Chapter 8 Swales and buffer strips

Swale systems can be attractive elements in urban developments

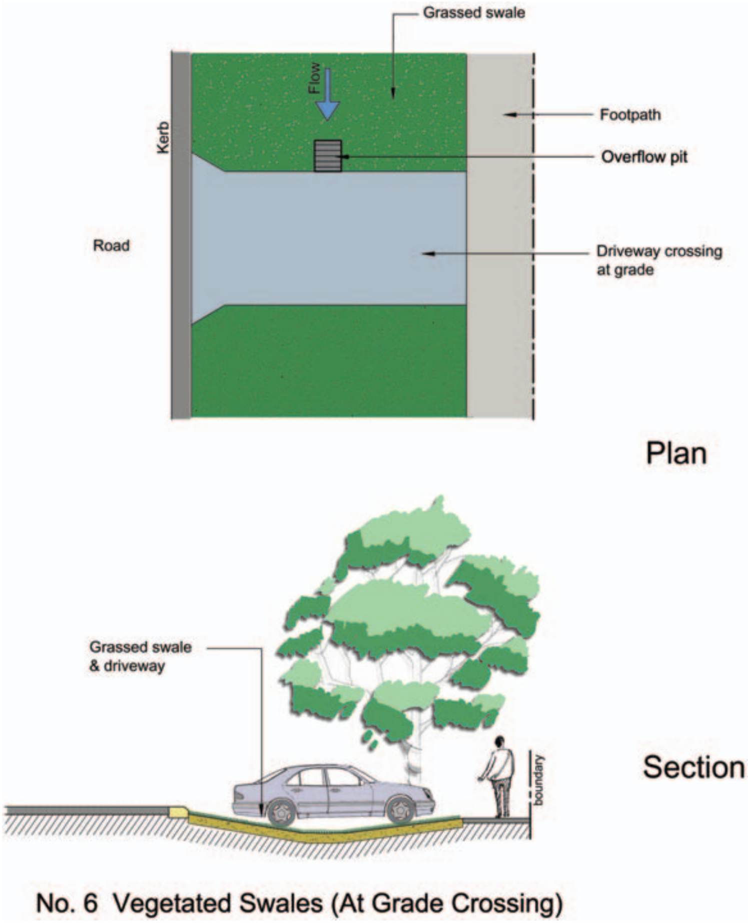
8.1 Introduction

Vegetated **swales** are used to convey **stormwater** in lieu of pipes and to provide for removal of coarse and medium sediment and are commonly combined with **buffer** strips. The system uses overland flow and mild slopes to slowly convey water downstream. Swales also provide a disconnection of impervious areas from hydraulically efficient pipe drainage systems. This results in slower travel times, thus reducing the impact of increased **catchment** imperviousness on peak flow rates.

Figure 8.1 shows illustrations of a vegetated swales with different versions of driveway crossings, including at-grade crossings (with mild side slopes) and with elevated crossings.

The interaction between flow and vegetation along swales facilitates pollutant settlement and retention. Swale vegetation acts to spread and slow velocities, which in turn aids sediment deposition. Swales alone can rarely provide sufficient treatment to meet objectives for all pollutants, but can provide an important pretreatment function for other **Water Sensitive Urban Design (WSUD)** measures. They are particularly good at coarse sediment removal and can be incorporated in street designs to enhance the aesthetics of an area.

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 though vegetation and rely upon well-distributed shallow flows across them. Interaction with the vegetation tends to slow velocities and coarse sediments are retained. Buffers can be used as edges to swales, particularly where flows are distributed along the banks of the swale.



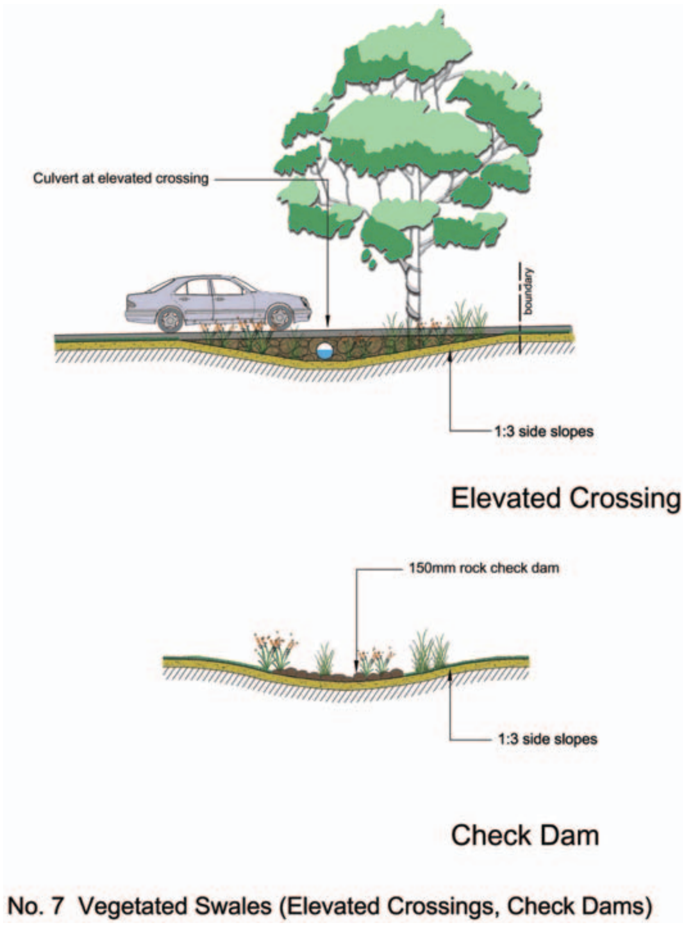


Figure 8.1 Swales with at-grade driveway crossing (plan view and section), elevated crossing and a check dam for flow spreading.

Figure 8.2 Swale systems: (L to R) heavily vegetated; use of check dams; grass swale with elevated crossings.

To convey flood flows along swales, in excess of a treatment design flow (typically the peak three-month ARI (Average Recurrence Interval) flow), pits draining to underground pipes can be used. Water surcharges from the swale down the pit. This is particularly useful in areas that have narrow verges, where a swale can only accommodate flows associated with the minor drainage system (e.g. five-year ARI for a certain length.

The longitudinal slope of a swale is the most important consideration in their design. They generally operate best with between 1% and 4% slopes. Slopes milder than this can tend to become waterlogged and have stagnant ponding because of the difficulty in constructing swales with small tolerances. However, shallow underdrains or a thin sand layer can alleviate this problem by providing a drainage path for small depressions along a swale. For slopes steeper than 4%, **check banks** (small porous rock walls) along swales can help to distribute flows evenly across the swales as well as reduce velocities.

Swales can use a variety of vegetation types including turf, sedges and tussock grasses. Vegetation is required to cover the whole width of the swale, be capable of withstanding design flows and be of sufficient density to provide good filtration. For best performance, the vegetation height should be above the treatment flow water level.

Grassed swales are commonly used and can appear as a typical road verge; however, the short vegetation offers sediment retention only to shallow flows. In addition, the grass is required to be mown and well maintained for the swale to operate effectively. Denser vegetated swales can offer improved sediment retention by slowing flows more and providing filtration for deeper flows. Conversely, vegetated swales have higher hydraulic roughness and therefore require a larger area to convey flows compared to grass swales. These swales can become features of a landscape, will require minimal maintenance once established, and be hardy enough to withstand large flows.

Another key consideration when designing swales is road or driveway crossings. Crossings can provide an opportunity for **check dams** (to distribute flows) or to provide temporary ponding above a bioretention system (refer to Section 8.3.5.2). A limitation with 'elevated' crossings can be their expense compared to at-grade crossings (particularly in dense urban

Figure 8.3 Elevated and at-grade driveway crossings across swales.

developments), safety concerns with traffic movement adjacent to the inlet and outlet and the potential for blockage of relatively small culvert systems.

Crossings can also be constructed at grade and act like a ford during high flows; however, this reduces maximum swale **batter slopes** to about 1 in 9 (with a flat base) to allow for traffic movement. These systems can be cheaper to construct than elevated crossings but require more space. They are well suited to low density developments.

Swales can also be constructed as centre medians in divided roads and in this case would also enhance the aesthetics of the street. This also avoids issues associated with crossings.

Traffic and deliveries needs to be kept off swales. Traffic (should swales be used for parking) can tend to ruin the vegetation and provide ruts that cause preferential flow paths that do not offer filtration. Traffic control can be achieved by selecting swale vegetation that discourages the movement of traffic or by providing physical barriers to traffic movement. For example, barrier kerbs with breaks in them (to allow distributed water entry, albeit with reduced uniformity of flows compared with flush kerbs) or bollards along flush kerbs can be used to prevent vehicle movement onto swales.

With flood flows being conveyed along a swale surface, it is important to ensure velocities are kept low to avoid scouring of collected pollutants and vegetation. These devices can be installed at various scales, for example, in local streets or on large highways.

The design process for swales involves firstly designing the system for conveyance and secondly ensuring the system has features that maximise its treatment performance.

Key design issues to be considered are:

1. verifying treatment performance and relationship to other measures in a treatment train
2. determining design flows
3. sizing the swale with site constraints
4. checking above-ground design:
   - velocities
   - slopes
   - design of **inlet zone** and overflow pits
   - above-design flow operation
5. making allowances to preclude traffic on swales
6. recommending plant species and planting densities
7. providing maintenance.

8.2 Verifying size for treatment

The curves below (Figures 8.4–8.9) show the pollutant removal performance expected for swales with varying slopes (1%, 3% and 5%) and vegetation height (0.05–0.5 m). Swales in isolation provide limited treatment for fine pollutants, but can perform pretreatment for other measures.

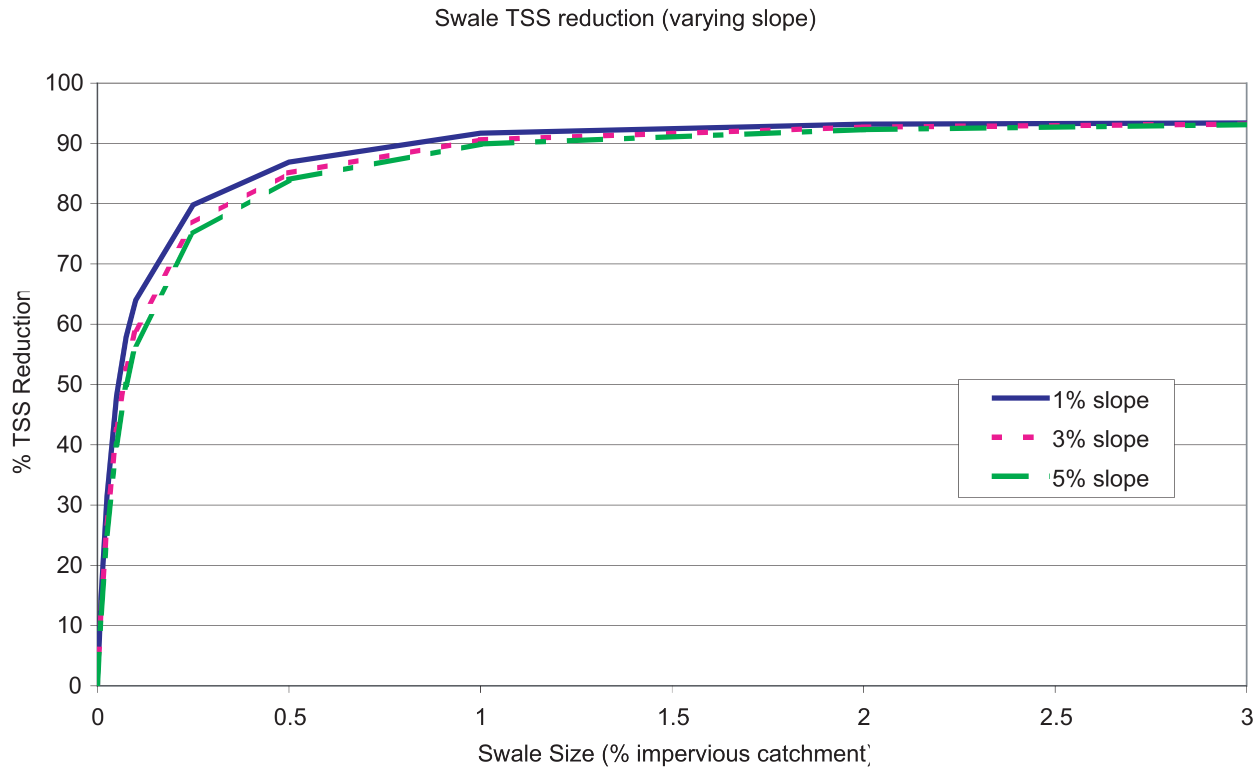


Figure 8.4 Performance of a swale in removing Total Soluble Solids (TSS) in Melbourne with varying channel slopes (vegetation height = 0.25 m).

The curves are based on the performance of the system in Melbourne and were derived using the Model for Urban Stormwater Improvement Conceptualisation (**MUSIC**) (Cooperative Research Centre for Catchment Hydrology 2003). To estimate an equivalent performance at other locations in Victoria, the **hydrologic design region** relationships should be used to convert the treatment area into an equivalent treatment area in Melbourne (reference

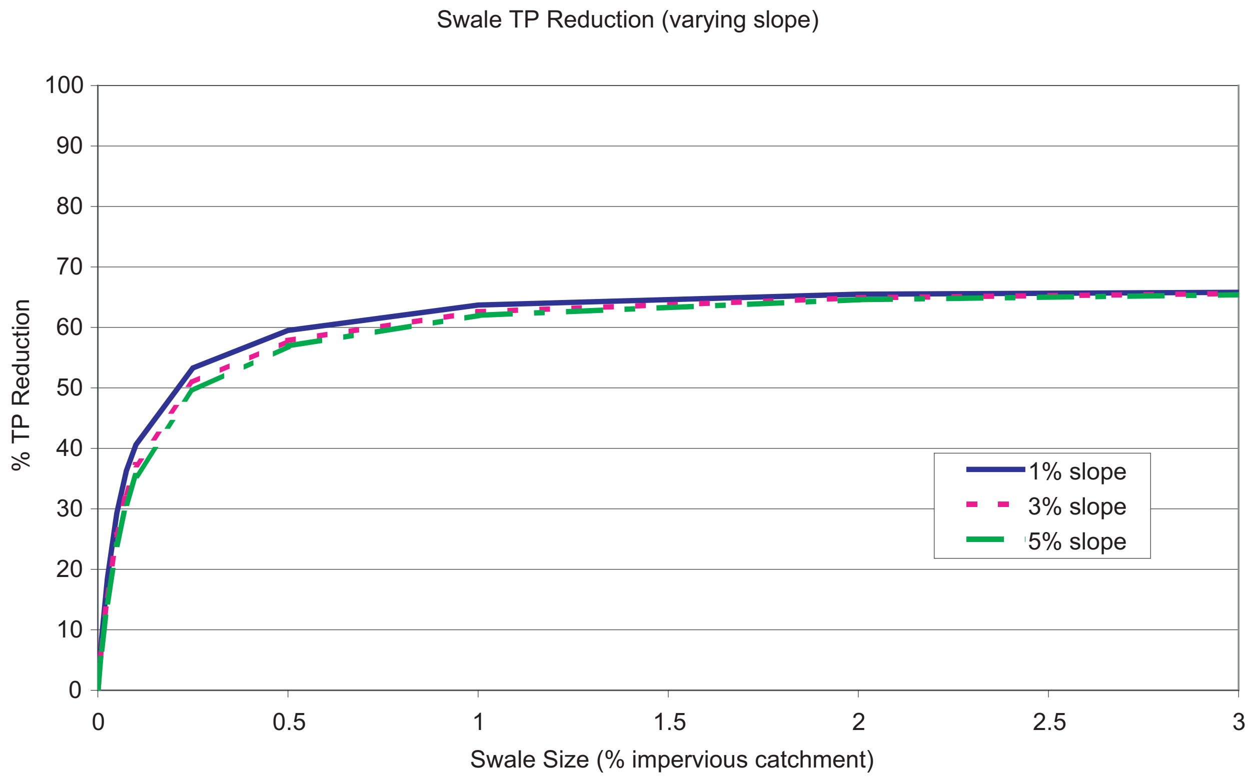


Figure 8.5 Performance of a swale in removing Total Phosphorus (TP) in Melbourne with varying channel slopes (vegetation height = 0.25 m).

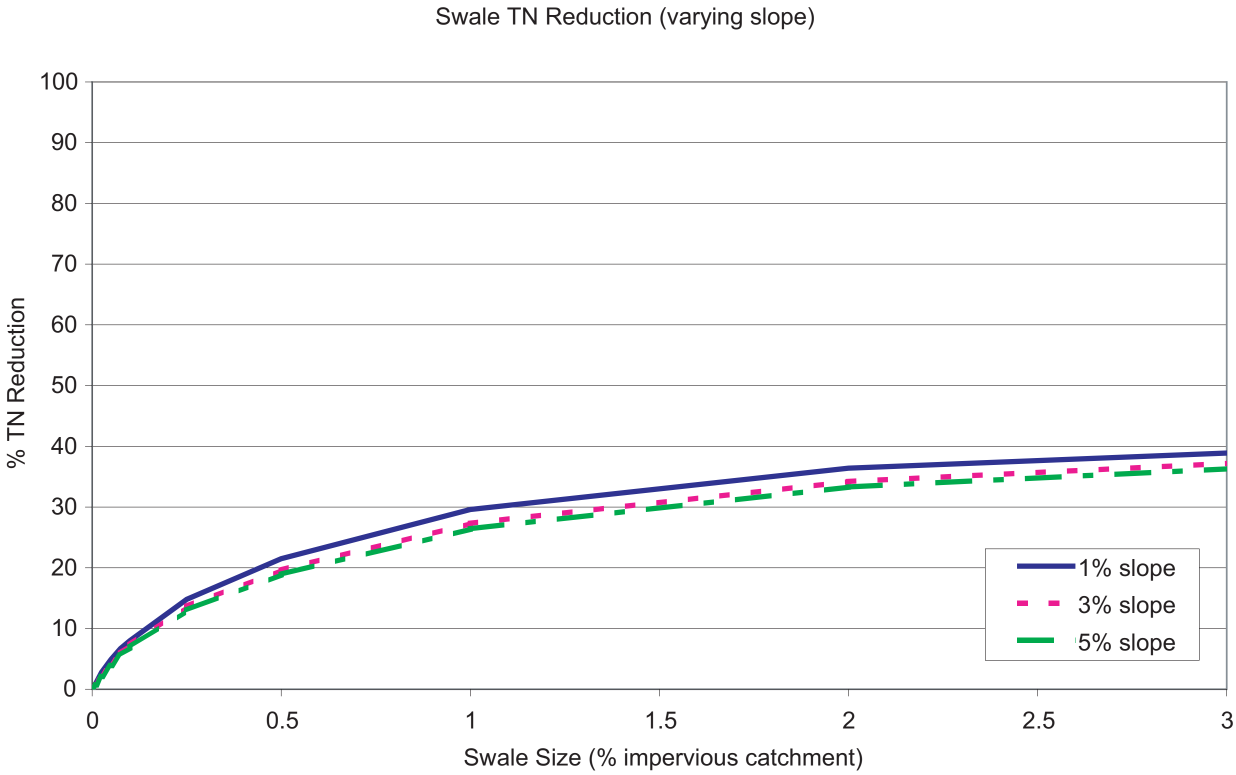


Figure 8.6 Performance of a swale in removing Total Nitrogen (TN) in Melbourne with varying channel slopes (vegetation height = 0.25 m).

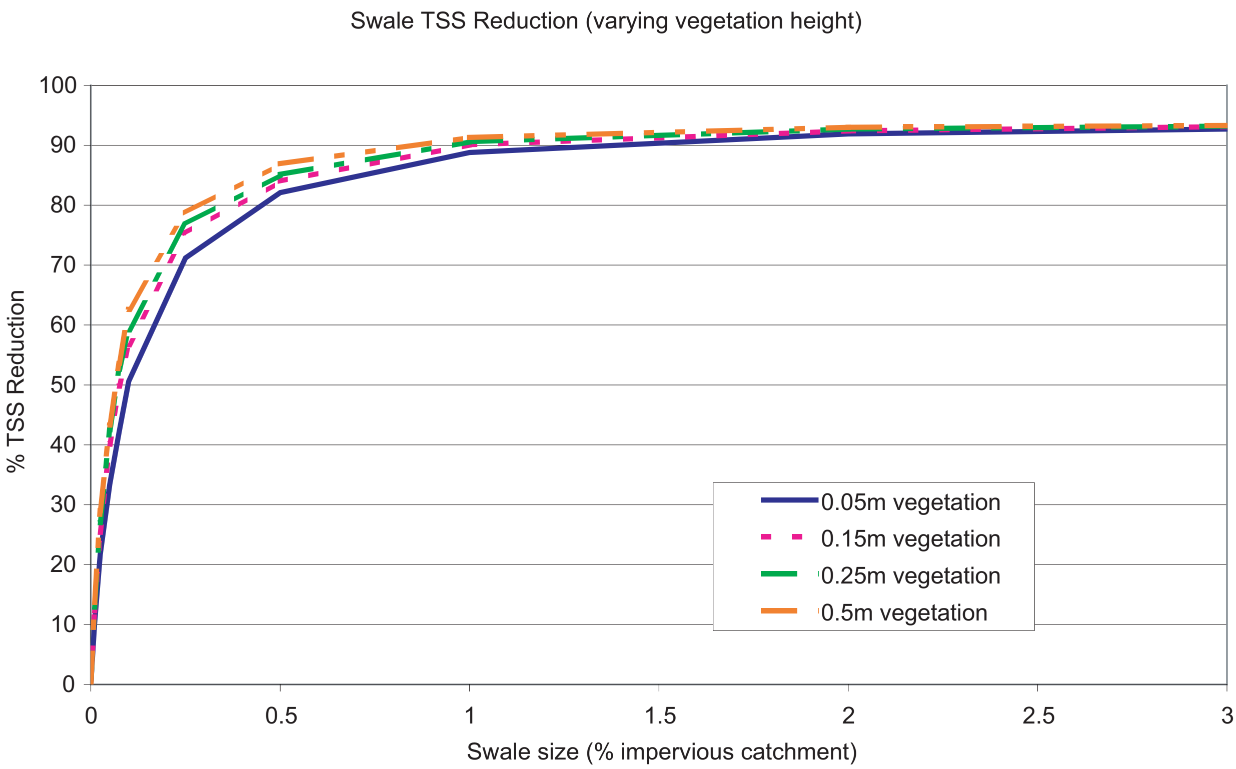


Figure 8.7 Performance of a swale in removing Total Soluble Solids (TSS) in Melbourne with varying vegetation height (channel slope = 3%).

site, see Chapter 2). In preference to using the curves, local data should be used to model the specific treatment performance of the system.

The curves were derived assuming the systems receive direct runoff (i.e. no pretreatment) and have the following characteristics:

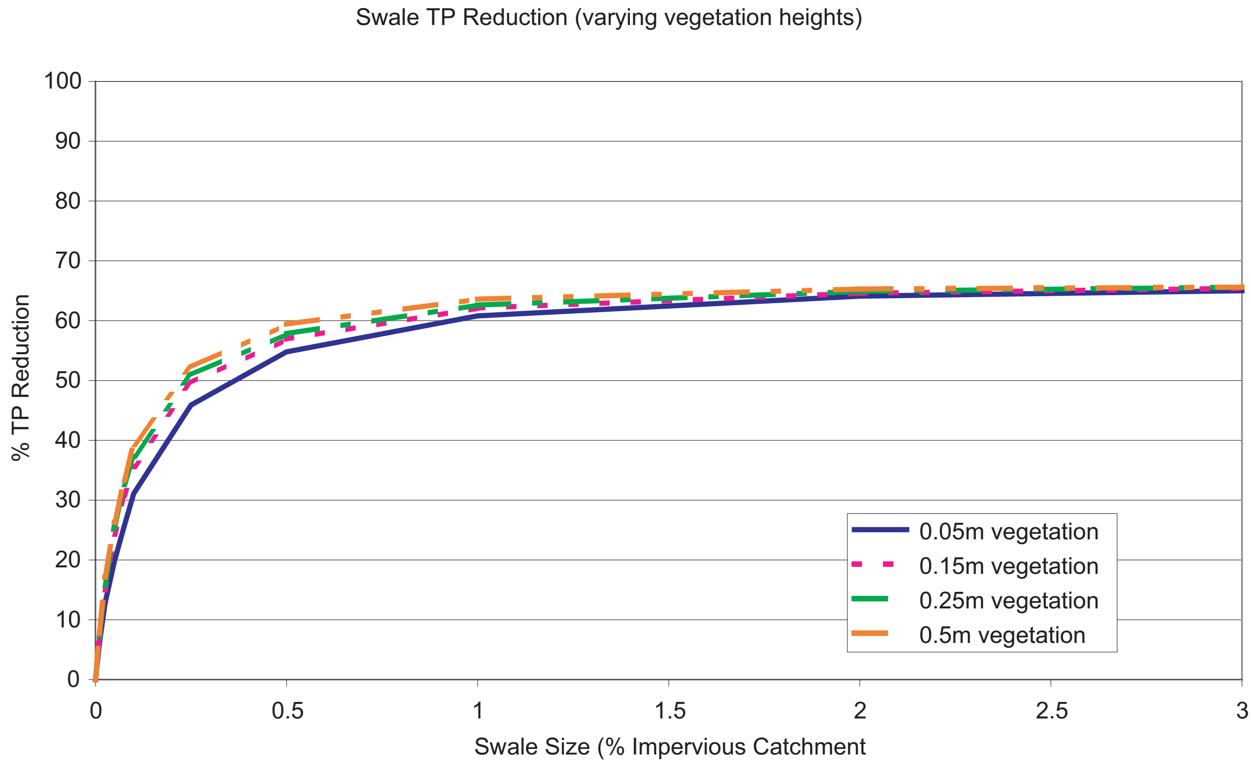


Figure 8.8 Performance of a swale in removing Total Phosphorus (TP) in Melbourne with varying vegetation height (channel slope = 3%).

Figure 8.9 Performance of a swale in removing Total Nitrogen (TN) in Melbourne with varying vegetation height (channel slope = 3%).

- base width of 2 m
- top width of 6 m
- 1 in 6 side slopes
- no infiltration through the base of the swale.

These curves can be used to check the expected performance of swales for removal of Total Soluble Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) with similar cross sections to the dimensions assumed above. If dimensions of a swale vary significantly from the values above, more detailed modelling of performance should be conducted. The *swale size* is represented as the *top width of the swale times its length* divided by the contributing *impervious catchment*.

8.3 Design procedure: swales

The following sections describe the design steps required for swale systems.

8.3.1 Estimating design flows

Two design flows are required for swale systems:

- minor flood rates (typically five-year ARI) to size the overflows to allow minor floods to be safely conveyed and not increase any flooding risk compared to conventional stormwater systems
- major flood rates (typically 100-year ARI) to check that flow velocities are not too large in the swale, that could potentially scour pollutants or damage vegetation.

8.3.1.1 Minor and major flood estimation

A range of hydrologic methods can be applied to estimate design flows. With typical catchment areas being relatively small, the **Rational Method** Design Procedure (Institution of Engineers 1987) is considered to be a suitable method for estimating design flows.

8.3.2 Dimensioning a swale

Constraints relating to a swale alignment and size need to be identified before a swale size can be checked against its flow capacity requirements. Iterations between these factors and an urban concept design may be necessary. Many of these factors should be considered during concept design; nevertheless, these should also be checked during detail design. Factors to be considered are:

- allowable width, given urban layout
- how flows are delivered into a swale (e.g. cover requirements for pipes or kerb details)
- longitudinal slope
- maximum side slopes and base width
- provision of crossings (elevated or at-grade).

Depending on which of the above factors are fixed, other variables can be 'gamed' to derive an acceptable swale configuration.

Once design flows are established, either a swale is sized to convey a particular flood frequency or the maximum length of swale is determined for a particular flood frequency. The calculation steps are identical in either approach. The following sections outline some considerations in relation to dimensioning a swale.

8.3.2.1 Side slopes and maximum width of a swale

A maximum width of swale is usually determined from an urban layout, particularly in redevelopment scenarios. This maximum width needs to be identified early in the design process as it informs the remainder of the swale design.

Alternatively, calculations can be made to estimate a required swale width to accommodate a particular flow (e.g. conveyance as the minor drainage system) to inform an urban design. Other considerations that may influence a swale width are how water is delivered to it and the maximum batter slopes (which can be affected by crossing types).

Selection of an appropriate side slope depends heavily on local council regulations and will be related to traffic access and the provision of crossings (if required). The provision of driveway crossings can significantly affect the required width of the swale. The slope of at-grade crossings (therefore, the swale) are governed by the trafficability of the change in slope across the base of the swale. Typically 1 in 9 side slopes with a small flat base will provide sufficient transitions to allow for suitable traffic movement for at-grade crossings.

Where narrower swales are required, elevated crossings can be used (with side slopes typically of between 1 in 3 and 1 in 6) and these will require provision for drainage under the crossings with a culvert or similar.

Crossings can provide good locations for overflow points in a swale. However, the distance between crossings will determine the feasibility of having overflow points at each one.

Selection of appropriate crossing type should be made in consultation with urban and landscape designers.

8.3.2.2 Maximum length of a swale

In many urban situations, the length of a swale is determined by the maximum allowable width and side slopes (therefore, depth). A swale of a set dimension (and vegetation type) will be capable of conveying flows up to a specific rate, after which flows will overtop the banks. This point is considered the maximum length of a swale. Overflow pits can be used in these situations where flows surcharge into underground pits and underground pipe networks for conveyance. A swale thus can be adjacent to a long length of road; however, it will not convey flows from an entire upstream catchment.

Manning's equation is used to size the swale, given the site conditions. This calculation is sensitive to the selection of **Manning's *n*** and this should vary according to flow depth (as it decreases significantly once flow depths exceed vegetation height). Consideration of the landscape and maintenance of the vegetation will need to be made before selecting a vegetation type.

8.3.3 Swale capacity – selection of Manning's *n*

To calculate the flow capacity of a swale, Manning's equation can be used. This allows the flow rate (Q) and levels to be determined for variations in dimensions, vegetation type and slopes.

$$\text{Manning's } Q = (A \times R^{2/3} \times S_o^{1/2}) \qquad \text{(Equation 8.1)}$$

Where A = cross-sectional area
R = hydraulic radius
S_o = channel slope
n = roughness factor.

Manning's n is a critical variable in the Manning's equation that relates to roughness of the channel. It varies with flow depth, channel dimensions and the vegetation type. For constructed swale systems, the values are recommended to be between 0.15 and 0.4 for flow depths shallower than the vegetation height (preferable for treatment) and can be significantly lower (e.g. 0.03) for flows with greater depth than the vegetation (however, it can vary greatly with channel slope and cross-section configuration) (see Cooperative Research Centre for Catchment Hydrology 2003, Appendix E).

It is considered reasonable for Manning's n to have a maximum at the vegetation height and then sharply reduce as depths increase (e.g. Figure 8.10). It is reasonable to expect the shape of the Manning's n relationship with flow depth to be consistent with other swale configurations, with the vegetation height at the boundary between 'Low flows' and 'Intermediate flows' (Figure 8.10) on the top axis of the diagram. The bottom axis of the plot has been modified from Barling and Moore (1993).

8.3.4 Inlet details

Inlets for swale systems can be from distributed runoff (e.g. from flush kerbs along a road) or from point outlets such as pipes. Combinations of these two entrance pathways can also be used.

8.3.4.1 Distributed flows (buffers)

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 shallow which maximises contact with vegetation. This area is often called a buffer. The requirement of the area is to ensure there is dense vegetation growth, flow depths are kept shallow (below the vegetation height) and erosion is avoided. This provides good pretreatment prior to flows being conveyed

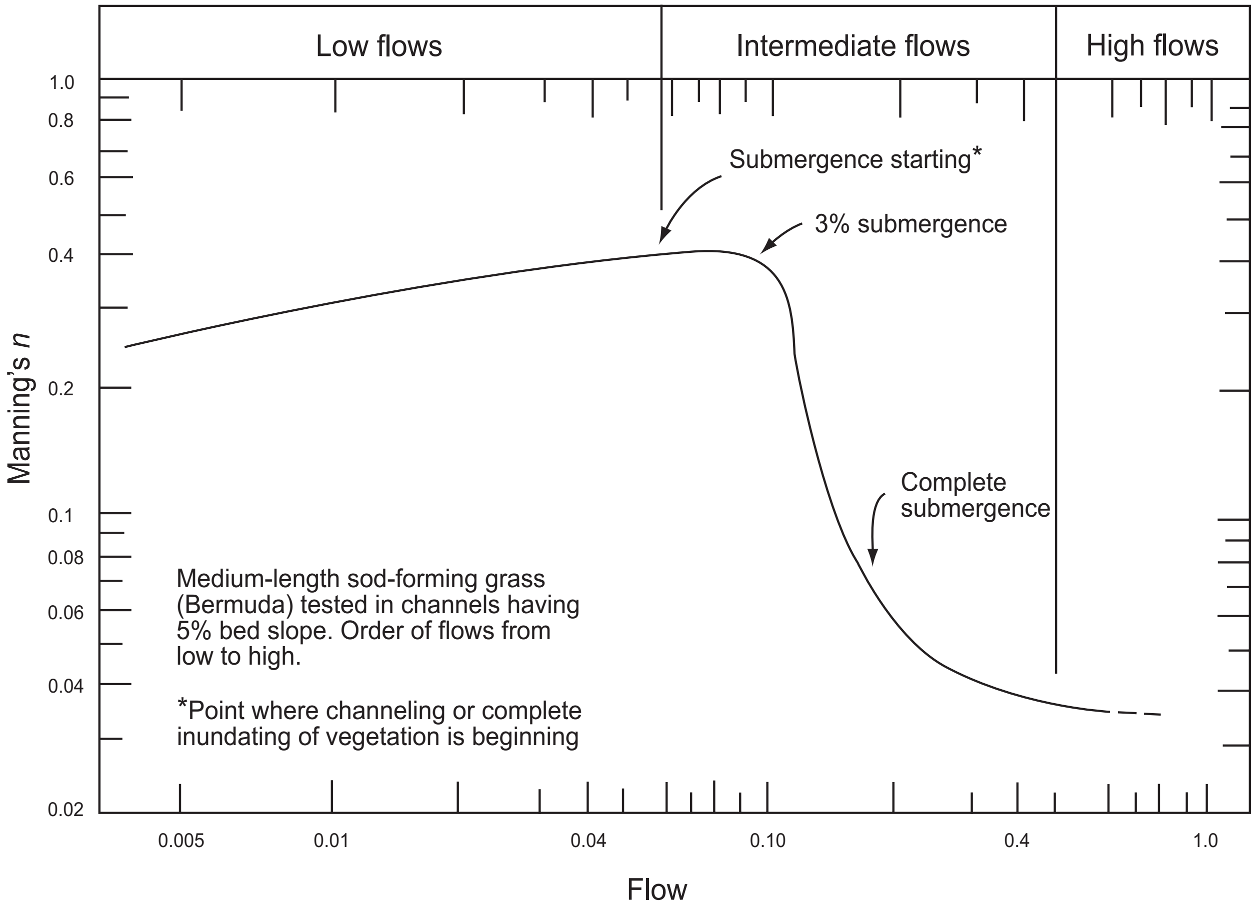


Figure 8.10 The effect of flow depth on hydraulic roughness (after Barling and Moore 1993).

down a swale. Creating distributed flows can be achieved either by having a flush kerb (Figure 8.11) or by using kerbs with regular breaks in them to allow for even flows across the buffer surface (Figure 8.12).

For distributed flows, it is important to provide an area for coarse sediments to accumulate (i.e. off the road surface). Sediment will accumulate on a street surface where the vegetation is the same level as the road (Figure 8.11). To avoid this accumulation, a tapered flush kerb can be used that sets the top of the vegetation between 40 mm and -50 mm lower than the road surface (Figure 8.11, diagram), which requires the top of the ground surface (before turf is placed) to be between 80 mm and -100 mm below the road surface. This allows sediments to accumulate off any trafficable surface.

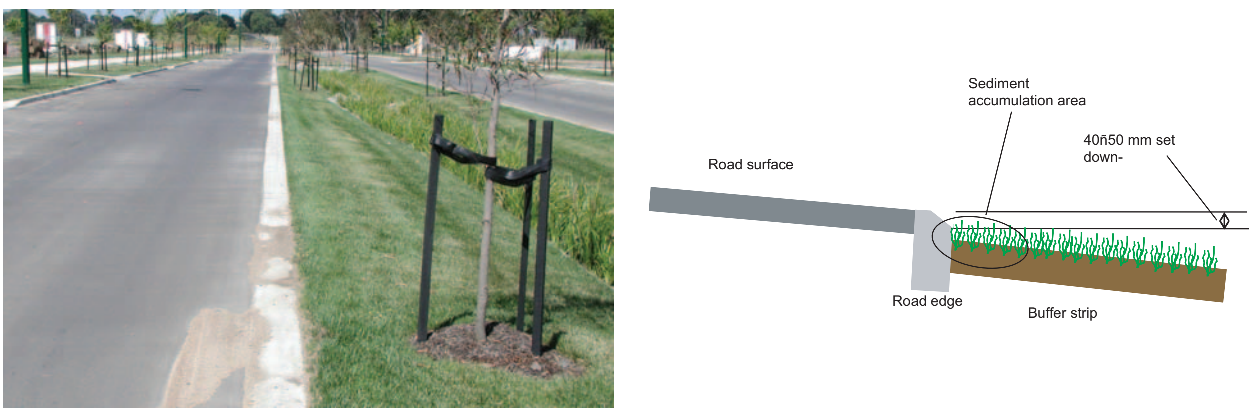


Figure 8.11 A flush kerb without setdown that shows accumulation of sediment on the street surface, and edge detail showing a recommended amount of setdown.

Figure 8.12 Different arrangements of kerbs with breaks to distribute inflows.

8.3.4.2 Direct entry points

Direct entry of flows can be from either overland flow or from a pipe system. For all point entrances into swales, it is important to consider energy dissipation at the inlet point to minimise any erosion potential. This can usually be achieved with rock beaching and dense vegetation.

The most common constraint on pipe systems is bringing the pipe to the surface of a swale within the available width. Generally the maximum width of the system will be fixed and so will maximum batter slopes along the swale (5:1 is typical, however 3:1 may be possible for shallow systems with bollards). Further constraints are the cover required for a pipe that crosses underneath a road, as well as the required grade of the pipe. These constraints need to be considered carefully.

In situations where geometry does not permit the pipe to reach the surface, a 'surcharge' pit can be used to bring flows to the surface. 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 underdrains to ensure drainage, 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.

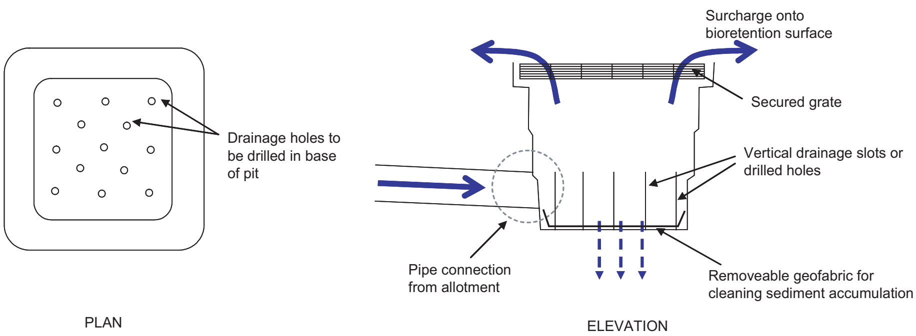


Figure 8.13 A surcharge pit for discharging allotment runoff into a swale.

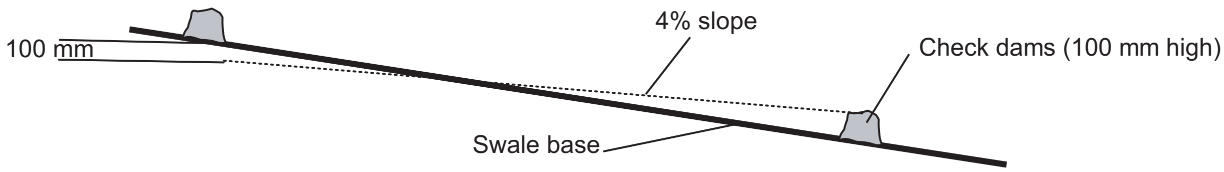


Figure 8.14 Location of check dams in swales.

These systems are most frequently used when allotment runoff is required to cross a road into a swale on the opposite side. Several allotments can generally be combined prior to crossing the road to minimise the number of road crossings. Figure 8.13 shows an example of a surcharge pit discharging into a swale.

8.3.5 Vegetation scour velocity check

Scour velocities over the vegetation along the swale are checked by applying Manning's equation. Selection of Manning's *n* needs to be appropriate to suit the vegetation height (see Section 8.3.3).

Manning's equation should be used to estimate flow velocities and ensure the following criteria are met:

- less than 0.5 m/s for minor storm (e.g. five-year ARI) discharges
- less than 1.0 m/s for major storm (e.g.100-year ARI) discharges.

8.3.5.1 Velocity check – safety

As swales are generally accessibly by the public, the flow depths and velocities need to be acceptable from a public risk perspective. To avoid people being swept away by flows along swales, a velocity–depth product check should be performed for design flow rates (see Institution of Engineers 2001, Book VIII, Section 1.10.4). Thus, the following standard needs to be met:

$$\text{Velocity (m/s)} \times \text{depth (m)} < 0.4 \text{ m}^2\text{/s}$$

8.3.5.2 Check dams

For steep swales (> 4%), check dams can be used to help distribute flows across a swale to avoid preferential flow paths and maximise contact with vegetation. Check dams are typically low level (e.g. 100 mm) rock weirs or driveway crossings that are constructed across the base of a swale. 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 (Figure 8.14).

8.3.6 High-flow route and overflow design

The design for high flows must safely convey flows associated with a minor drainage system (e.g. five-year ARI flows) to the same level of protection that a conventional stormwater system provides. Flows are to be contained within the swale. Where the capacity of the swale system is exceeded at a certain point along its length, an overflow pit is required. This will discharge excess flows into an underground drainage network for conveyance downstream. The frequency of overflow pits is determined from the capacity of the swale. This section suggests a method to dimension the overflow pits.

The locations of overflow pits is variable, but it is desirable to locate them just upstream of crossings to reduce flows across the crossing.

Typically, grated pits are used and the allowable head for discharges is the difference in level of the invert and the nearby road surface. This should be at least 100 mm, but preferably more.

To size a grated overflow pit, two checks should be made to check 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 opening required (assumed drowned outlet conditions). The larger of the two pit configurations should be adopted. In addition, a blockage factor is be to used that assumes the orifice is 50% blocked.

For free overfall conditions (weir equation):

$$Q_{minor} = B \times C \times L \times H^{3/2} \qquad \text{(Equation 8.2)}$$

with B = blockage factor (0.5), C = 1.7 and H = available head above the weir crest

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

For drowned outlet conditions (orifice equation):

$$Q_{minor} = B \times C \times A\sqrt{2gh}$$

with B = blockage factor (0.5)
C = 0.6 and
H = available head above weir crest.

8.3.7 Vegetation specification

Lists of plants are provided that are suitable for swales (see Appendix A, Table A.1). Consultation with landscape architects is recommended when selecting vegetation to ensure the treatment system complements the landscape of the area.

8.3.8 Design calculation summary

Swales — **CALCULATION CHECKLIST**

CALCULATION TASK	OUTCOME	CHECK
1 Identify design criteria		
Conveyance flow standard (ARI)		year
Vegetation height		mm ☐
2 Catchment characteristics		
		m^2
		m^2
Slope		%
Fraction impervious		
f_{imp}		☐
3 Estimate design flow rates		
Time of concentration		
Estimate from flow path length and velocities		minutes ☐
Identify rainfall intensities		
Station used for IFD data:		
Major flood – 100-year ARI		mm/hr
Minor flood – 5-year ARI		mm/hr
Peak design flows		
Q_{minor}		m^3/s
Q_{100}		m^3/s ☐
4 Swale design		
Manning's *n* below vegetation height		
Manning's *n* at capacity		☐
5 Inlet details		
Adequate erosion and scour protection?		
Flush kerb setdown?		mm ☐
6 Velocities over vegetation		
Velocity for 5-year flow (<0.5 m/s)		m/s
Velocity for 100-year flow (<1.0 m/s)		m/s
Safety: Vel x Depth (<0.4)		m^2/s ☐
7 Overflow system		
Spacing of overflow pits		
Pit type		☐
8 Plant selection		☐

8.4 Checking tools

Checking aids are included for designers and referral authorities. In addition, advice on construction techniques and lessons learnt from building swale systems are provided.

Checklists are provided for:

- design assessments
- construction (during and post)
- operation and maintenance inspections
- asset transfer (following defects period).

8.4.1 Design assessment checklist

The *Swale Design Assessment Checklist* presents the key design features that should be reviewed when assessing a design of a swale. These considerations include configuration, safety, maintenance and operational issues that should be addressed during the design phase.

Where an item results in an 'N' when reviewing the design, the design procedure should be assessed to determine the effect of the omission or error.

In addition to the*Checklist*, a proposed design should have all necessary permits for its installations. The referral agency should ensure that all relevant permits are in place.

Land 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 Handover Checklist* (see Section 8.4.4).

8.4.2 Construction advice

General advice is provided for the construction of swales. It is based on observations from construction projects around Australia.

Building phase damage

It is important to protect soil and vegetation during the building phase as uncontrolled building site runoff is likely to cause excessive **sedimentation**, introduce weeds and litter and require replanting after building. A staged implementation can be used– [i.e. during building use geofabric, some soil (e.g. 50 mm) and instant turf (laid perpendicular to flow path)] to provide erosion control and sediment trapping. After building, remove the interim measures and revegetate, possibly reusing turf at subsequent stages.

Traffic and deliveries

Ensure traffic and deliveries do not access swales during construction. Traffic can compact the filter media and cause preferential flow paths, 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 wastes.

Inlet erosion checks

It is good practice to check the operation of inlet erosion protection measures following the first few rainfall events. These need to be checked early in the system's life, to avoid continuing problems. If problems occur in these events, then erosion protection should be enhanced.

Sediment build-up on roads

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 pavement surface. Generally a set down from kerb of 50 mm to the top of vegetation (if turf) is adequate. Therefore, total set down to the base soil is about 100 mm (with 50 mm turf on top of base soil).

Timing for planting

Timing of planting vegetation depends on a suitable time of year (and potential irrigation requirements) as well as timing in relation to the phases of development. For example, temporary planting set up during construction for sediment control (e.g. with turf) can then be removed and the area planted out with long-term vegetation.

Swale Design Assessment Checklist					
Swale location:					
Hydraulics	Minor flood: (m^3/s)		Major flood: (m^3/s)		
Area	Catchment area (ha):				
Treatment				**Y**	**N**
Treatment performance verified from curves?					
Inlet zone/hydraulics				**Y**	**N**
Station selected for IFD appropriate for location?					
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 does not impact on traffic amenity?					
Overflow pits provided where flow capacity exceeded?					
Inlet flows appropriately distributed?					
Energy dissipation provided at inlet?					
Velocities within swale cells will not cause scour?					
Set down of at least 50 mm below kerb invert incorporated?					
Cells				**Y**	**N**
Maximum ponding depth and velocity will not impact on public safety (V x D <0.4)?					
Maintenance access provided to invert of conveyance channel?					
Protection from gross pollutants provided (for larger systems)?					
Vegetation				**Y**	**N**
Plant species selected can tolerate periodic inundation and design velocites?					
Plant species selected integrate with surrounding landscape design?					

8.4.3 Construction checklist

CONSTRUCTION INSPECTION CHECKLIST

Wetlands

INSPECTED BY:	
DATE:	
TIME:	
WEATHER:	
CONTACT DURING VISIT:	

SITE: ______________________

CONSTRUCTED BY: ______________________

DURING CONSTRUCTION									
Items inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
Preliminary works	Y	N				Y	N		
1. Erosion and sediment control plan adopted					18. Concrete and reinforcement as designed				
					19. Inlets appropriately installed				
2. Limit public access					20. Inlet energy dissipation installed				
3. Location same as plans					21. No seepage through banks				
4. Site protection from existing flows					22. Ensure spillway is level				
5. All required permits in place					23. Provision of maintenance drain(s)				
Earthworks					24. Collar installed on pipes				
6. Integrity of banks					25. Low flow channel rocks are adequate				
7. Batter slopes as plans					26. Protection of riser from debris				
8. Impermeable (eg. clay) base installed					27. Bypass channel stabilised				
9. Maintenance access to whole wetland					28. Erosion protection at macrophyte outlet				
10. Compaction process as designed					**Vegetation**				
11. Placement of adequate topsoil					29. Vegetation appropriate to zone (depth)				
12. Levels as designed for base, benches, banks and spillway (including freeboard)					30. Weed removal prior to planting				
13. Check for groundwater intrusion					31.Provision for water level control during establishment				
14. Stabilisation with sterile grass					32. Vegetation layout and densities as designed				
Structural components									
15. Location and levels of outlet as designed					33. Provision for bird protection				
16. Safety protection provided					34. By-pass channel vegetated				
17. Pipe joints and connections as designed									
FINAL INSPECTION									
1. Confirm levels of inlets and outlets					9. Check for uneven settling of banks				
2. Confirm structural element sizes					10. Evidence of stagnant water, short circuiting or vegetation scouring				
3. Check batter slopes									
4. Vegetation planting as designed					11. Evidence of litter or excessive debris				
5. Erosion protection measures working					12. Provision of removed sediment drainage area				
6. Pre-treatment installed and operational									
7. Maintenance access provided					13. Evidence of debris in high flow bypass				
8. Public safety adequate					14. Macrophyte outlet free of debris				

COMMENTS ON INSPECTION

ACTIONS REQUIRED

1.	
2.	
3.	
4.	
5.	
6.	

8.4.4 Asset handover checklist

Asset Handover Checklist		
Asset location:		
Construction by:		
Defects and liability period		
Treatment	**Y**	**N**
System appears to be working as designed visually?		
No obvious signs of under-performance?		
Maintenance	**Y**	**N**
Maintenance plans provided for each asset?		
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?		

8.5 Maintenance requirements

Swale systems treat runoff by filtering it through vegetation and then passing the runoff downstream. Treatment relies upon contact with vegetation and, therefore, maintaining vegetation growth is the main maintenance objective. In addition, they are used for flood conveyance and need to be maintained to ensure adequate flood protection for local properties.

The potential for rilling and erosion along a swale needs to be carefully monitored, particularly during establishment stages of the system.

The most intensive period of maintenance is during plant establishment (first two years) when weed removal and replanting may be required. It is also when large loads of sediments could affect plant growth, particularly in developing catchments with poor building controls.

Other components of the system that require careful consideration are the inlet points (if the system does not have distributed inflows). The inlets can be prone to scour and build-up of litter and surcharge pits in particular will require routine inspections. Occasional litter removal and potential replanting may be required.

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

Maintenance is primarily concerned with:

- flow to and through the system
- maintaining vegetation
- preventing undesired vegetation from taking over the desirable vegetation
- removal of accumulated sediments
- litter and debris removal

Vegetation maintenance will include:

- removal of noxious plants or weeds
- re-establishment of plants that die.

Sediment accumulation at the inlet points needs to be monitored. Depending on the catchment activities (e.g. building phase), the deposition of sediment can tend to smother plants and reduce the ponding volume available. Should excessive sediment build-up, it will affect on plant health and require removal before it reduces the infiltration rate of the filter media.

Similar to other types of practices, debris removal is an ongoing maintenance function. Debris, if not removed, can block inlets or outlets, and can be unsightly. Inspection and removal of debris should be done regularly, but debris should be removed whenever it is observed on a site.

Inspections are also recommended following large storm events to check for scour.

8.5.1 Operation and maintenance inspection form

The *Swale and Buffer Maintenance Checklist* is designed to be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time.

Swale and Buffer Maintenance Checklist			
Inspection frequency: 3 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 (e.g. 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?			
Comments:			

8.6 Swale worked example

8.6.1 Worked example introduction

As part of a development in Ballarat, runoff from allotments and a street surface is to be collected and conveyed in a vegetated swale system to downstream treatments, the intention being for a turf swale system. An additional exercise in this worked example is to investigate the consequences on flow capacity of using a vegetated (e.g. sedges) swale (vegetation height equal to 300 mm).

A concept design for the development suggested this system as part of a treatment train. The street will have a one-way crossfall (to the high side) with flush kerbs, to allow for distributed flows into the swale system across a buffer zone.

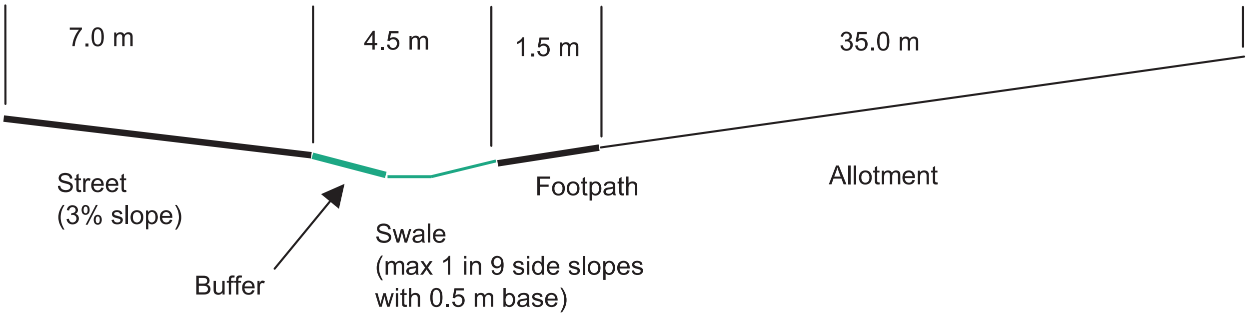


Figure 8.15 Cross section of proposed buffer/swale system.

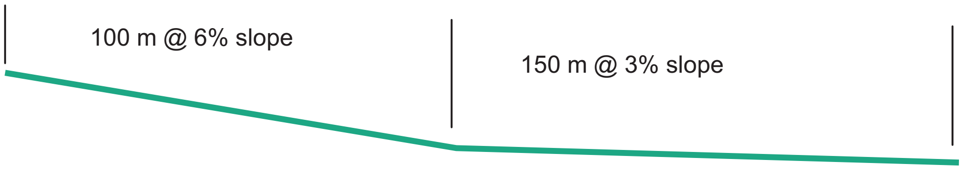


Figure 8.16 Long section of proposed buffer/swale system.

The swale is to convey minor flood events, including all flows up to a five-year ARI storm. However, the width of the swale is fixed (at 4.5 m) and there will be a maximum catchment area the swale can accommodate, above which an underground pipe will be required to preserve the conveyance properties of the downstream swale. Access to the allotments will be via an at-grade crossover with a maximum slope of 1 in 9 (11%).

The contributing catchment area includes 35 m deep (10 m wide) allotments on one side, a 7 m wide road pavement surface and a 1.5 m footpath, and 4.5 m swale and services easement (Figure 8.15). The area is 250 m long with the top 100 m having a 6% slope and the bottom 150 m having a 3% slope (Figure 8.16).

Allotment runoff is to be discharged under a footpath via a conventional stormwater pipe directly into the swale system with appropriate erosion control.

The design criteria for the buffer/swale system are to:

- promote sedimentation of coarse particles through the buffer by providing for an even flow distribution and areas for sediment accumulation (i.e. set down at kerb edge)
- provide traffic management measures that will preclude traffic damage (or parking) within the buffer or swale (e.g. bollards or parking bays)
- provide check dams to control velocities and spread flows (potentially using crossings)
- provide driveway access to lots given side slope limits
- be able to convey five-year ARI flows within the swale and underground pipe system.

This worked example focuses on the design of the buffer strip and vegetated swale conveyance properties. Analyses to be undertaken during the detailed design phase include:

Figure 8.17 Similar buffer swale system for conveying runoff.

- the swale system to accommodate driveway crossovers and check dams where required
- vegetation selection such that the hydraulic capacity of the swale is sufficient
- maximum length of swale to convey five-year flows before an underground pipe is required
- velocities maintained to acceptable levels
- an overflow structure from swale to underground pipe (if required).

Additional design elements will be required, including:

- street kerb details such that sheet flow is achieved through the buffer strip
- house lot drainage so that erosion control is provided
- buffer strip vegetation
- swale vegetation (integral with hydraulic design of the system).

8.6.1.1 Design objectives

The design objectives of the swale are to:

- convey at least all flows up to the peak five-year ARI storm event
- promote sedimentation of coarse particles within the buffer by providing an even flow distribution
- prevent traffic damage to the buffer swale system
- control flow velocities to prevent erosion
- allow for suitable driveway gradients (max 1:9) to be provided at crossovers into properties.

8.6.1.2 Site characteristics

The site characteristics for the swale are as follows.

Catchment area	Lots	8 750 m^2
	Roads and concrete footpath	2 125 m^2
	Swale and services easement	1 125 m^2
	Total	12 000 m^2.
Landuse/surface type	Residential lots, roads/concrete footpaths, swale and service easement.	
Overland flow slope:	Total main flow path length = 250 m	
	Upper section = 100 m at a 6% slope	
	Lower section = 150 m at a 3% slope.	
Soil type:	Clay	
Fraction impervious:	Lots $f = 0.65$.	
	Roads/footpath $f = 1.00$	
	Swale/service easement $f = 0.10$.	

8.6.1.3 Confirm size for treatment

Interpretation of Figures 8.4 to 8.9 with the input parameters below is used to estimate the reduction performance of the swale system to ensure the design will achieve target pollutant reductions. Note that the treatment areas need to be adjusted to the equivalent areas at the reference site (Melbourne) using the hydrologic design region **adjustment factors** to interpret Figure 8.4 to 8.9.

- Ballarat location (Western Plains hydrologic design region)
- Average slope of 5% along swale
- Vegetation height of 50 mm.

To interpret the graphs the area of swale base to the impervious catchment needs to be estimated. Then this percentage needs to be adjusted back to the equivalent area for the Melbourne region (the reference site). This value can then be used to interpret the performance graphs in Figure 8.4 to 8.9.

Area of swale base / impervious catchment area:

$$0.5 \times 250/[(0.65 \times 8750) + (1.0 \times 2125) + (0.1 \times 1125)] = 1.6\%.$$

Adopting the Western Plains hydrologic design region adjustment factor equation for swales (see Chapter 2, Table 2.1):

Adjustment factor = 0.539 (MAR) + 0.622
= 0.539 (0.70) + 0.622 = 0.999.

Therefore, the area required in Melbourne × 0.999 = area required in Ballarat.

To apply the performance curves the area = 1.6%/0.999 = 1.6%.

From the figures using an equivalent area in the reference site, it is estimated that pollutant reductions are 90%, 63% and 28% for TSS, TP and TN, respectively.

8.6.2 Estimating design flows

With a small catchment, the Rational Method Design Procedure is considered an appropriate approach to estimate the five-year and 100-year ARI peak flow rates. The steps in these calculations follow.

8.6.2.1 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 in *Australian Rainfall and Runoff* (Institution of Engineers 2001), t_c is estimated to be 10 minutes.

Design rainfall intensities

Adopt the values from Intensity–Frequency Duration (IFD) table for Ballarat:

t_c	Five-year	100-year
10 min	67 mm/hr	140 mm/hr

Design runoff coefficient

To calculate the design runoff coefficient, apply the rational formula method outlined in ARR (Institution of Engineers 2001, Book VIII, Section 1.5.5 iii):

$C^1{}_{10} = 0.1 + 0.0133\ ({}^{10}I_1 - 25)$ ($C^1{}_{10}$ = pervious runoff coefficient)

$C_{10} = 0.9f + C^1{}_{10}\ (1\text{-}f)$ (f = fraction impervious).

$f = (8750 \times 0.65 + 2125 \times 1 + 1125 \times 0.1)/12\,000 = 0.66.$

${}^{10}I_1 = 30.1$ mm/hr (Ballarat)

$C^1{}_{10} = 0.17$ $C_{10} = 0.65$

$C_y = F_y\, C_{10}$

$C_5 = 0.95 \times 0.65 = 0.62.$

$C_{100} = 1.2 \times 0.65 = 0.78.$

Peak design flows

As it is a small catchment the peak design flows (Q) are calculated by using the Rational Method as follows:

$Q = 0.002788 \times C \times I \times A$

$Q_5 = 0.002788 \times 0.62 \times 67 \times 1.2 = 0.14\ m^3/s$

$Q_{100} = 0.002788 \times 0.78 \times 140 \times 1.2 = 0.36\ m^3/s$

C = runoff coefficient

A = area (ha)

I = rainfall intensity (mm/hr)

8.6.3 Swale dimensions

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

8.6.4 Swale flow capacity

The capacity of the swale is first estimated at the most downstream point. This is considered the critical point in the swale as it has the largest catchment and has the mildest slope (it is assumed that the dimension of the swale will be the same for both the steep and mild-sloped areas for aesthetic reasons). Flow velocities will also need to be checked at the downstream end of the steep section of swale.

The worked example first 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.

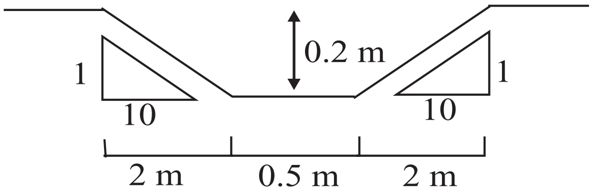


Figure 8.18 Cross section of an at-grade driveway crossing caption to be provided

8.6.4.1 Selection of Manning's *n*

A range of Manning's *n* values are selected for different flow depths appropriate for grass. It is first assumed that the flow height for a five-year ARI storm will be above the vegetation and, therefore, Manning's *n* is quite low. A figure of 0.04 is adopted. (The flow depth will need to be checked to ensure it is above the vegetation.) Thus,

- adopt slope 3% (minimum longitudinal slope)
- Manning's $n = 0.04$ (at 0.2 m depth)
- side slopes 1(v):10(h)

Manning's equation $Q = (AR^{2/3}S_o^{1/2})/n$
$Q_{cap} = 0.50\ m^3/s >> Q_5\ (0.14\ m^3/s)$.

Therefore, the nominated swale has sufficient capacity to convey the required peak Q_5 flow without any requirement for an additional piped drainage system. The capacity of the swale ($Q_{cap} = 0.50\ m^3/s$) is also sufficient to convey the entire peak Q_{100} flow of 0.36 m^3/s without impacting on the adjacent road and footpath.

To investigate flow rates at lower depths, 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:

Table 8.1 Manning's *n* and flow capacity variation with flow depth – turf

Flow depth (m)	Manning's *n*	Flow rate (m^3/s)
0.05	0.30	0.003
0.1	0.30	0.01
0.15	0.10	0.10
0.2	0.04	0.50

From Table 8.1, it can be seen that the five-year ARI flow depth is above the vegetation height and therefore the Manning's *n* assumption would seem reasonable.

8.6.4.2 Option 2 – assume higher vegetation

For the purposes of this worked example, the capacity of the swale 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 8.2 presents the adopted Manning's *n* values and the corresponding flow capacity of the swale for different flow depths.

Table 8.2 Manning's *n* and flow capacity variation with flow depth – sedges

Flow depth (m)	Manning's *n*	Flow rate (m^3/s)
0.05	0.35	0.003
0.1	0.32	0.01
0.15	0.30	0.03
0.2	0.30	0.07

It can be seen in Table 8.2 that the swale with current dimensions is not capable of conveying a five-year discharge. Either the swale depth would need to be increased or overflow pits provided to convey a five-year ARI flow.

This worked example continues using grass for the remainder.

8.6.5 Inlet details

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 50 mm higher than the start of the swale and has a taper that will allow sediments to accumulate in the first section of the buffer, off the pavement surface. Traffic control is achieved by using traffic bollards.

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.

These are detailed in the construction drawings.

8.6.6 Velocity checks

Two velocity checks are performed to ensure vegetation is protected from erosion at high flow rates. The five-year and 100-year ARI flow velocities are checked and need to be kept below 0.5 m/s and 1.0 m/s, respectively.

Velocities are estimated using Manning's equation:

First, velocities are checked at the most downstream location (i.e. slope = 3%):

$$D_{5\text{-year}} = 0.16 \text{ m}$$

$$V_{5\text{-year}} = 0.44 \text{ m/s} < 0.5 \text{ m/s therefore OK.}$$

$$D_{100\text{-year}} = 0.19 \text{ m}$$

$$V_{100\text{-year}} = 0.70 \text{ m/s} < 1.0 \text{ m/s therefore OK.}$$

Second, velocities are checked at the bottom of the steeper section (i.e. slope = 6% with reduced catchment area):

$$D_{5\text{-year}} = 0.13 \text{ m } (Q_5 = 0.06 \text{ m}^3\text{/s})$$

$$V_{5\text{-year}} = 0.29 \text{ m/s} < 0.5 \text{ m/s therefore OK}$$

$$D_{100\text{-year}} = 0.15 \text{ m } (Q_{100} = 0.15 \text{ m}^3\text{/s})$$

$$V_{100\text{-year}} = 0.47 \text{ m/s} < 1.0 \text{ m/s therefore OK.}$$

8.6.6.1 Velocity check – safety

The velocity–depth product at both critical points (bottom of steep section and bottom of entire swale) needs to be less than 0.4 m^2/s during a 100-year ARI flow to meet pedestrian safety criteria.

At bottom of steep section:

$$V = 0.47 \text{ m/s}, d = 0.15 \text{ m; therefore, } V \times d = 0.07 \text{ m}^2\text{/s} < 0.4 \text{ m}^2\text{/s therefore OK.}$$

At bottom of swale:

$$V = 0.70 \text{ m/s}, d = 0.19 \text{ m; therefore } V \times d = 0.13 \text{ m}^2\text{/s} < 0.4 \text{ m}^2\text{/s therefore OK.}$$

8.6.6.2 Check dams

Given the steep slope of the upper part of the swale (6%), check dams are required to help to distribute flows across the base of the swale in the upper section. These are to be placed every

10 m along the steep part of the swale, be about 100 mm high and be constructed of stone. The check dams are to cross the base of the swale and merge into the batters.

8.6.7 Overflow structures

As the swale can carry a five-year ARI discharge, overflow structures are not required for this worked example. See Chapter 5 for an example including the design of an overflow pit.

8.6.8 Vegetation specification

To complement 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 actual species will be selected by the landscape designer.

8.6.9 Calculation summary

The completed *Swales Calculation Summary* shows the results of the design calculations.

Swales — CALCULATION SUMMARY

CALCULATION TASK	OUTCOME		CHECK
1 Identify design criteria			
Conveyance flow standard (ARI)	5	year	
Vegetation height	50	mm	✓
2 Catchment characteristics			
Upper area	4,800	m^2	
Total area	12,000	m^2	
Slope	3 and 6	%	
Fraction impervious			
f_{imp}	0.66		✓
3 Estimate design flow rates			
Time of concentration			
Estimate from flow path length and velocities	10	minutes	✓
Identify rainfall intensities			
Station used for IFD data:	Ballarat		
Major flood – 100-year ARI	140	mm/hr	
Minor flood – 5-year ARI	67	mm/hr	
Peak design flows			
Q_{minor}	0.14	m^3/s	
Q_{100}	0.36	m^3/s	✓
4 Swale design			
Manning's *n* below vegetation height	0.3		
Manning's *n* at capacity	0.04		✓
5 Inlet details			
Adequate erosion and scour protection?	rock pitching		
Flush kerb setdown?	50	mm	✓
6 Velocities over vegetation			
Velocity for 5-year flow (<0.5 m/s)	0.09	m/s	
Velocity for 100-year flow (<1.0 m/s)	0.49	m/s	
Safety: Vel x Depth (<0.4)	0.13	m^2/s	✓
7 Overflow system			
Spacing of overflow pits	not required		
Pit type			✓
8 Plant selection	turf		✓

8.6.10 Construction drawing

Figure 8.19 shows the construction drawing for the swale worked example.

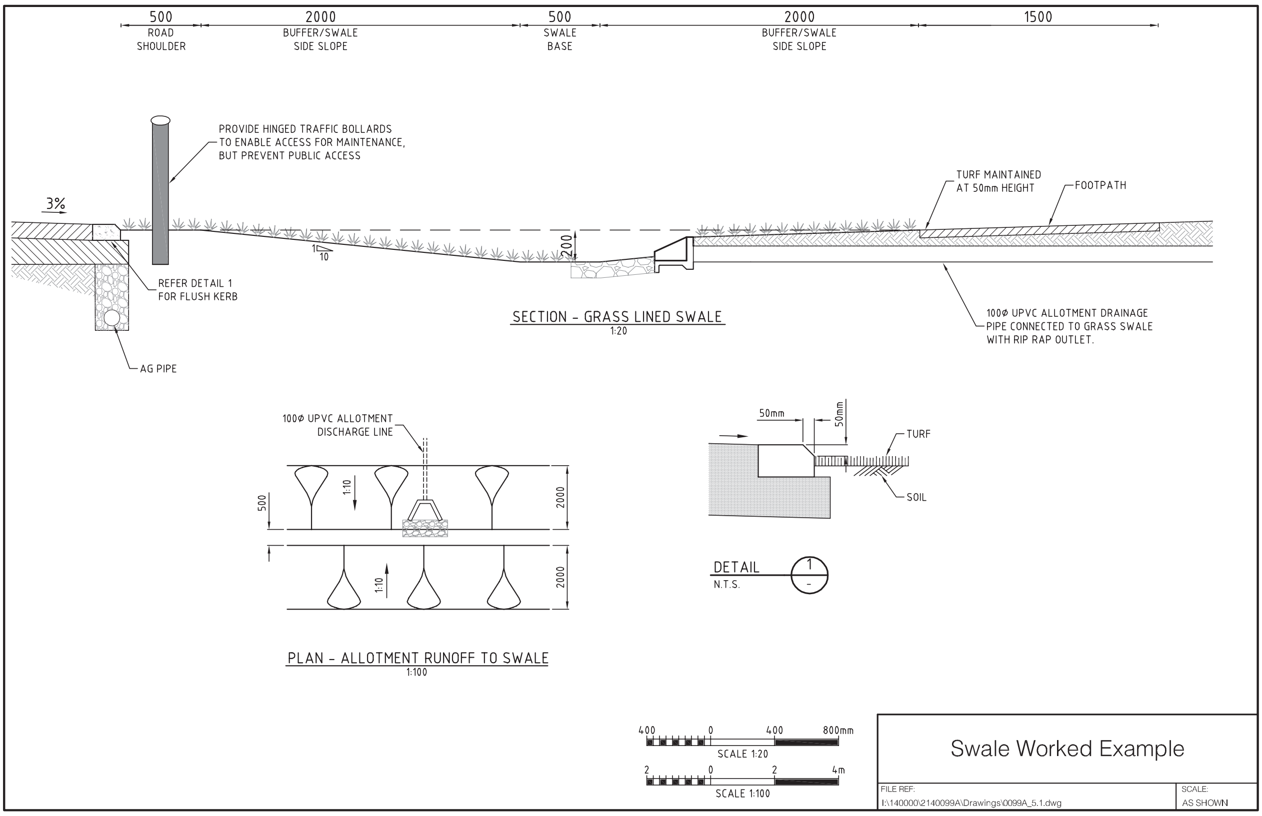


Figure 8.19 Swale worked example

8.7 References

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