4 Conveyance Systems

4.1 Swales and Buffer Strips

Background

Swales are very important for disconnecting impervious areas from downstream surface water bodies and receiving environments. These systems convey stormwater, promoting infiltration and reducing stormwater runoff peak flow, velocity and volume, and remove coarse and medium sediments, including suspended solids and trace metals. Swales also assist in protecting surface water bodies from frequent storm events by reducing flow velocity compared to discharges from hydraulically efficient piped drainage systems.

A vegetated swale is a broad, shallow channel with vegetation covering the side slopes and base. Vegetation can range from grass to native sedges and shrubs, depending on hydraulic and landscape requirements. Vegetated swales are used instead of the conventional piped system as part of stormwater conveyance. They are usually placed in public open space (Figure 2), or within the median or along the shoulders of main roads, rather than within residential lots and verges. Typically combined with buffer strips and/or bioretention systems, vegetated swales are reliant on hydraulic roughness and gentle slopes to retard flow velocities. Swales also have lower capital costs than traditional piped systems and enhance biological diversity and create beneficial habitat, as well as improve visual aesthetics within a community.

The treatment efficiency of swales is variable for different pollutants and swales may not provide sufficient treatment on their own to meet water quality objectives. However, when used as part of the overall stormwater management system, swales are a useful at-source and in-transit water quantity management tool, whilst providing initial treatment for water quality outcomes.

Buffer strips are areas of vegetation through which runoff passes while travelling to a discharge point and are therefore aligned perpendicular to the direction of flow. They reduce sediment loads by passing a sheet flow of shallow depth through vegetation. The vegetation acts to slow the flow and trap coarse sediments. Buffer strips typically require uniformly distributed flow, such as sheet flow that comes off a road, carpark or other impervious area. Buffer strips also can be applied around other structural BMPs, such as living streams and constructed wetlands.

Figure 1. Flush kerbing and broken kerbing used to allow flow from a carpark into a swale at Point Fraser, Perth. (Photograph: Department of Water 2006.)

Figure 2. Vegetated swale in Gosnells, making use of native species in a parkland setting. (Photograph: Department of Water 2004.)
The processes which occur in vegetated swales and buffer strips are quite complex, and involve physical and biochemical components. Physical processes for particulate removal (and consequently particle-bound pollutants, such as phosphorus) include infiltration, deposition and filtration. Nitrogen removal is a function of denitrification, biostorage (plant and animal uptake) and changes in soil storage.

While providing water conveyance, vegetated swales and buffer strips will often retain and detain water at different times of the year, due to the seasonal nature of local rainfall and variability in groundwater levels. For example, in summer, autumn and early winter in the south-west of WA (when groundwater levels are at their lowest), a swale in sandy soils may perform as a retention/detention system, with the majority of storm events infiltrating and little or no flow occurring.

**Performance efficiency**

While essentially a conveyance based system, one of the major roles of swales is to provide disconnection from the receiving environment. Research and past experiences suggest that vegetated swales represent a practical and potentially effective technique for controlling urban runoff quantity and quality. While limited local WA performance data exists for vegetated swales, it is known that riffles, gentle slopes, permeable soil, dense vegetation cover and slow velocity all contribute to successful pollutant removal by the swale system.

Monitoring in the United States of America showed that even vegetated strips adjacent to major roads that were not intended for treatment of stormwater runoff played an important part in reducing the concentrations of pollutants and reducing the volume of stormwater discharged to surface waters as a result of infiltration into the soil (Lantin and Barrett 2005). Studies in the United States of America showed that vegetated swales were capable of removing many pollutants found in stormwater, with reported removal efficiencies of 83% for sediment, 75% for hydrocarbon, 67% for lead, 63% for zinc and 63% for aluminium (Schueler 1995). Removal of heavy metals appears to be directly related to removal of sediment.

Observations in Aberdeen (Scotland) and Brisbane found grass swales and filter strips to be effective means for removal of sediment from urban stormwater runoff (Deletic and Fletcher 2006). An exponential decrease for total suspended solids (TSS) along the grass length was recorded. The removal of TSS along the grass swale is a primarily physical process (sedimentation and filtration), reflecting the balance between flow and particle settling velocity. The higher the flow rate, the longer the distance (and therefore grass length) required to remove suspended solids. Removal of total nitrogen (TN) and total phosphorus (TP) also occurred in the form of exponential decay along the grass length. As the removal performance of grass swales and filter strips is a function of flow rate, grass density, particle size and density, the above conclusions therefore, may not apply in different field situations.

*Australian Runoff Quality* (Engineers Australia 2006) provides estimates of typical expected annual pollutant load removal efficiencies for vegetated swales, as shown in Table 1, based on research of eastern states catchments. Actual swale performance will vary depending on individual design parameters such as temporal variation in flow and pollutant input concentration, vegetation height, infiltration capacity, length of swale and detention (contact) time.

Swale performance in WA is often likely to vary from the efficiencies of swales in the eastern states shown in Table 1, particularly at sites with sandy soils and shallow groundwater. Additionally, infiltration is more likely to be a dominant process at sandy sites. Annual pollutant load removal efficiencies for swales on sandy soils would usually be expected to be higher than shown in Table 1 due to the increased infiltration rate reducing surface water discharge.
Table 1. Typical annual pollutant load removal efficiencies for vegetated swales

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Expected removal</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litter</td>
<td>&gt;90%</td>
<td>Should be 100%, provided there is adequate vegetation cover and flow velocities below 0.5 m/s.</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td>60–80%</td>
<td>Assumes low level of infiltration. Will vary with varying particle size distribution.</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>25–40%</td>
<td>Depends on speciation and detention time.</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>30–50%</td>
<td>Depends on speciation and particle size distribution.</td>
</tr>
<tr>
<td>Coarse sediment</td>
<td>&gt;90%</td>
<td>Assumes re-suspension and scouring prevented by controlling inflow velocity &lt;0.8 m/s and maintaining dense vegetation.</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>20–60%</td>
<td>Highly variable, depends on particle size distribution, ionic charge, detention time, etc.</td>
</tr>
</tbody>
</table>

(Source: Engineers Australia 2006)

**Cost**

Standard cost data for construction of swales and buffer strips in Western Australia is not readily available.

As a guide, a range of costs for swale and buffer strip construction and maintenance for eastern states areas is presented in Table 2, based on data contained in Taylor (2005). Note: The dollar values quoted in this table have not been adjusted for inflation. For example, if the source of a cost estimate is a 2002 reference, the dollar values are in 2002 Australian dollars.

Table 2. Cost estimates for swales and buffer strips

<table>
<thead>
<tr>
<th>Publication/ Data source</th>
<th>Construction ($/m²)</th>
<th>Annual Maintenance ($/m²/yr)</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Swales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lloyd et al. (2002)</td>
<td>-</td>
<td>$2.50</td>
<td>-</td>
<td>Grass swale</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>$9.00</td>
<td>-</td>
<td>Vegetated swales (initial)</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>$1.50</td>
<td>-</td>
<td>Vegetated swales (after 5 yrs)</td>
</tr>
<tr>
<td>Fletcher et al. (2003)</td>
<td>$4.50</td>
<td></td>
<td>Melbourne</td>
<td>Hydromulching, earthwork and labour</td>
</tr>
<tr>
<td></td>
<td>$9.50</td>
<td></td>
<td></td>
<td>Rolled turf</td>
</tr>
<tr>
<td></td>
<td>$15 – $20</td>
<td></td>
<td></td>
<td>Vegetated swale</td>
</tr>
<tr>
<td>URS (2003)</td>
<td>$10</td>
<td>-</td>
<td>Western Sydney</td>
<td>Grass swale (seeded)</td>
</tr>
<tr>
<td></td>
<td>$18</td>
<td>-</td>
<td></td>
<td>Rolled turf</td>
</tr>
<tr>
<td><strong>Buffer Strips</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walsh (2001)</td>
<td>$3.50</td>
<td>-</td>
<td>Melbourne</td>
<td>Turf buffer strip</td>
</tr>
<tr>
<td></td>
<td>$7.50</td>
<td>-</td>
<td></td>
<td>Sedge/mulch buffer strips</td>
</tr>
<tr>
<td></td>
<td>$20 – $50</td>
<td>-</td>
<td></td>
<td>Native grasses and shrubs</td>
</tr>
</tbody>
</table>
Design considerations

The most important design consideration for a swale drain is the longitudinal slope. It is important to ensure flow velocities along a swale are kept sufficiently low to avoid scouring of vegetation and collected pollutants. Typically, the slope is considered to be most efficient between 1% and 4% to ensure that velocities do not scour the channel or compromise public safety, whilst at the same time limit ponding at low flows.

Where the longitudinal slope exceeds 4%, riffles along swales can help to distribute flows evenly across the swale as well as reduce velocities. The riffles maximise the retention time within the swale, further decreasing the velocities and better promoting particulate settling.

Vegetated swales can be used for water quality treatment wherever the local climate and soils permit the establishment and maintenance of a dense vegetative cover. The principal selection criteria for swales should firstly address the function of conveyance and secondly ensure that the system has features that will maximise treatment objectives and habitat and aesthetic values.

Pre-treatment for swales may include litter traps at point source inlets and buffer strips parallel to the top of the banks to pre-treat sheet flows entering the swale.

The selection of vegetation can impact the overall performance of the swale. Vegetation should be designed to cover the entire width of the swale, be capable of withstanding peak flows and be sufficiently dense to provide good filtration. For best performance, the vegetation height should be above the treatment flow water level. To ensure that swales are both functional and aesthetically pleasing, they should be incorporated into landscaping features. Using local species, vegetated swales can be low maintenance and be hardy enough to withstand long periods without water once established. Types of suitable vegetation that can be used in a swale include grasses, sedges and tussock grasses and other ground covers (e.g. herb form plants).

Swales are most effective when located within public open space or within the centre medians or verges of roads. Swales should not be located within residential verges if other options are available, due to maintenance and safety issues, as well as the need to provide driveway crossings. To protect the vegetation and thus the integrity of the swale, it is imperative that traffic movements along the swales be prevented. Traffic (including parking) can ruin the vegetation, compact the swale, cause rutting and harden the surface to provide preferential flow paths that do not allow infiltration. Traffic controls can be achieved by selecting swale vegetation along the edges that discourage vehicular movements or by providing physical barriers such as bollards (Figure 3) and non-mountable kerbing.

Another key consideration is the provision of road (median) or driveway crossings. Where possible, the location of the swale should minimise the need for crossovers. ‘At grade’ crossings follow the profile of the swale. Crossings when constructed ‘at grade’ reduce the maximum allowable swale batter slopes to approximately 1:9 (vertical to horizontal) to ensure that vehicles can traverse the crossing.

Most crossings are elevated with a culvert system to alleviate low flows. The disadvantage with elevated crossings is cost, particularly in dense urban developments. In addition, safety concerns with traffic movement under potential flood conditions due to blockages or when flows exceed the culvert capacity need to be addressed. For swales located on steep grades, crossings can be designed as a form of riffle to control flows.

Figure 3. Bollards used to prevent vehicular access onto a swale for conveying road runoff in Mandurah. (Photograph: Grahame Heal, City of Mandurah.)
Another consideration when locating a swale is to ensure that it will not be in the line of other services, such as sewers and underground electricity. These services will need regular maintenance and as such should not be within swales. Temporary bunding or sediment controls should be installed to protect the swale during road and housing/building construction.

Standing water in poorly designed vegetated swales can result in potential safety, odour and mosquito problems. There is also some potential for unstable conditions and erosion in extreme events that exceed the design event for the system. Therefore, other structural controls within a catchment should be designed to manage stormwater quantity, so that excessively large flows are not conveyed into the swale.

**Design guidelines**

Swales can be designed for greenfield applications or in retrofitting scenarios to replace a proportion of the traditional piped network.

Design of vegetated swales needs to consider three types of storm events:

- frequent storm flows (typically up to 6 months to 1 year ARI) for water quality treatment;
- minor storm flows (typically up to 5 year ARI) for conveyance and prevention of nuisance flooding; and
- major flood flows (up to 100 year ARI) to check flow velocities, velocity depth criteria, conveyance within the road reserve and freeboard to the adjoining properties.

Design flows for particular storm events can be estimated using a range of hydrologic methods with varying complexity. For small simplistic catchments, the Rational Method is suitable for peak flow estimation, while for large more complex catchments, use of hydrologic/hydraulic models may be more appropriate for design.

A description of buffer strips is contained in the Inlet structures subsection.

**Swale geometry**

The swale’s geometrical design is an iterative process that needs to take into consideration the site’s constraints including topography, development layout and density, how flow reaches the swale and available reserve width. Design considerations are outlined below:

- The longitudinal slope of a swale is typically controlled by catchment topography. To maintain conveyance and prevent ponding during low flows, the longitudinal slope should not be less than 1%, unless additional treatments such as subsoil drains are present or swales are located in soils providing infiltration opportunities. For more information about prevention of ponding (and therefore reducing mosquito breeding risks), see the Design Considerations and Design Guidelines sections of the Infiltration Basins and Trenches BMP. Where slopes are steeper than 4%, riffles should be constructed at regular intervals to prevent scouring and reduce flow velocities.

- Swale dimensions and contributing catchment area should be selected to ensure 1 year ARI flow velocities for the swale are maintained at less than 0.5 m/s. Swales located within road reserves can be subjected to velocities associated with major flood flows being conveyed along the road corridor. The resultant velocities within the swale should be checked to ensure that the maximum velocity does not exceed 1.8 m/s to prevent scour.

- Riffles are typically low level (e.g. 100 mm) porous rock weirs that are constructed across the base of a swale. A rule of thumb for locating riffles is to ensure that the maximum grade taken from the toe of the...
upstream riffle to the crest of the downstream riffle does not exceed 4% (Figure 4). Further information about riffle design is provided in the Living Streams BMP in this chapter.

![Figure 4. Location of riffles in a swale.](image)

- Side baffers should be constructed at 1:6 where possible and should not be steeper than 1:3. The batter slope needs to be able to cater for the design flow, as well as providing a suitable grade for vegetation establishment, access for maintenance, crossovers for lot access and public safety. Typically, the side batter is limited by the available reserve width.

The required width of the swale is that which can adequately contain the design flow within the banks of the swale, given the above design considerations.

**Hydraulic capacity**

The hydraulic capacity of a swale can be determined by use of hydraulic models or, for areas not subject to backwater effects, by application of Manning’s equation for open channel flow:

\[ Q = \frac{1}{n}A R^{2/3} S^{1/2} \]

Where:

- \( Q \) = flow (\( m^3/s \))
- \( n \) = roughness coefficient
- \( S \) = longitudinal slope (\( m/m \))
- \( A \) = Cross sectional area of flow (\( m^2 \))
- \( R \) = Hydraulic Radius (m), defined as \( A/P \), where \( P \) is the wetted perimeter (m)

Application of Manning’s equation allows both the flow rate and depth to be determined for a range of geometric configuration and vegetation types. The discharge calculations from this equation are significantly influenced by the roughness coefficient, which varies with flow depth, channel dimensions and vegetation type. Typically, between 0.15 and 0.40 is considered reasonable for flow depths less than the vegetation height. The trade-off with planting taller, denser vegetation to increase water quality treatment is that greater setback areas for the swale are required. As flow depth extends beyond the full vegetation height, a sharp reduction in the roughness coefficient can be expected and a corresponding increase in velocity. Figure 5 shows the relationship between the roughness coefficient and the flow depth, with reference to a medium-length sod-forming grass tested in a swale with 5% bed slope. It can be reasonably expected that this relationship will remain consistent with other swale configurations, though there may be a marginal reduction in Manning’s \( n \) for sheet flows. Manning’s \( n \) values can also be estimated from tables (e.g. refer to Report No. 9 of Water and Rivers Commission/Department of Environment 1999–2003).
Inlet structures (including buffer strips)

Inlets for swales can either be distributed (via buffer strips) or via point sources such as kerb breaks (Figure 1), pipes and bubble-up manholes.

For distributed flows such as buffer strips, it is essential to provide an area for coarse sediment to accumulate. Typically, the top of vegetation should be at least 40–50 mm below the flush kerb (Figure 6). This would require the top of ground surface (before turf is placed) to be between 80–100 mm below the flushed kerb.

Point source entry can either be from overland flow (e.g. kerb breaks) or from a pipe system. The main consideration for point source entrances into swales is the dissipation of energy at the inlet point to minimise erosion potential. This can usually be achieved with rock beaching and/or dense vegetation.

Bubble-up structures need to be made accessible for maintenance purposes so that any build-up of coarse sediment and debris can be monitored and removed if necessary (Figure 7). The use of bubble-up structures must ensure that residual runoff stored in the manhole can be dissipated, to reduce the risk of mosquito breeding. This can be achieved by making the base of the structure permeable, subject to the nature of the underlying soil permeability. If swales are installed within public open space, it is preferable for them to be
installed within a garden bed rather than in the middle of a grassed area, to improve the recreational amenity and aesthetics of the swale.

Figure 7. Example bubble-up structure for discharging to a swale.

Vegetation

Swales can use a variety of vegetation including turf, sedges and tufted grasses.

Vegetation is required to cover the whole width of a swale in order to have a water quality filtering function, rather than simply a conveyance and/or infiltration function. For a turf swale, a fine, close growing, water resistant grass should be selected to increase the surface area of the vegetation exposed to the runoff and thereby improve the effectiveness of the system. Turf swales (see Figure 3 for an example) are useful in residential areas but need to be mown and maintained regularly.

Swales vegetated with sedges and tufted grasses (see Figures 1 and 2 for examples) have a higher hydraulic roughness and require a larger area and more frequent inlet pits to convey the flows compared to turf swales. The dense form and height of tuft grasses or sedges can provide an attractive landscape feature. Pollutant removal efficiency varies greatly depending on the specific plants involved. Selection should therefore emphasise pollution control, but must also ensure that vegetation will be able to thrive under local conditions. Sedges and tuft grasses should preferably be native and should not be weed species.

A description of common rushes, sedges, bulrushes and submergents of the south-west of WA is contained in Report No. 8 of the River Restoration Manual (Water and Rivers Commission/Department of Environment 1999-2003). The manual provides details of common species and those available commercially for rehabilitation projects, including details of appearance, location, soil type, water quality, water depth and propagation.

Maintenance

A monitoring and maintenance plan should be developed for the swale. The maintenance objectives for a vegetated swale system include retaining the hydraulic and pollutant removal efficiency of the channel, and maintaining a dense, healthy vegetation cover. A well-designed and maintained vegetated swale can have a long operating life.

Maintenance should include frequent inspection during the first few months to ensure vegetative cover is establishing well. If required, reseed or plant an alternative species. Once established, continue to inspect biannually for signs of erosion. Weed control and periodic mowing of grass swales (typically biannually),
with grass never cut shorter than the design flow depth, are recommended. Cuttings should be removed from the channel and disposed in a local composting facility. Similarly, vegetated swales should be pruned and harvested in place of mowing. Information on maintenance of vegetation is provided in Water and Rivers Commission/Department of Environment (1999–2003) and BMP 2.2.7 of Chapter 7.

Before winter and after major storm events, debris and blockages should be cleared. Accumulated sediments should be removed to avoid the transportation of resuspended sediments during periods of high flow and to prevent a damming effect from sand bars. Repair of damaged areas within the channel should be undertaken as required. For example, if the channel develops ruts or holes, it should be repaired utilising a suitable soil that is properly tamped and seeded. The vegetation cover should be thick and reseeded as necessary. Swales should also be inspected regularly for ponding, as it can become a nuisance due to mosquitoes breeding in standing water if obstructions develop (e.g. debris accumulation, invasive vegetation) and/or slopes of swales are too flat and inadequately maintained, allowing water to pool for more than four days.

Appropriate traffic control solutions must also be maintained so that correct driving paths are taken and to prevent parking on swales.

**Worked example**

As part of a residential development, runoff from a street surface and footpath is to be collected and conveyed in a grassed swale system, located within the verge adjacent to parkland, to downstream treatments. An additional exercise in this worked example is to investigate the consequences on flow capacity of using a vegetated swale with vegetation height up to 300 mm.

The street and footpath will have a one-way crossfall with flush kerbs, to allow for distributed flows into the swale system across the side batter (buffer zone). The swale is to convey minor flood events, including all flows up to 5 year ARI. The width of the swale is fixed at 4.5 m. 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. The maximum slope of the swale banks is 1:9 (11%) to allow for easy access for maintenance and safe access for pedestrians to the adjacent parkland.

The contributing catchment area includes a 7 m wide road pavement surface, a 1.5 m wide footpath and a 4.5 m wide swale easement (Figure 8). 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 9).

![Figure 8. Cross section of proposed buffer/swale system.](image)

![Figure 9. Long section of proposed buffer/swale system.](image)
Design objectives

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

- design the swale system, including riffles where required
- select vegetation such that the hydraulic capacity of the swale is sufficient
- determine the required capacity of the swale to convey 5 year flows
- check velocities are maintained to acceptable levels
- design the overflow structure from the swale to an underground pipe (if required)
- configure the street kerb details so sheet flow is achieved through the buffer strip
- select suitable buffer strip vegetation

Site characteristics

Catchment area
- Roads and concrete footpath: $250 \times (7 + 1.5) = 2125 \text{ m}^2$
- Swale easement: $250 \times 4.5 = 1125 \text{ m}^2$
- TOTAL = 3250 m$^2$ (i.e., 0.325 ha)

Overland flow slope:
- Total main flowpath length = 250 m
- Upper section = 100 m at 6% slope
- Lower section = 150 m at 3% slope

Soil type: Clay

Fraction impervious:
- Roads/footpath = 1.00
- Swale easement = 0.10

Estimating design flows

The following example uses calculation methods from *Australian Rainfall and Runoff* (Institution of Engineers Australia 2001). Alternatively, this analysis could be performed using a hydrologic model.

The time of concentration ($t_c$) is estimated assuming overland flow across the allotments and along the swale. From procedures in *Australian Rainfall and Runoff* (Institution of Engineers Australia 2001) Book VIII, $t_c$ is estimated to be 10 minutes.

Based on Intensity Frequency Duration calculations for Perth Airport, consistent with Institution of Engineers Australia (2001) Book II, rainfall shown in Table 3 is adopted for design purposes.

**Table 3. Design rainfalls for calculated time of concentration**

<table>
<thead>
<tr>
<th>$t_c$</th>
<th>6 month ARI</th>
<th>5 year ARI</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min</td>
<td>34 mm/hr</td>
<td>66 mm/hr</td>
</tr>
</tbody>
</table>

Based on Institution of Engineers Australia (2001) Book VIII, the overall runoff coefficient for the catchment is calculated as follows:

$$C_{10} = C_{10}^{\text{pervious}} + 0.133 (10^{I_{10}} - 25)$$

$$C_{10} = 0.9f + C_{10}^{\text{pervious}} (1-f)$$

$$C_{10} = 0.9f + C_{10}^{\text{pervious}} (1-f)$$

$$f = \text{fraction impervious}$$

$$10^{I_{10}} = 10 \text{ year ARI 1 hour rainfall intensity}$$
\[ f = \frac{2125 \times 1 + 1125 \times 0.1}{3250} = 0.69 \]

**I** = 29.0 mm/hr (Perth Airport)

\[ C_{10} = 0.15 \quad C_{10} = 0.67 \]

Runoff coefficients for various ARI are then calculated as \( C_y = F_y C_{10} \), with the frequency factor \( F_y \) defined in Table 1.6 of Institution of Engineers Australia (2001) Book VIII.

\[ C_1 = 0.8 \times 0.67 = 0.53 \]

\[ C_5 = 0.95 \times 0.67 = 0.63 \]

As the minimum ARI considered for runoff coefficients is 1 year in Institution of Engineers Australia (2001) Book VIII, this is conservatively adopted for calculation of 6 month ARI peak design flows.

Using the Rational Method, peak design flows for the catchment are calculated as:

\[ Q = 0.00278 \times C \times I \times A \]

Where:

- \( I \) = rainfall intensity (mm/hr)
- \( C \) = runoff coefficient
- \( A \) = catchment area (ha)

\[ Q_{6mth} = 0.00278 \times 0.53 \times 34 \times 0.325 = 0.016 \text{ m}^3/\text{s} \]

\[ Q_{5yr} = 0.00278 \times 0.63 \times 66 \times 0.325 = 0.038 \text{ m}^3/\text{s} \]

**Swale design**

To facilitate access, the cross section shown in Figure 10 is proposed.

![Swale design cross section](image)

*Figure 10. Proposed swale cross section.*

The capacity of the swale is then estimated at the most downstream point. This 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 gentle 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 considers the swale capacity using a grass surface with a vegetation height of 50 mm. A range of roughness coefficients (Manning’s \( n \)) are selected for different flow depths appropriate for grass (Table 4). The height for a flow at the channel capacity will be above the vegetation and therefore Manning’s \( n \) is quite low and a figure of 0.04 is adopted (refer to Figure 5). Manning’s \( n \) is varied according to the flow depth with reference to the vegetation height (as shown in Figure 5) and the corresponding discharge can be calculated simply in a spreadsheet application using the following procedure:
Flow rate at channel capacity:

- Adopted slope = 3% (minimum longitudinal slope)
- Manning’s $n = 0.04$ (at 0.2 m depth)
- Side slopes 1:10
- Area $A = 0.5 \text{ m}^2$
- Wetted perimeter $P = 4.52 \text{ m}$
- Hydraulic radius $R = A/P = 0.111$

Manning’s equation:

$$Q = (AR^{5/3}S^{1/2})/n$$

$Q_{\text{cap}} = 0.50 \text{ m}^3/\text{s}$

| Table 4. 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           |
| 0.10            | 0.30           | 0.01            |
| 0.15            | 0.10           | 0.10            |
| 0.20            | 0.04           | 0.50            |

The capacity flow for the swale ($Q_{\text{cap}} = 0.50 \text{ m}^3/\text{s}$) is greater than the required peak flow rate ($Q_s = 0.038 \text{ m}^3/\text{s}$). Therefore, the nominated swale has sufficient capacity without any requirement for an additional piped drainage system. From Table 4, it can be seen that both the 6 month and 5 year ARI flow depths are above the vegetation height.

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 5 presents the adopted Manning’s $n$ values and the corresponding flow capacity of the swale for different flow depths.

Table 5 demonstrates that the swale with dimensions shown in Figure 10 is capable of conveying a 5 year ARI flow.

This worked example continues using grass for the remainder of its analysis.

| Table 5. 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           |
| 0.10            | 0.32           | 0.01            |
| 0.15            | 0.30           | 0.03            |
| 0.20            | 0.30           | 0.07            |
Inlet details

Flows reach the swale directly from the road and footpath surface.

Direct runoff from the pavement 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 between the road and the footpath.

Velocity checks

Two velocity checks are performed to ensure vegetation is protected from erosion at high flow rates. Velocity is checked to be kept below 0.5 m/s for the 5 year ARI flow event. Velocities are estimated using Manning’s equation.

Firstly, velocities are checked at the most downstream location (slope = 3%). From Table 4, \( d_{5\text{-year}} = 0.12 \) m, i.e., the flow depth for the 5 year ARI flow event (\( Q_5 = 0.038 \) m\(^3\)/s), and the corresponding Manning’s \( n = 0.24 \).

Therefore, to calculate the velocity:

\[
A = 0.204 \text{ m}^2 \\
P = 2.91 \text{ m} \\
R = A/P = 0.070 \text{ m} \\
V_{5\text{-year}} = \frac{0.07^{1/3} \times 0.03^{1/2}}{0.24} \\
= 0.12 \text{ m/s} < 0.5 \text{ m/s}, \text{ therefore OK}
\]

Secondly, velocities are checked at the bottom of the steeper section (i.e. slope = 6% with reduced catchment area). \( Q_5 = 0.015 \) m\(^3\)/s for this section.

\[
d_{5\text{-year}} = 0.10 \text{ m} \\
n = 0.30 \\
A = 0.15 \text{ m}^2 \\
P = 2.51 \text{ m} \\
R = 0.060 \text{ m} \\
V_{5\text{-year}} = 0.12 \text{ m/s} < 0.5 \text{ m/s}, \text{ therefore OK}
\]

For larger storm events, when the swale is flowing at full capacity, the maximum velocity will be 1.0 m/s. Some scour may occur that would require repair following these infrequent large flow events.

Vegetation specification

To complement the landscape design of the area, a turf species is to be used in the swale. For this application, a turf with a height of 50 mm has been assumed. Selection of a suitable species will be determined by the landscape architect, consistent with application requirements and design assumptions.
References and further reading


Institution of Engineers Australia 2001, Australian Rainfall and Runoff, Volume One, a guide to flood estimation, Pilgrim, D.H. (Editor-in-Chief), Institution of Engineers Australia, Barton, Australian Capital Territory.


