations to size the overflow pits are presented below:

<u>Swale 1:</u>

$Q_2 = 0.058$ m^3/s

Check for free overflow using Equation 2.2:

$$Q_{weir} = B \cdot C_w \cdot L \cdot H^{3/2}$$

Q = 0.058 = 0.5 x 1.66 x L x 0.2 $^{3/2}$

Therefore L = 0.8 m (Therefore, a pit dimension of 0.2 m x 0.2 m would be sufficient. However, the minimum pit dimensions to be used in the local Council authority should be checked).

Check for drowned outlet conditions using Equation 2.3:

$$Q_{orifice} = B \ C_d \ A\sqrt{2 \ g \ h}$$

Q = 0.058 = 0.5 x 0.6 x A x √3.924

Therefore A = 0.098 m^2 or 0.32 m x 0.32 m (as with free overflow conditions the minimum pit dimension for use in the local council authority should be checked).

Drowned outlet conditions are the 'control' and therefore the selected overflow pit dimension is 320 mm x 320 mm with a grate cover.

Swale 2:

Q_2 = 0.048 m^3/s

Check for free overflow using Equation 2.2:

$$Q_{weir} = B \quad C_w \quad L \quad h^{3/2}$$

Q = 0.048 = 0.5 x 1.66 x L x 0.2 $^{3/2}$

Therefore L = 0.65 m (a pit dimension of 0.16 m x 0.16 m would be sufficient. However, the minimum pit dimensions for use in the local Council authority should be checked).

Check for drowned outlet conditions using Equation 2.3:

$$Q_{orifice} = B \cdot C_d \cdot A\sqrt{2 \cdot g \cdot h}$$

Q = 0.048 = 0.5 x 0.6 x A x √3.924

Therefore A = 0.081 m^2 or 0.28 m x 0.28 m (as with free overflow conditions the minimum pit dimensions for use in the local Council authority should be checked).

Drowned outlet conditions are the 'control' and therefore the selected overflow pit dimension is 280 mm x 280 mm with a grate cover that complies with local council regulations.

2.9.7 Step 7: Traffic Control

Traffic control in the worked example is achieved by using traffic bollards mixed with street trees.

Plate 2-5: Traffic bollards mixed with street trees to protect swale from vehicles

2.9.8 Step 8: Vegetation specification

To compliment the landscape design of the area, a turf species is to be used. For this application a turf with a height of 50 mm has been assumed. The landscape designer will select the actual species.

2.9.9 Calculation summary

The following table shows the results of the design calculations for Swale 1 only. The same calculation summary layout may be used for Swale 2.

SWALES – DESIGN CALCULATION SUMMARY SHEET					
	Calculation Task		CALCULATION SUMMARY		
			Outcome		Check
	Catchment Characteristics (Swale 1)				
		Catchment Area	0.384	ha	✓
		Catchment Land Use (i.e. residential, Commercial etc.)	High density		
		Catchment Slope	2	%	
	Conceptual Design				
		Swale Top Width	4	m	✓
		Swale Length	75	m	
		Swale Location (road reserve/ park/other)	Road res		
		Road Reserve Width	15	m	
1	Confirm Treatment Performance of Concept Design				
		Swale Area	300	m^2	✓
		TSS Removal	85	%	
		TP Removal	55	%	
		TN Removal	14	%	
2	Determine Design Flows				
	Time of concentration				
	Swale 1				
		2 year ARI	17	minutes	✓
		50 year ARI	12	minutes	
	Swale 2				
		2 year ARI	11	minutes	✓
		50 year ARI	8	minutes	
	Identify Rainfall intensities				
	Swale 1				
		$I_{2\text{ year ARI}}$	96.1	mm/hr	✓
		$I_{50\text{ year ARI}}$	227	mm/hr	
	Swale 2				
		$I_{2\text{ year ARI}}$	115	mm/hr	✓
		$I_{50\text{ year ARI}}$	265	mm/hr	
	Design Runoff Coefficient				
		$C_{2\text{ year ARI}}$	0.75		✓
		$C_{50\text{ year ARI}}$	0.98		
	Peak Design Flows				
		2 year ARI	0.048	m^3/s	✓
		50 year ARI	0.146	m^3/s	
3	Dimension the Swale				
	Swale Width and Side Slopes				
		Base Width	0.4	m	✓
		Side Slopes – 1 in	9		
		Longitudinal Slope	2	%	
		Vegetation Height	50	mm	
	Maximum Length of Swale				
		Manning's *n*	0.04		✓
		Swale Capacity	0.357		
		Maximum Length of Swale	<80		
4	Design Inflow Systems				
		Swale Kerb Type	Flush		✓
		60 mm set down to Buffer/ Swale Vegetation	Yes	Yes/ No	
		Adequate Erosion and Scour Protection (where required)	N/A		
5	Verification Checks (refer to local Council Development Guidelines)				
		Velocity for 2year ARI flow (< 0.5 m/s)	0.43	m/s	✓
		Velocity for 50 year ARI flow (< 2 m/s)	0.54	m/s	
		Velocity x Depth for 50 year ARI (< 0.4 m^2/s)	0.08	m^2/s	
		Depth of Flow over Driveway Crossing for 50 year ARI (< 0.3 m)	0.15	m	
		Treatment Performance consistent with Step 1	Yes		
6	Size Overflow Pits (Field Inlet Pits)				
		System to convey minor floods – Swale 1	320 x 320	L x W	✓
		System to convey minor floods – Swale 2	280 x 280	L x W	

2.10 References

Barling RD & Moore ID 1993, 'The Role of Buffer Strips in the Management of Waterway Pollution', in Woodfull J *et al*. (eds), *The Role of Buffer Strips in the Management of Waterway Pollution from Diffuse Urban and Rural Sources*, LWRRDC Occasional Paper No. 01/93, Canberra

BCC 2000 (with revisions 2004), *Subdivision and Development Guidelines (Standard Drawings)*, BCC, Brisbane, http://www.brisbane.qld.gov.au

CRCCH (Cooperative Research Centre for Catchment Hydrology) 2005, *MUSIC: User Guide*, *Manual for MUSIC Version 3.0*, CRCCH, Melbourne

DMR (Queensland Department of Main Roads) 1997, *Road Landscape Manual*, prepared by EDAW (Aust) Pty Ltd for DMR, Brisbane

DNRW, IPWEA & BCC (Department of Natural Resources and Water, Institute of Public Works Engineering Australia – Qld Division & Brisbane City Council) 1998, *Queensland Urban Drainage Manual (QUDM) Second Edition*, prepared by Neville Jones & Associates and Australian Water Engineering for DNRW, IPWEA & BCC, Brisbane.

Duncan HP 1995, *A Review of Urban Storm Water Quality Processes*, Cooperative Research Centre for Catchment Hydrology, Report 95/9, Melbourne, Australia

Engineers Australia 2006, *Australian Runoff Quality*, Engineers Australia, ACT,http://www.arq.org.au/

Leinster, S 2006, *Delivering the Final Product – Establishing Water Sensitive Urban Design Systems*, 7th International Conference on Urban Drainage Modelling and 4th International Conference on Water Sensitive Urban Design Book of Proceedings, Volume 2, A Deletic and T Fletcher (eds), Melbourne.

Standards Australia 2003, *AS 4419-2003: Soils for landscaping and garden use*, Standards Australia

Weibel SR, Weidner RB, Cohen JM & Christianson AG, 1996, 'Pesticides and Other Contaminants in Rainfall and Runoff', *Journal American Water Works Association*, vol. 58, no. 8, August 1966, pp. 1075-1084