Chapter 7 Swale/ buffer Systems

Definition:

A vegetated swale is a vegetation-lined channel used to convey stormwater in lieu of pipes.

Purpose:

- Vegetated swales provide a desirable 'buffer' between receiving waters (e.g. creek, wetland) and impervious areas of a catchment
- The interaction with vegetation promotes an even distribution and slowing of flows thus encouraging coarse sediments to be retained.

Implementation considerations:

- Swales can be incorporated in urban designs along streets or parklands and add to the Aesthetic character of an area.
- Operates best with longitudinal slopes of 2% to 4%. Milder sloped swales may become waterlogged and have stagnant ponding, the use of underdrains can alleviate this problem. For slopes steeper than 4%, check banks can help to distribute flows as well as slow velocities. Dense vegetation and drop structures can be used to serve the same function as check dams but care needs to be exercised to ensure that velocities are not excessively high.
- Swales can use a variety of vegetation types. Vegetation is required to cover the whole width of a swale, be capable of withstanding design flows and be of sufficient density to provide good filtration. For best treatment performance, vegetation height should be above treatment flow water levels.
- If runoff enters directly into a swale, perpendicular to the main flow direction, the edge of the swale acts as a buffer and provides pre-treatment for the water entering the swale.

Vegetation is selected by required appearance & treatment performance

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7.1 Introduction

Vegetated swales are used to convey stormwater in lieu of pipes and remove coarse and medium sediment and are commonly combined with buffer strips. Swales also provide a disconnection of impervious areas from hydraulically efficient pipe drainage systems resulting in slower travel times thus reducing the impact of increased catchment imperviousness on peak flow rates.

Figure 7.1 illustrates vegetated swales with different options for driveway crossings, including at-grade crossings (with mild side slopes) and elevated crossings.

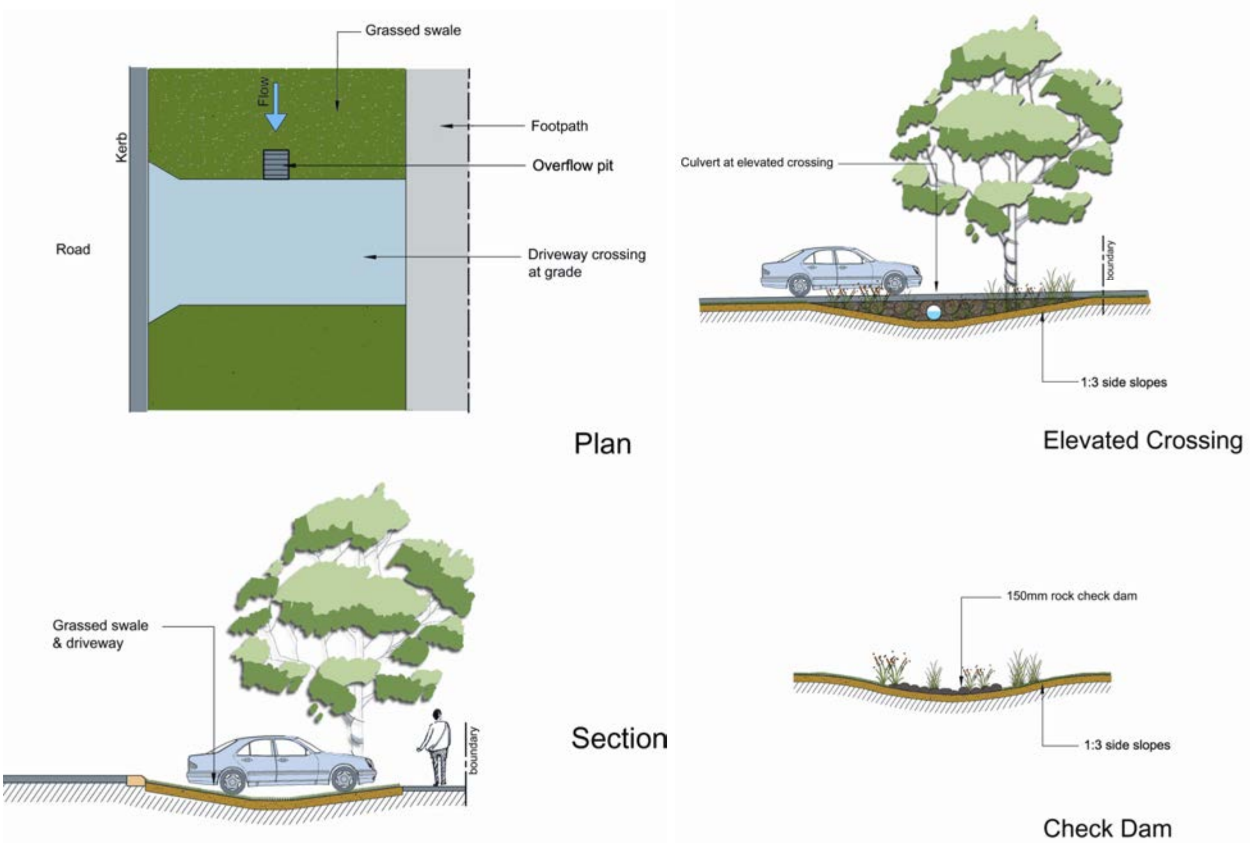


Figure 7.1. Swales with at-grade driveway crossing (L), elevated crossing (top R) and a check dam for flow spreading

The interaction between flow and vegetation along swales facilitates pollutant settlement and retention. Swale vegetation acts to spread flows and reduce velocities, which in turn aids filtration and sediment deposition. Swales alone can rarely provide sufficient treatment to meet objectives for all pollutants, but can provide an important pre-treatment function for other 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, well-distributed flow through vegetation. Vegetation reduces 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.

To convey flood flows along swales, in excess of a treatment design flow (typically the peak 3-month ARI flow), pits draining to underground pipes can be used. Overflows from the swale enter the pit when a designated depth is reached. This is particularly useful in areas with narrow verges, where a swale can only accommodate flows associated with the minor drainage system (e.g. 5 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. 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 dams or banks (small porous rock walls) along swales can help to distribute flows and reduce velocities.

Swales can be designed with 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.

Figure 7.2. Swale systems: heavily vegetated, use of check dams, grass swale with elevated crossings

Grassed swales are commonly used and can appear as a typical road verge, however the short vegetation offers sediment retention to only shallow flows. In addition, the grass is required to be mown and well maintained in order 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 and, once established, require minimal maintenance 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 Chapter 5). A limitation with ‘elevated’ crossings can be their expense compared to at-grade crossings (particularly in dense urban developments), safety concerns with traffic movement adjacent to the inlet and outlet and the potential for blockage of with small culverts.

Crossings can also be constructed at grade and act like a ford during high flows, however, this reduces maximum swale batter slopes to approximately 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.

Figure 7.3. Elevated and at-grade driveway crossings across swales

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.

It is extremely important to keep traffic and deliveries off swales and means to ensure this is a key concern during swale design. Traffic can 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.

Swales 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 it’s treatment performance and long-term viability.

Key design issues to be considered are:

Verifying treatment performance and relation to other measures in a treatment train

Determine design flows

Dimension the swale with site constraints

Above ground design

- check velocities
- check slopes
- design of inlet zone and overflow pits
- check above design flow operation
- Allowances to preclude traffic on swales
- Recommend plant species and planting densities
- Provision for maintenance.

7.2 Verifying size for treatment

The curves below show the pollutant removal performance expected for swales with varying slopes (1%, 3% and 5 %) and vegetation height (0.05 to 0.5m). It is important to recognise that swales in isolation provide limited treatment for fine pollutants, but can perform pretreatment for other measures.

The curves are based on the performance of the system at the reference site and were derived using the Model for Urban Stormwater improvement Conceptualisation (MUSIC) (eWater, 2009). To estimate an equivalent performance at other locations in Tasmania, the hydrologic design region relationships should be used to convert the treatment area into an equivalent treatment area, refer to 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:

- a base width of 2m
- a top width of 6m
- 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 TSS, TP and 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*.

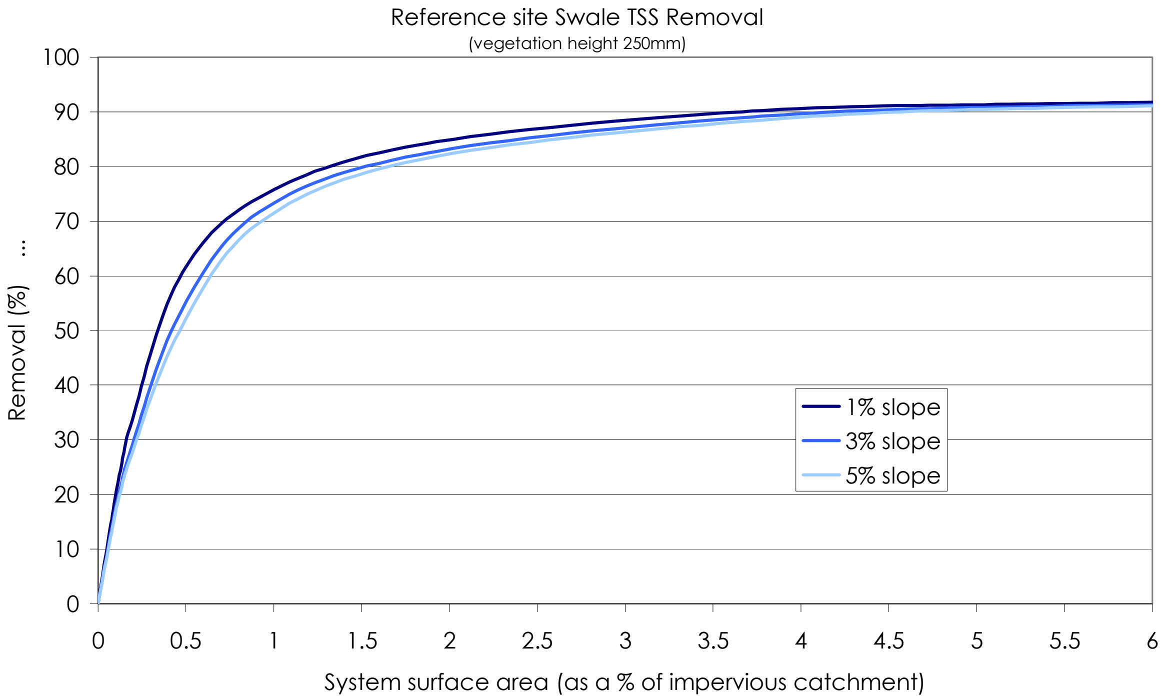


Figure 7.4. TSS removal in swale systems with varying slope

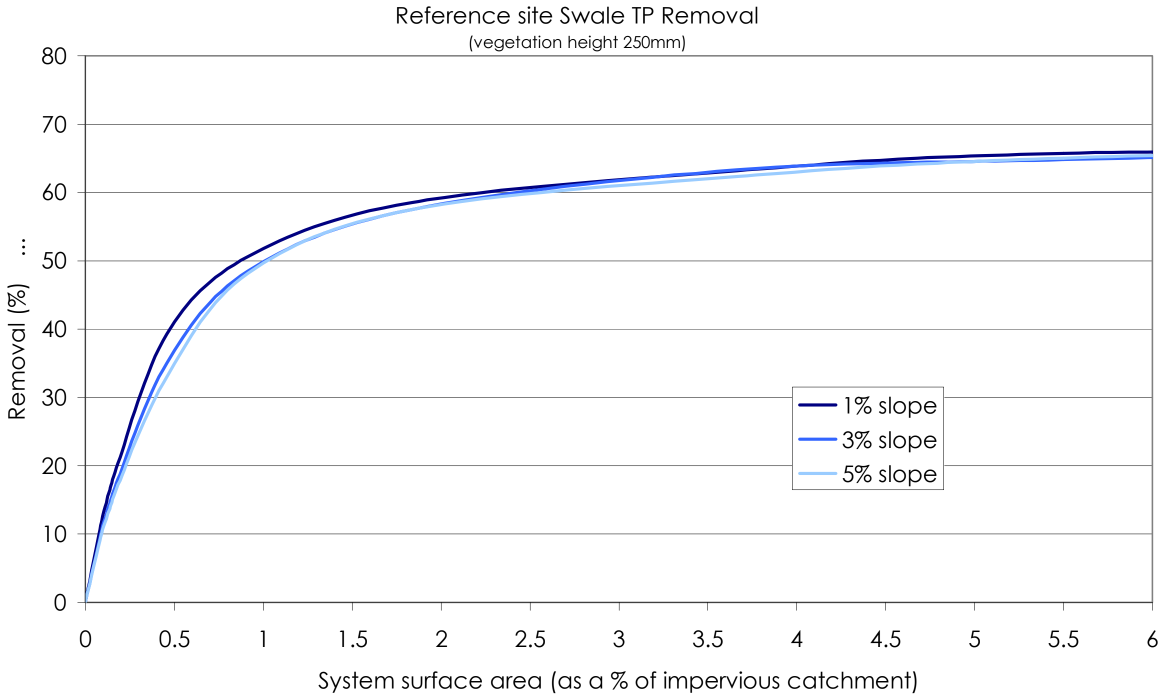


Figure 7.5. TP removal in swale systems with varying slope

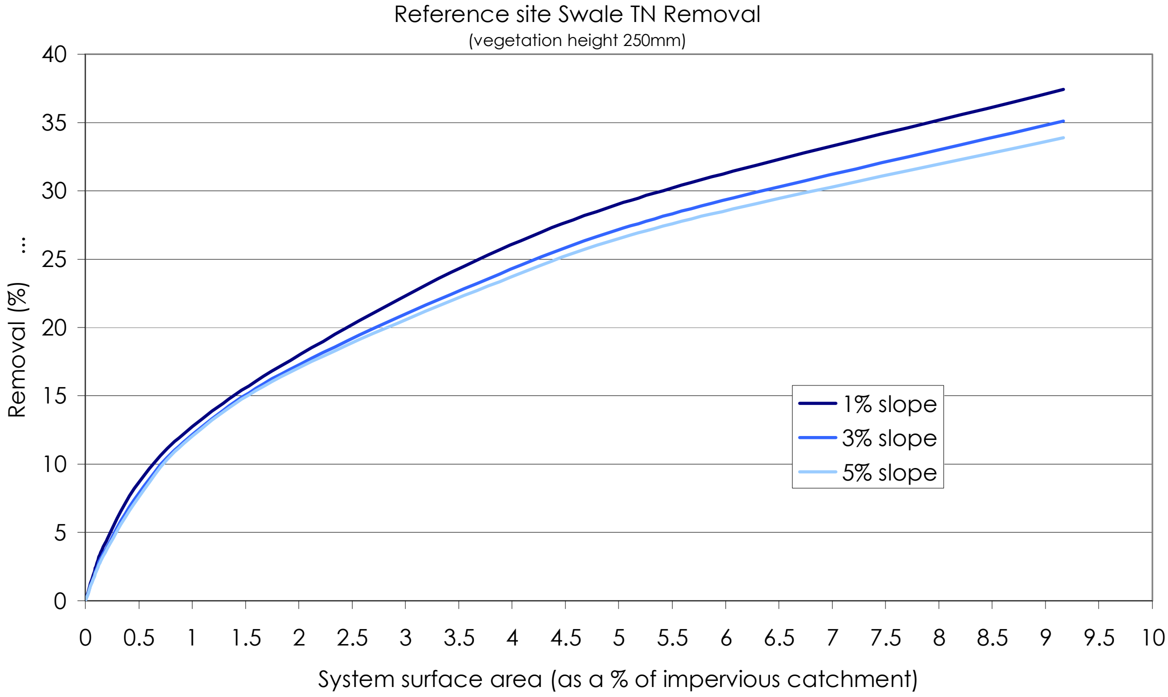


Figure 7.6. TN removal in swale systems with varying slope

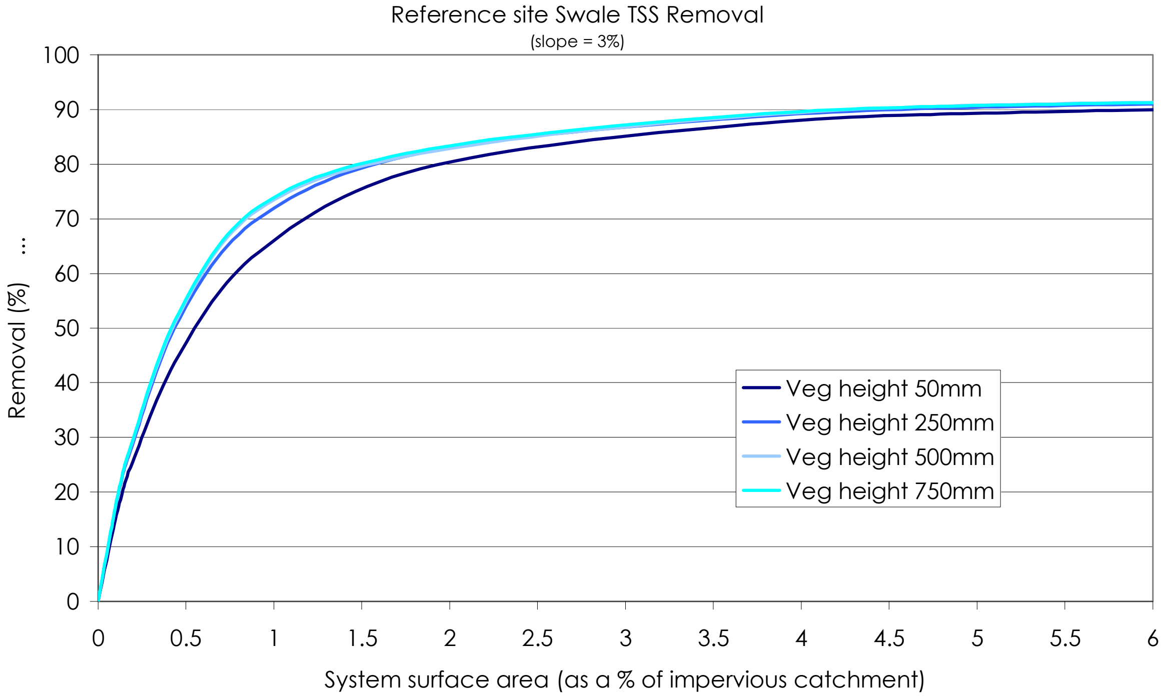


Figure 7.7. TSS removal in swale systems with varying vegetation height

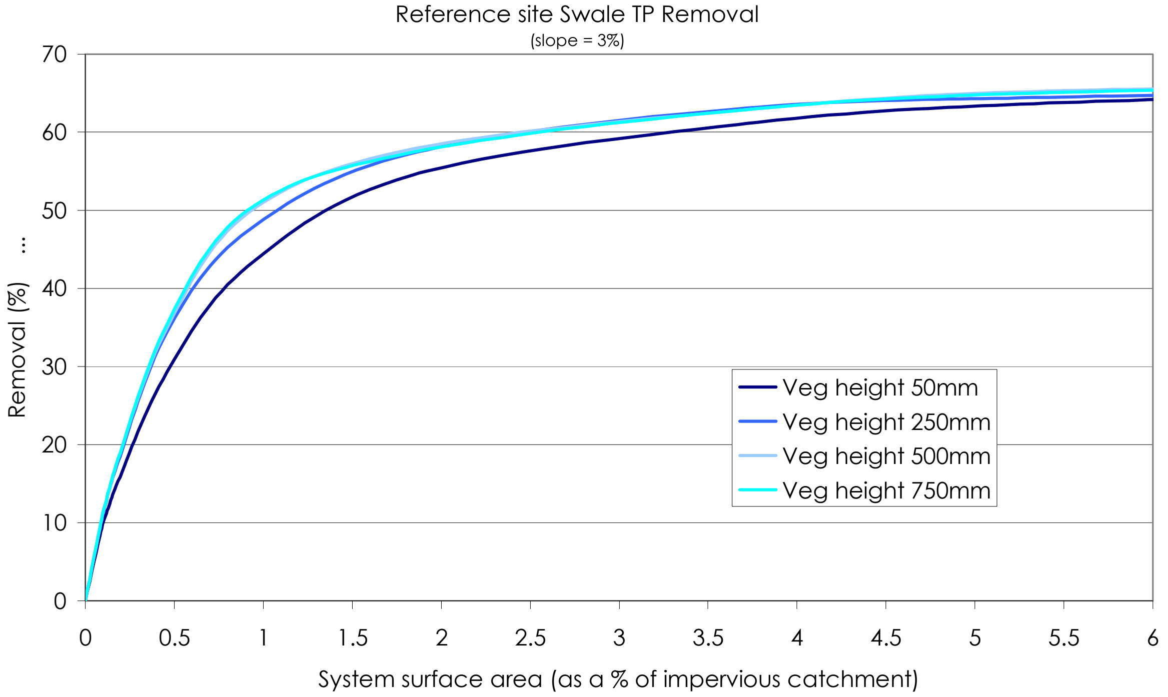


Figure 7.8. TP removal in swale systems with varying vegetation height

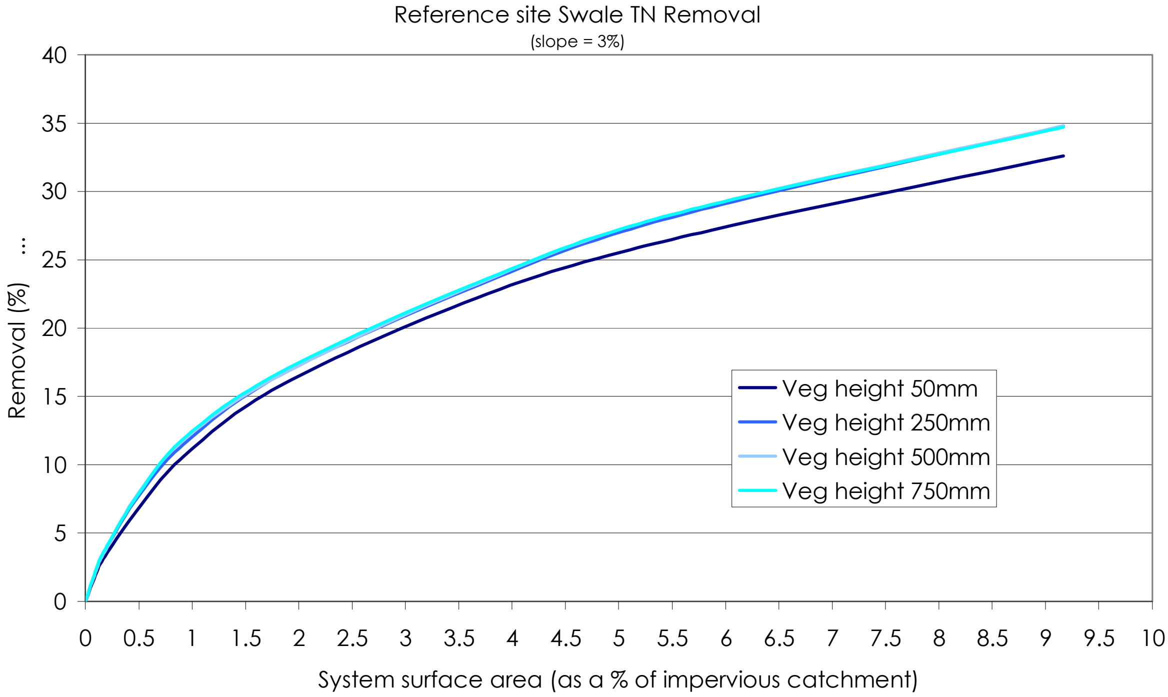


Figure 7.9. TN removal in swale systems with varying vegetation height

7.3 Design procedure: Swales

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

7.3.1 Estimating design flows

Two design flows are required for swale systems:

- Minor flood rates (typically 5-year ARI) to size overflows and allow conveyance for minor floods and not increase flood 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 scour pollutants or damage vegetation

7.3.1.1 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 is considered to be a suitable method for estimating design flows.

7.3.2 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, should also be checked during detail design. Factors to consider 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 altered to derive an acceptable configuration.

Once design flows are established, 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.

7.3.2.1 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 is heavily dependent on local council regulations and will relate to traffic access and the provision of crossings (if required). The provision of driveway crossings can significantly impact on the required width of the swale. The slope of at-grade crossings (and therefore the swale) are governed by the trafficability of the change in slope across the base of the swale. Typically 1:9 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 how feasible having overflow points at each one is.

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

7.3.2.2 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, 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.

7.3.3 Swale capacity - selection of Mannings "n"

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

Manning's $Q = (AR^{2/3}S_o^{1/2})/n$

Equation 7.1

Where A = cross section area

R = hydraulic radius

S = channel slope

n = roughness factor

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, 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). Further discussion on selecting an appropriate Manning's '*n*' for a swale is provided in Appendix F of the MUSIC modelling manual (eWater, 2009).

It is considered reasonable for Manning's 'n' to have a maximum at the vegetation height and then sharply reduce as depths increase. Figure 8.10 shows a plot of varying Manning's *n* with flow depth for a grass swale. 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 8.10) 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.

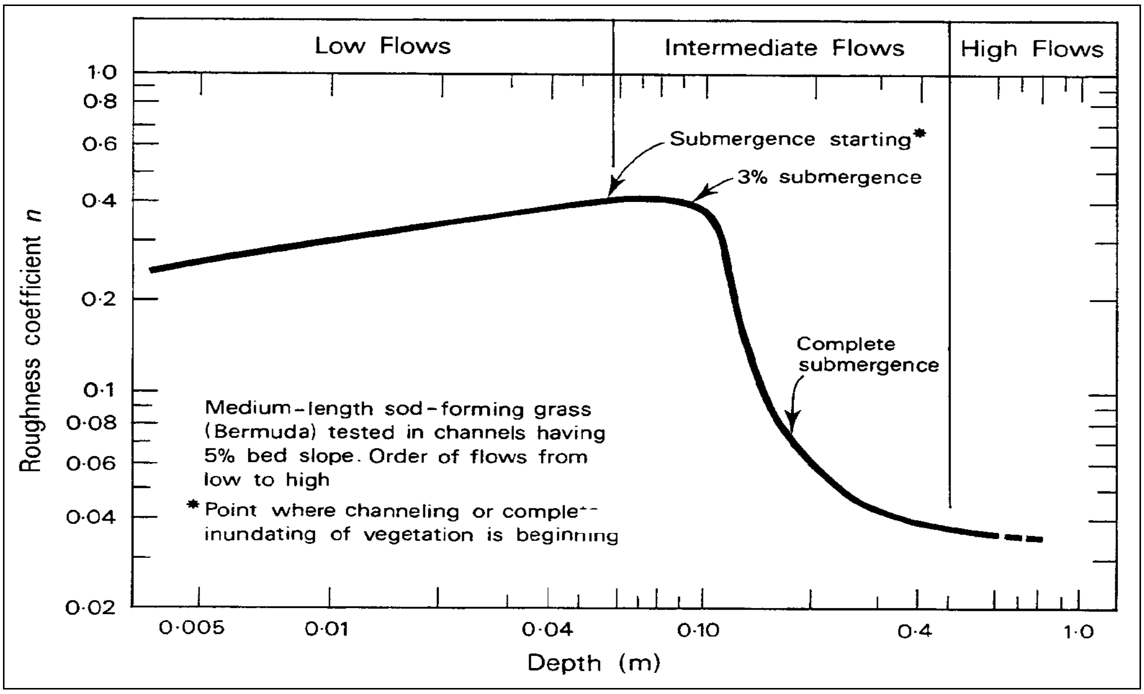


Figure 7.10. Impact of flow depth on hydraulic roughness adapted from Barling and Moore (1993)

7.3.4 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.

7.3.4.1 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 down a swale. Creating distributed flows 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.

For distributed flows, it is important to provide an area for coarse sediments to accumulate, that is off the road surface. The photograph in Figure 7.11 shows sediment accumulating on a street surface where the vegetation is the same level as the road. To avoid this accumulation, a tapered flush kerb can be used that sets the top of the vegetation between 40-50mm lower than the road surface (Figure 7.11), which requires the top of the ground surface (before turf is placed) to be between 80-100 mm below the road surface. This allows sediments to accumulate off any trafficable surface.

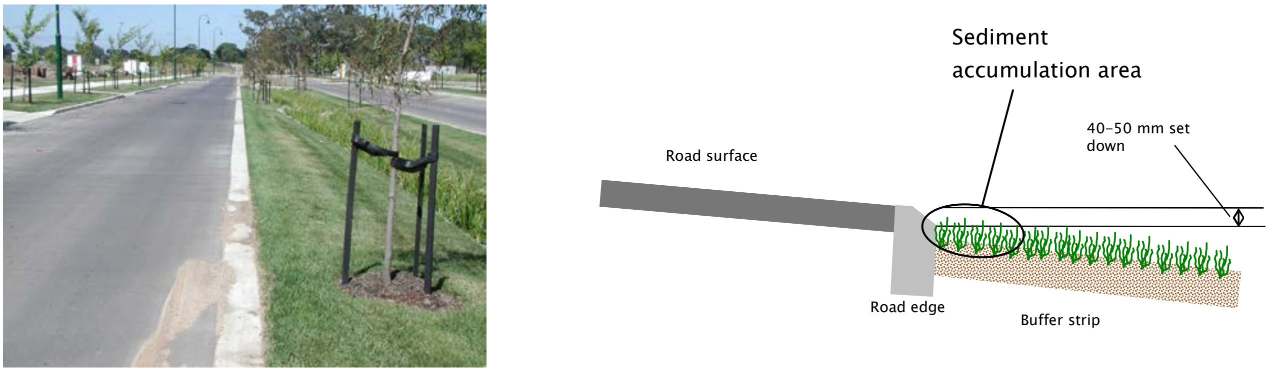


Figure 7.11. Photograph of flush kerb without setdown, edge detail showing setdown

Figure 7.12. Photograph of different arrangements of kerbs with breaks to distribute inflows

7.3.4.2 Direct entry points

Direct entry of flows can either be from overland flow or from a pipe system. For all point entrances into swales, energy dissipation at the inlet point is an important consideration 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 doesn't 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 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.

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 7.13 shows an example of a surcharge pit discharging into a swale.

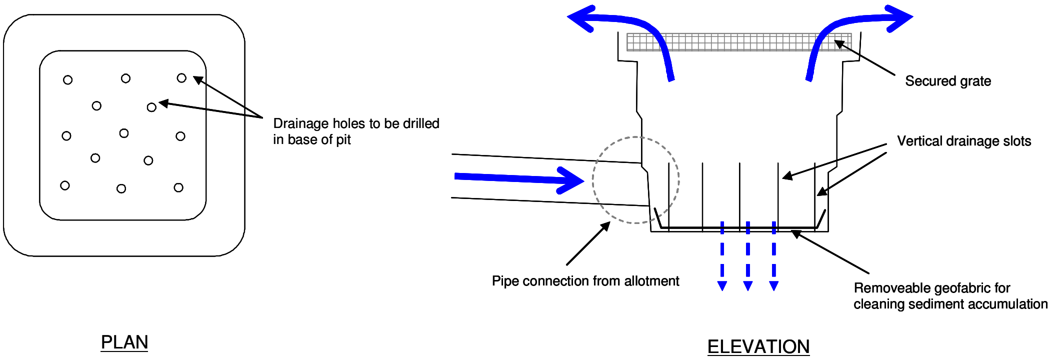


Figure 7.13. Example of surcharge pit for discharging allotment runoff into a swale

7.3.5 Vegetation scour velocity check

Scour velocities over the vegetation along the swale are checked by applying Manning's equation. An important consideration is the selection of an appropriate Manning's 'n' that suits the vegetation height. The selection of an appropriate 'n' is discussed more in the Section 4.3.

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.5-year ARI) discharges
- Less than 1.0 m/s for major storm (e.g.100-year ARI) discharges

7.3.5.1 *Velocity check – safety*

As swales are generally accessibly by the public it is important to check that flow depths and velocities are 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, as in ARR BkVIII Section 1.10.4.

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

7.3.5.2 *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. 100mm) 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 should be at 4% grade from 100 mm below the toe of an upstream check dam (see Figure 8.14).

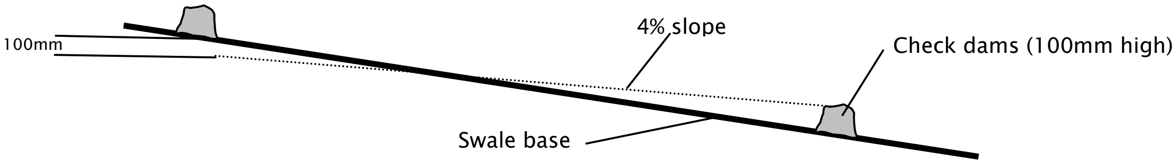


Figure 7.14. Location of check dams in swales

7.3.6 High-flow route and overflow design

The design for high flows must safely convey flows associated with a minor drainage system (e.g. 5-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 it's 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.

Weir flow condition – *when free overall conditions occur over the pit (usually when the extended detention storage of the retarding basin is not fully engaged),* ie.

$$P = \frac{Q_{des}}{B \cdot C_w \cdot H^{1.5}}$$

Equation 7.2

P = Perimeter of the outlet pit

B = Blockage factor (0.5)

H = Depth of water above the crest of the outlet pit

Q_{des} = Design discharge (m^3/s)

C_w = weir coefficient (1.7)

Orifice flow conditions – *when the inlet pit is completely submerged (corresponding to conditions associated with larger flood events*), ie.

$$A_o = \frac{Q_{des}}{B \cdot C_d \sqrt{2gH}}$$

Equation 7.3

C_d = Orifice Discharge Coefficient (0.6)
B = Blockage factor (0.5)
H = Depth of water above the centroid of the orifice (m)
A_o = Orifice area (m^2)
Q_{des} = Design discharge (m^3/s)

It is important that an outlet pit is prevented from blockage by debris. Design consideration needs to include means of preventing blockage of the outlet structure.

7.3.7 Vegetation specification

Table B.1 in Appendix B provides lists of plants that are suitable for swales. Consultation with landscape architects is recommended when selecting vegetation, to ensure the treatment system compliments the landscape of the area.

7.3.8 Design calculation summary

Swales **CALCULATION SUMMARY**

	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 (<0.5m/s)	m/s	
		Velocity for 100 year flow (<1.0m/s)	m/s	
		Safety: Vel x Depth (<0.4)	m^2/s	☐
7	**Overflow system**			
		spacing of overflow pits		
		pit type		☐
8	**Plant selection**			☐

7.4 Checking tools

This section provides a number of checking aids 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).

7.4.1 Design assessment checklist

The checklist below 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, referral should be made back to the design procedure to determine the impact 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 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 (see 7.4.4).

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%?					
Mannings '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 50mm 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?					

7.4.2 Construction advice

This section provides general advice for the construction of swales. It is based on observations from construction projects around Australia.

Building phase damage

Protection of soil and vegetation is important during building phase, uncontrolled building site runoff is likely to cause excessive sedimentation, introduce weeds and litter and require replanting following the building phase. Can use a staged implementation - i.e. during building use geofabric, soil (e.g. 50mm) and instant turf (laid perpendicular to flow path) to provide erosion control and sediment trapping. Following building, remove 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. 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.

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 50mm to the top of vegetation (if turf) is adequate. Therefore, total set down to the base soil is approximately 100 mm (with 50mm turf on top of base soil).

Timing for planting

Timing of vegetation is dependent 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 during construction for sediment control (e.g. with turf) then remove and plant out with long term vegetation.

7.4.3 Construction checklist

CONSTRUCTION INSPECTION CHECKLIST

Swales

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			**Structural components**	Y	N		
1. Erosion and sediment control plan adopted					11. Location and levels of pits as designed				
					12. Safety protection provided				
2. Traffic control measures					13. Location of check dams as designed				
3. Location same as plans					14. Swale crossings located and built as designed				
4. Site protection from existing flows									
Earthworks					15. Pipe joints and connections as designed				
5. Level bed of swale					16. Concrete and reinforcement as designed				
6. Batter slopes as plans					17. Inlets appropriately installed				
7. Longitudinal slope in design range					18. Inlet erosion protection installed				
8. Provision of shallow drainage for mild slopes					19. Set down to correct level for flush kerbs				
					Vegetation				
9. Compaction process as designed					20. Stablisation immediately following earthworks				
10. Appropriate topsoil on swale									
					21. Planting as designed (species and densities)				
					22. Weed removal before stabilisation				
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

1.

2.

3.

4.

5.

6.

7.4.4 Asset transfer 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 (eg drawings, survey, models) provided?		
Asset listed on asset register or database?		

7.5 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 have a flood conveyance role that needs to be maintained to ensure adequate flood protection for local properties.

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

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 could impact on plant growth, particularly in developing catchments with poor building controls.

Other components of the system that will 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:

- Maintenance of 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 impact 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 if located in a visible location. 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.

7.5.1 Operation & maintenance inspection form

The form below should 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 (eg crossovers)?			
Traffic damage present?			
Evidence of dumping (eg 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:			

7.6 Swale worked example

7.6.1 Worked example introduction

As part of a development in Hobart, 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 300mm).

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.

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 4.5m) 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%).

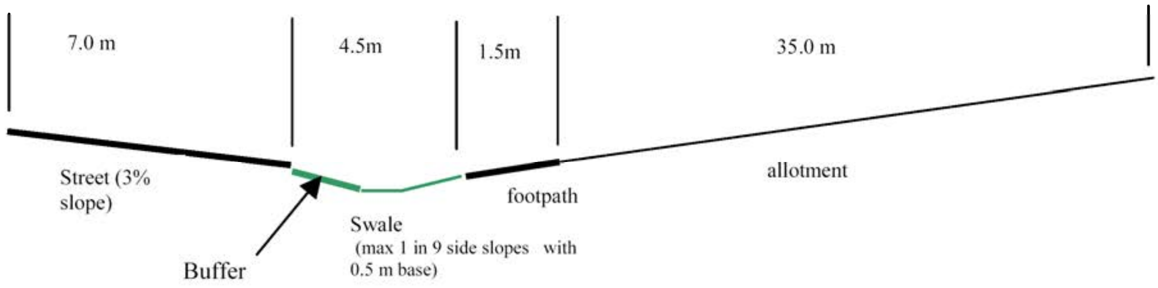


Figure 7.15. Cross section of proposed buffer/swale system

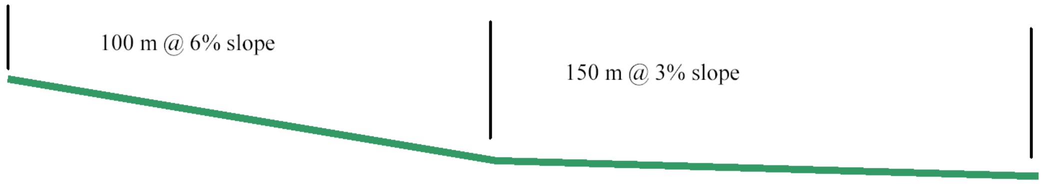


Figure 7.16. Long section of proposed buffer/swale system

The contributing catchment area includes 35 m deep (and 10m wide) allotments on one side, a 7m wide road pavement surface and a 1.5 m footpath and 4.5 m swale and services easement (Figure 7.15). The area is 250 m long with the top 100m having a 6% slope and the bottom 150m 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.

Figure 7.17. Similar buffer swale system for conveying runoff

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);
- Provision of driveway access to lots given side slope limits; and
- Provision to convey 5-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 the following:

- Design the swale system to accommodate driveway crossovers and check dams where required
- Select vegetation such that the hydraulic capacity of the swale is sufficient
- Determine maximum length of swale to convey 5 year flows before an underground pipe is required
- Check velocities are maintained to acceptable levels
- Overflow structure from swale to underground pipe (if required).

Additional design elements will be required, including:

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

7.6.1.1 Design Objectives

- Swale shall convey at least all flows up to the peak 5-year ARI storm event.
- Sedimentation of coarse particles will be promoted within the buffer by providing an even flow distribution.
- Prevent traffic damage to the buffer swale system.
- Flow velocities to be controlled to prevent erosion.
- Allowance for suitable driveway gradients (max 1:9) to be provided at crossovers into properties.

7.6.1.2 Site Characteristics

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

7.6.1.3 Confirm size for treatment

Interpretation of 7.2 Verifying size for treatment 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.

- Reference site location
- 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.

Area of swale base / impervious catchment area

$$0.5x250/\ [(0.65x8750)+(1.0x2125)+(0.1x1125)] = 1.6\%$$

To apply the performance curves the area = 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. For real-world design, the adjustment factor/hydrologic region methodology should be applied to calculate the actual size of system required at the development site.

DESIGN NOTE – The values derived from 7.2 Verifying size for treatment will only be valid if the design criteria for the proposed installation are similar to those used to create the Figures. Site specific modelling using programs such as MUSIC (eWater, 2009) may yield a more accurate result.

7.6.2 Estimating design flows

With a small catchment, the Rational Method is considered an appropriate approach to estimate the 5 and 100 year ARI peak flow rates. The steps in these calculations follow below.

See Appendix E Design Flows – t_c for a discussion on methodology for calculation of time of concentration.

7.6.2.1 Major and minor design flows

The procedures in Australian Rainfall and Runoff (ARR) are used to estimate the design flows.

Step 1 – Calculate the time of concentration.

The time of concentration is estimated assuming overland flow across the allotments and along the swale. From procedures in AR&R, t_c is estimated to be 10 minutes.

Rainfall Intensities for the area of study (for the 5 and 100 year average recurrence intervals) are estimated using ARR (1998) with a time of concentration of 10 minutes are:

t_c	100yr	5yr
10 min	140*	67*

* These figures are for the worked example only. The appropriate region and corresponding rainfall intensities must be selected for each individual project.

Step 2 – Calculate design runoff coefficients (using the method outlined in Australian Rainfall and Runoff Book VIII (Engineers Australia, 2003)).

Apply method outlined in Section1.5.5 (iii) ARR 2001 Bk VIII

$C_{10} = 0.9f + C^1{}_{10}\,(1-f)$

Fraction impervious

$f = (8750 \times 0.65 + 2125 \times 1 + 1125 \times 0.1)/12000$

$= 0.66$

Apply the rational formula method outlined in Section 1.5.5 (iii) AR&R 2001 Bk VIII:

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

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

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

Calculate C_{10} (10 year ARI runoff coefficient)

$C_{10} = 0.9f + C^1{}_{10}\,(1-f)$

$C_{10} = 0.65$

Step 3 – Convert C_{10} to values for C_5 and C_{100}

Where – $C_y = F_y \times C_{10}$

Runoff coefficients as per Table 1.6 Book VIII ARR 1998

	C_5	C_{100}
Cell A	0.65	0.78

Step 4 – Calculate peak design flow (calculated using the Rational Method).

$$Q = \frac{CIA}{360}$$

Where – C is the runoff coefficient (C_5 and C_{100})

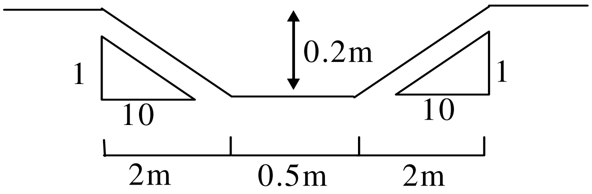
I is the design rainfall intensity mm/hr (I_5 and I_{100})

A is the catchment area (Ha)

Q_5	Q_{100}
0.14	0.36

7.6.3 Swale dimensions

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



7.6.4 Swale flow capacity

The capacity of the swale is firstly estimated at the most downstream point. It is considered to be 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 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.

7.6.4.1 *Selection of manning* n

A range of Manning's *n* values are selected for different flow depths appropriate for grass. It is firstly assumed that the flow height for a 5 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)

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

Manning's $Q=(AR^{2/3}S_o^{1/2})/n$

$Q_{cap} = 0.50m^3/s >> Q_5\ (0.14m^3/s)$

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} = $0.50m^3/s$) is also sufficient to convey the entire peak Q_{100} flow of $0.36m^3/s$ 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 7-1. Manning's *n* and flow capacity variation with flow depth - turf

Flow Depth	Mannings n	Flow rate
(m)		(m3/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 the table of Manning's equation output, it can be seen that the 5 year ARI flow depth is above the vegetation height and therefore the Manning's *n* assumption would seem reasonable.

7.6.4.2 Option 2 – assume higher vegetation

For the purposes of this worked example, the capacity of the swale is also estimated when using 300mm 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.

The table on the following page presents the adopted Manning's *n* values and the corresponding flow capacity of the swale for different flow depths.

Table 7-2. Manning's *n* and flow capacity variation with flow depth - sedges

Flow Depth	Mannings n	Flow rate
(m)		(m3/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 above that the swale with current dimensions is not capable of conveying a 5-year discharge. Either the swale depth would need to be increased or overflow pits provided to convey a 5-year ARI flow.

This worked example continues using grass for the remainder.

7.6.5 Inlet details

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

7.6.6 Velocity checks

Two velocity checks are performed to ensure vegetation is protected from erosion at high flow rates. 5-year and 100-year ARI flow velocities are checked and need to be kept below 0.5m/s and 1.0 m/s respectively.

Velocities are estimated using Manning's equation:

Firstly, velocities are checked at the most downstream location (ie. slope = 3%)

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

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

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

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

Secondly, velocities are checked at the bottom of the steeper section (ie. slope = 6% with reduced catchment area)

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

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

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

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

7.6.6.1 Safety check

Check at both critical points (bottom of steep section and bottom of entire swale) that velocity depth product is less than 0.4 during a 100 year ARI flow.

At bottom of steep section:

V= 0.47 m/s, d= 0.15m; therefore V.d = 0.07 m^2/s <0.4 therefore OK.

At bottom of swale:

V= 0.70 m/s, d= 0.19m; therefore V.d = 0.13 m^2.s <0.4 therefore OK.

7.6.6.2 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 approximately 100 mm high and be constructed of stone. The check dams are to cross the base of the swale and merge into the batters.

7.6.7 Overflow structures

As the swale can carry a five year ARI discharge, overflow structures are not required for this worked example. See Chapter 4 for an example including the design of an overflow pit.

7.6.8 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 actual species will be selected by the landscape designer.

7.6.9 Calculation summary

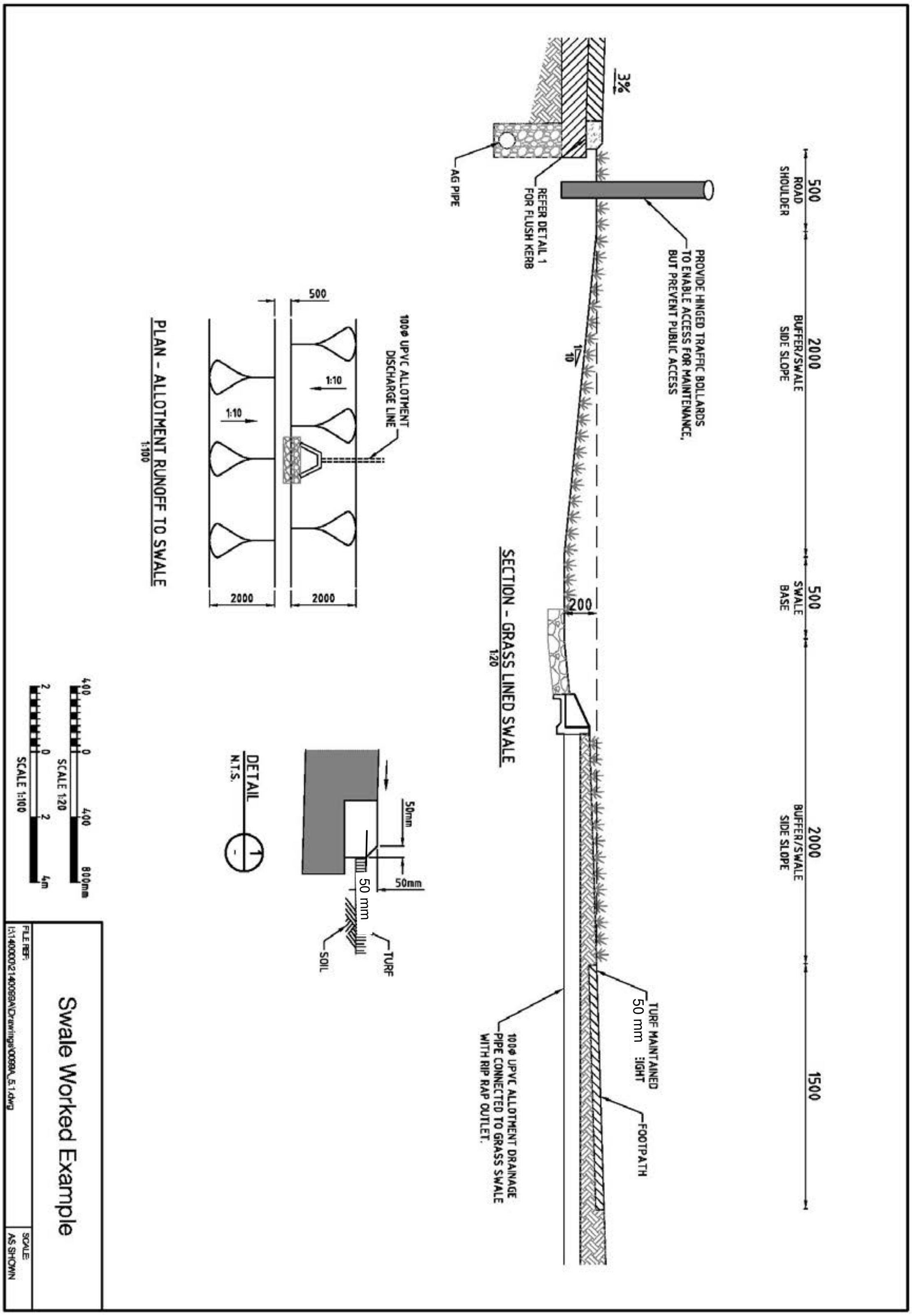
The sheet overleaf shows the results of the design calculations.

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:	Hobart		
		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 (<0.5m/s)	0.09	m/s	
		Velocity for 100 year flow (<1.0m/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*		☑

7.6.10 Construction drawings



7.7 References

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