Chapter 9
Swale and filter strip design, construction and maintenance

9.1 Introduction

Swales and filter strips use vegetation in conjunction with slow and shallow-depth flow for stormwater runoff treatment. As runoff passes through the vegetation, contaminants are removed by the combined effects of filtration, infiltration, adsorption, and biological uptake. Vegetation also decreases the velocity of flow and allows for particulates to settle.

The principal difference between swales and filter strips is that swales accept concentrated flow while filter strips accept flow as distributed or sheet flow.

Contaminant removal depends on the residence time of water through the swale or filter strip and the depth of water relative to the height of vegetation. Good contact with vegetation and soil is required to promote the operation of the various mechanisms that capture and transform contaminants, so spreading flow in minimal depth over a wide area is best.

Water residence time depends on the:

- volume of runoff
- the velocity at which it travels
- the length over which it flows

Velocity is a function of the area of flow, the slope and the friction imparted by the vegetation. Swale and filter strip performance depends on a number of geometric, hydrologic and hydraulic variables including:

- swale or filter strip width and length
- flow depth and velocity
- volumetric flow rate
- slope
- vegetation characteristics including density and height

Any or all of these variables can theoretically be manipulated to maximise water residence time and contact and achieve a desired level of performance.

The design guidance provided here enables swales and filter strips to achieve compliance with Regional Plan requirements for water quality. If a specific site does not allow for optional design, smaller swales and filter strips may still provide significant benefit if implemented in conjunction with other practices to provide pre-treatment as part of a treatment train component.

9.2 Water quality performance

The passage of stormwater through vegetated swales utilises a number of physical, chemical, and biological factors to reduce stormwater contaminants.

Physical factors include:

- reduction of flow speed by the vegetation to improve settlement

- filtration by the dense vegetation
- the rough nature of the soil/vegetation interface which improves retention of settled material and reduces resuspension
- infiltration, which in suitable soils can be a major contaminant removal and volume reduction mechanism.

Chemical factors include:

- contact between stormwater contaminant and the abundant organic matter in swales which can result in complexing and adsorption
- chemical conversion of soluble contaminants to insoluble forms.

Biological factors include:

- microorganisms which degrade organic contaminants
- uptake of nutrients and contaminants by swale vegetation
- the provision of large surface areas of vegetation to which contaminants become absorbed

Plate 9-1: Example of a well designed and maintained swale

9.2.1 Suspended solids

Khan et al (1992) showed that a 60 m long swale used to treat runoff from a 6 hectare suburban catchment achieved an average suspended solids concentration reduction of 83% for six storms.

Yousef et al (1987) reported mass reductions that were much higher than concentration reductions, indicating the importance of infiltration in the systems they studied.

Barrett et al (1998) reported a TSS load removal of 86% in field monitoring of storm events in Texas USA. Yu et al (2001) recorded mass removal of TSS averaging 94%.

Wong, (undated) states that reported removal efficiencies of suspended solids range from 25% to 80% depending on the grading of the suspended solids in the stormwater.

Fletcher (2002) reported TSS concentration reduction of 73-94% (mean 83%) and mass reduction of 57-88% (mean 69%) for a synthetic stormwater with TSS concentration of 150 mg/L. Fletcher (2002) showed that the reduction in TSS concentration during passage through the swale was lower at higher hydraulic loadings. Larger TSS particles were found to settle out rapidly, while smaller particles remained in suspension. Fletcher (2002) concluded that swale length (as a measure of hydraulic loading or detention time) has a significant impact on TSS removal performance, particularly if fine particles are present. In cases where fine material is of specific concern and available swale length is limited, other measures such as bioretention systems or wetlands may be required.

The ARC funded a monitoring project of an existing grassed swale that was not designed in accordance with these guidelines to get a rough estimate of performance. The swale selected was adjacent to the Albany to Orewa motorway approximately one kilometre south of the Silverdale interchange, adjacent to the southbound lanes of the motorway. The results were highly vaiable (20 storms total) with results between -100% and 76% reduction. The ratios of suspended solids to turbidity for inflow and outflow samples were significantly different, although there was no obvious reason why the outflow suspended solids and turbidity were often higher than inflow suspended solids and turbidity.

9.2.2 Heavy metals

Khan et al (1992) showed that stormwater-borne metals attached to particulates such as lead, zinc, iron and aluminium were reduced by 63-72% during passage through a 60 metre swale. Metals less attached to particulates such as copper and dissolved metals, had generally low removals.

In the motorway monitoring project, passage of the motorway stormwater through the trial swale achieved consistent removals of total copper (average removal 60%), total lead (average removal 90%) and total zinc (average removal 80%).

9.3 Applicability

Swales and filter strips may be used in a variety of land uses including residential, commercial, and industrial. They are typically located on property boundaries or adjacent to impervious surfaces where they can substitute for kerb and gutter. When used, they should be incorporated into site drainage, street drainage and drainage planning. As they are effective for lower and velocities and volumes, the size of the contributing catchment (under 4 hectares) and the associated volume of runoff need to be limited.

Swales and filter strips are aesthetically pleasing than concrete and are generally less expensive to construct.

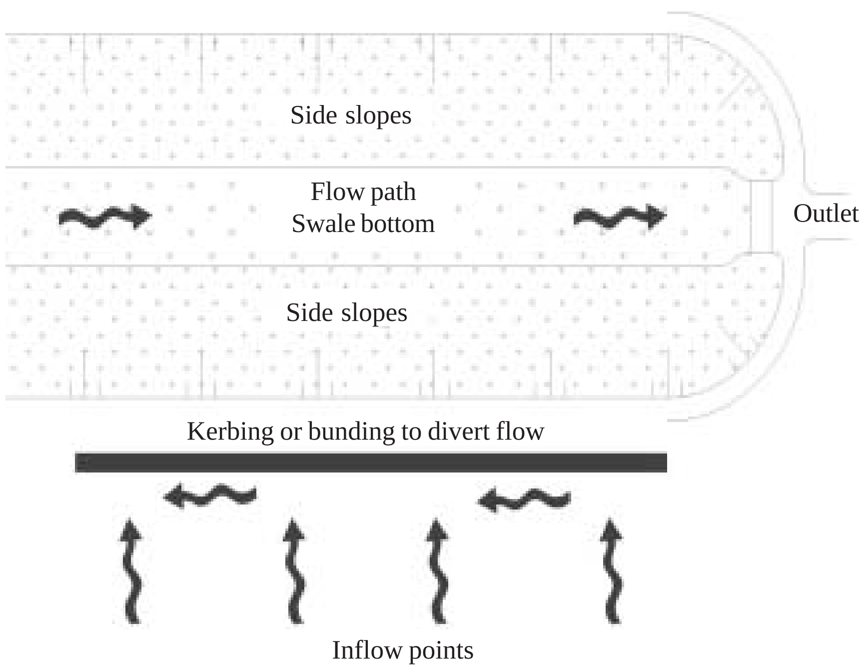
Dense grasses reduce flow velocities and protect against erosion during larger storm events.

Swales and filter strips can be used as the pretreatment or polishing segment of a treatment train, or for basic treatments for contaminated stormwater runoff from roadways, driveways, car parks and highly impervious ultra-urban areas. In cases where hydrocarbons, high TSS or debris are present in the runoff, such as high use sites, a pretreatment (or post treatment) system for those components would be necessary.

Swales or filter strip design needs to consider paths for flows that exceed water quality storms. To protect receiving environment water quality, it is better for larger flows to bypass swales or filter strips, as flow velocities would reduce water quality performance. However most higher flows will travel through them, and velocities for these larger events must be considered, less for water quality performance than for erosion control. If a 10% storm is passed through swales or check dams, the velocity of flow should not exceed the maximum velocities shown in Table 9-1 in order to prevent resuspension of deposited sediments.

Inflow points are another consideration for swale performance. A swale accepting inflow of stormwater throughout its length will not provide the necessary residence time to provide treatment for all the inflow. For proper treatment, all inflow must be diverted to an inlet point that gives a long enough flow path flow to achieve the appropriate residence time as shown in Figure 9-1.

Figure 9-1
Swale with flow diversion to inlet



9.4 Objectives

Swales and filter strips have different objectives.

9.4.1 Vegetated swales

Vegetated swales can take the place of conventional stormwater conveyance systems. Piped systems such as kerb and channel with catchpits provide no water quality function and may worsen receiving system impacts by increasing flow velocities and erosive forces. Although vegetated swales vary in their intended objectives and design, their overall objective is to slow stormwater flows, capture some contaminants and reduce the total volume of runoff.

Plate 9-2: Swale monitoring location south of Silverdale

Swales act in two ways to affect stormwater flows:

> Conveyance of water in a swale decreases in the velocity of flow as compared with conventional storm drainage because as the water passes over and through the vegetation, it encounters resistance.
> Water quality can also be affected by passage through vegetation. Physical, chemical, and biological processes occur that reduce contaminant delivery downstream.

Table 9-1 provides some general guidance on swale and filter strip design.

Table 9-1
Design criteria

Design parameter	Swale	Filter strip
Applicable longitudinal slope	1% - 5%	1% - 5%
Maximum velocity	0.8 m/s (WQ storm)	0.4 m/sec (WQ storm)
Maximum water depth above vegetation (WQ storm)	100 mm	25 mm
Manning coefficient	See equations in Section 9.6.2	
Maximum bottom width	2 m	NA
Minimum hydraulic residence time	9 minutes	9 minutes
Maximum catchment area served	4 hectares	4 hectares
Minimum length	30 m	sufficient to attain residence time
Maximum side slope	3H:1V (shallower if possible for mowing purposes)	NA
Maximum drainage flowpath	NA	50 m
Maximum longitudinal slope of contributing area	NA	5% unless energy dissipation is provided
Maximum lateral slope	0%	2%

9.4.2 Filter strips

Plate 9-3: Detail of a swale check dam

Filter strips intercept stormwater flows before they become concentrated and then distribute the flow evenly across the filter strip. As the water travels across the filter strip it slows down due to frictional resistance of the vegetation to flow. Some of the runoff may infiltrate into the ground.

Redirecting stormwater runoff from impervious surfaces to filter strips could be termed 'hydrologic disconnection', with the objective being to minimise volumes of stormwater diverted to reticulation. In these cases, footpaths and driveways and other impervious features are designed to drain evenly onto adjacent areas, not into a piped system.

An excellent example of a filter strip is the riparian buffer zone, where a sensitive stream system is buffered from stormwater off adjacent developed areas. Although the full range of functions provided by the riparian buffer zone are more complex than the filter strip, conceptually the riparian buffer zone is an elaborate filter strip.

9.5 Design approach

Several swale and filter strip design factors can increase or decrease their performance for water quality treatment.

9.5.1 Factors that increase performance

- low slopes
- permeable soils or underdrainage
- dense grass cover
- longer lengths
- use in conjunction with other practices
- use of check dams for swales

9.5.2 Factors that decrease performance

- compacted soils
- short residence time
- large storm events
- short grass heights

Plate 9-4: Swale level spreader to maintain dispersed flow in swale bottom

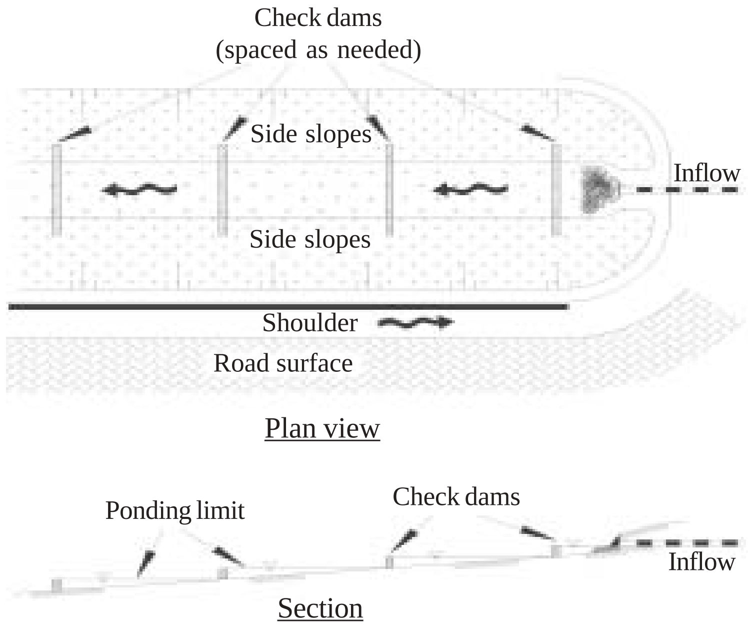
- steep slopes
- high runoff velocities
- dry weather flow
- damage from vehicles

Swales with slopes of less than 2% need a perforated pipe underdrain.

Slopes greater than 5% need check dams to reduce flow velocities. Check dams are installed so that the crest of the downstream dam is at the same elevation as the toe of the upstream dam.

Level spreaders must be installed at the head of any swale greater than a 5% slope and every 15 metres to ensure flow uses the entire swale bottom. The level spreaders can be used to also meet checkdam requirements. A detail of swales with check dams is provided in Figure 9-2.

Figure 9-2
Swale with check dam detail



9.6 Design procedure

The procedures for swale and filter strip design are basically the same. The steps are given in full for swales, and notes are included to allow the procedure to be applied to filter strips.

9.6.1 Initial steps

1. Estimate runoff flow rate for the water quality storm. Use 1/3 of the 2-year 24-hour rainfall as the water quality storm and calculate the runoff according to TP 108, with separate calculations for pervious and impervious areas.

   Swales are practicable only for small catchments for which TP 108 sets the time of concentration (t_c) to 10 minutes, and it is therefore possible to replace part of the TP 108 calculation routine with a formula. An example is provided in the case study.

   The calculation steps are then:

   (a) Determine the water quality storm depth $P_{24} = P_{24,2\text{-year}}/3$, obtaining $P_{24,2\text{-year}}$ from Fig. A1 of TP 108.

   (b) Calculate the peak rainfall rate = $16.2 x P_{24}/24$ hours

   (c) Calculate Storage (S) for pervious surfaces from eq. 3.2 in TP 108:
   $S = 25.4(1000/CN-10)$.

   (d) Calculate the peak runoff rate from the pervious surfaces, with $I_a = 5$ mm:
   Runoff/Rainfall = $(P_{24} - 2I_a)(P_{24} - 2I_a + 4S)/P_{24} - 2I_a + 2S)^2$
   Peak runoff rate = P_{24} x Pervious area x (Runoff/Rainfall)

   (e) Repeat the last two steps for impervious surfaces, using CN = 98 (so that S = 5.2 mm) and $I_a = 0$

   (f) Add the two peak runoff rates to get the peak runoff rate for the catchment.

(g) Multiply by 0.89 to allow for peak dampening due to the 10 minute time of concentration. The result is the peak outflow from the catchment and the design flow rate for the swale or filter strip.

2. Establish the slope of the swale or filter strip

3. Select a vegetation cover

<u>9.6.2 Design steps</u>

1. Select the type of vegetation and design depth of flow

2. Select a value of Manning's n (equations developed from swale study project, 2003)

For 150 mm grass and $d < 60$ mm $n = 0.153\ d^{-0.33} / (0.75 + 25s)$
$d > 60$ mm $n = 0.013\ d^{-1.2} / (0.75 + 25s)$

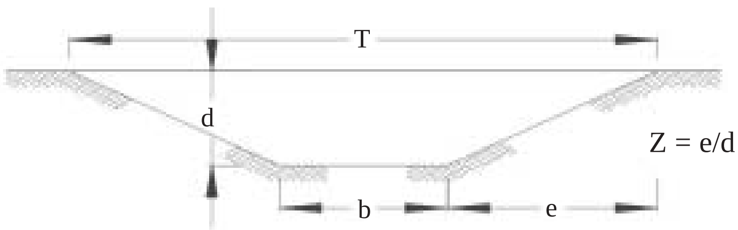
For 50 mm grass and $d < 75$ mm $n = (0.54\text{-}228\ d^{2.5}) / (0.75 + 25s)$
$d > 75$ mm $n = 0.009d^{-1.2} / (0.75 + 25s)$

Where:
d = depth of flow (m) for water quality storm
s = longitudinal slope as a ratio of vertical rise/horizontal run (m/m)

3. Select a swale shape (trapezoid or parabolic) from Figure 9-3.

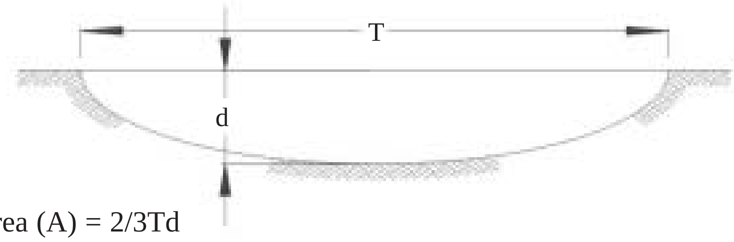
4. Use Manning's equation and first approximations relating hydraulic radius and dimensions for the selected shape (use a trapezoidal shape for a swale or a rectangular shape for a filter strip) to obtain a working value of a swale or filter strip width dimension

Figure 9-3
Channel geometry



Cross sectional area (A) = $bd + Zd^2$
Top width (W) = $b + 2dZ$

$$\text{Hydraulic radius (R)} = \frac{bd + Zd^2}{b + 2d\,(Z + 1)^{1/2}}$$



Cross sectional area (A) = 2/3Td
Top width (W) = 1.5A/d

$$\text{Hydraulic radius (R)} = \frac{T^2 d}{1.5T^2 + 4d^2}$$

$Q = AR^{0.67}s^{0.5}/n$ (1)

$A_{rectangle} = Td$ (2)

$R_{rectangle} = Td/(T+2d)$ (3)

Where:

Q	=	design runoff flow rate (m^3/s, cms)
n	=	Manning's n (dimensionless)
s	=	longitudinal slope as a ratio of vertical rise/horizontal run (m/m so dimensionless)
A	=	cross-sectional area (m^2)
R	=	hydraulic radius (m)
T	=	top width of trapezoid/parabolic shape or width of a rectangle
d	=	depth of flow (m) for water quality storm
b	=	bottom width of trapezoid (m)

If equations (2) and (3) are substituted into equation 1 and solved for T, complex equations result that are difficult to solve manually. However, approximate solutions can be found by recognising that T>>d and z^2>>1, and that certain terms are nearly negligible. The approximation solutions for rectangular and trapezoidal shapes are:

Rrectangle = d   Rtrapezoid = d   Rparabolic = 0.67 d   Rv = 0.5d

Substituting Rtrapezoid and Atrapezoid = $bd+Zd^2$ into equation (1), and solve for the bottom width b (trapezoidal swale)

$b = (Qn / d^{1.67}s^{0.5}) - Zd$

For a trapezoid, select a side slope Z of at least 3. Compute b and then top width T, where T = b + 2dZ.

b for a filter strip can be as great as uniform flow distribution can be assured. For a parabolic swale configuration, refer to figure 9-3.

5. Calculate A:

$A_{rectangle} = Td$ or $A_{trapezoid} = bd + Zd^2$

$A_{filter\ strip} = Td$

6. Calculate the flow velocity at design flow rate:

$V = Q/A$

If V > 0.8 m/sec (or V > 0.4 m/sec. for filter strip), repeat steps 1 - 6 until the condition is met. A greater velocity will flatten grasses and reduce filtration. A velocity lower than this maximum value will allow a 9 minute hydraulic residence time. If the value of V suggests that a longer swale or filter strip will be needed than space permits, investigate how Q can be reduced, or increase d and/or T and repeat analysis.

7. Calculate the swale length (L, metres)

L = Vt (60 sec/min)

Where t = hydraulic residence time (min)

Use t = 9 minutes for this calculation.

If, from the analysis, the length is less than 30 metres, increase it to 30 metres (the minimum allowed).

8. If there is still not enough space for the swale or filter strip, the following solutions should be considered:

> divide the site drainage to multiple swales or filter strips
> increase vegetation height and design depth of flow (the design must ensure that the vegetation remains standing during the design storm).
> reduce the developed surface area to gain space
> increase the longitudinal slope
> use the swale or filter strip in conjunction with another stormwater practice.

9.6.3 Check for stability

If runoff from events larger than the water quality design storm goes through the swale or filter strip, perform a stability check for the 10 year, 24 hour storm using TP 108. Estimate Q for that event as recommended in item 1 of the Initial Steps. For the 10 year storm, the flow velocities are required to be less than 1.5 m/sec, although higher velocities may be allowed if erosion protection is provided.

9.7 Plant material

Vegetative cover in a swale or filter strip generally consists of a continuous and dense cover of relatively long grass. In swales the grass should be maintained at heights of typically 150 mm and not less than 100 mm and should stay at these heights with minimal care. In filter strips, grass can be shorter (50 mm) since flow depths over the filters are generally small. Dense and well developed grass reduces the water velocity and improves performance.

9.7.1 Wetting

Grass species should be able to withstand periodic wetting, including total submergence for short periods in summer, and continued wetting and periods of total submergence in winter. Mowing will be restricted during the winter due to wet conditions.

9.7.2 Species

The most common grass used for swales in the Auckland Region is perennial rye grass species.

9.8 Wetland swales

A wetland swale is a variation of a basic swale for use where the longitudinal slope is slight, water tables are high, or continuous low base flow is likely to result in saturated soil conditions. If soil is saturated for more than about two weeks, typical grasses will die.

The geometry of wetland swales is the same as that of normal swales except for the following modifications:

> The maximum bottom width may be increased to 7 metres, but a

Plate 9-5: Wetland swale

length-to-width ratio of 5:1 must be provided. The minimum swale length remains at 30 metres.

- > If longtitudinal slopes are greater than 5%, the wet swale must be stepped so that the slope within the stepped sections averages less than 5%.
- > A high-flow bypass is required for flows greater than the water quality storm, to protect wetland vegetation from damage.
- > Flows will be more protracted than in normal swales and more like flow in streams. Since vegetation growing in streams is often less dense, an increase in treatment area is needed to ensure that equivalent contaminant removal is achieved.

9.9 Construction

A key requirement of any vegetative treatment system is to obtain a stand of vegetation that can effectively filter runoff. Ideal vegetation characteristics include a dense, uniform growth of fine-stemmed plants that can tolerate soil saturation and the climatological, soil, and pest conditions of the area. Drainage areas are generally fairly small, less than 4 hectares.

It is essential to maintain proper hydraulic conditions to avoid uneven, channelised flows through the swale or filter strip. Uneven flow across its width reduces contaminant removal because runoff bypasses vegetation, shortening treatment time. Channelised flow also may erode swales or filter strips, exacerbating the downstream water quality problems that they were intended to mitigate.

9.9.1 Important inspection aspects related to design

Design of swales and filter strips is fairly straight forward. Their primary treatment process is filtering runoff through vegetation. It is important to note the following important design aspects of swales and filter strips.

1. The bottom width of swales should be no less than 600 mm if it is to be mowed and no greater than 2 metres to prevent concentration of flow.
2. Sequence of construction for overall site development and construction of the swale and filter strip.
3. Do the post-development drainage patterns resemble the pre-development ones? Placement of swales and filter strips along natural flow paths and contours should be detailed on the approved plans.
4. To assure even sheet flow in a swale or filter strip and avoid channelized flow, the bottom must be flat with no lateral slope across the bottom of the swale or vegetative filter strip.
5. The design of inflow to the swale or filter strip should quickly dissipate runoff velocity to minimise erosion potential. Dissipation practices such as riprap pads and level spreaders should be used.
6. Outflow from swales and filter strips should either be diffuse (to avoid erosion damage to downstream facilities or water bodies) or into a stable conveyance system. Swales should be equipped with raised storm drain outlets to prevent erosion.
7. Generally, swales should be longer than 30 metres to reduce short circuiting, with their total length depending upon the flow and the 9 minute minimum required residence time. No minimum width has been established for filter strips since this is a very site specific design parameter. These dimensions must be specified on the approved plans.
8. Longitudinal slopes should be fairly slight, with maximum slopes of 5% (can be greater with use of check dams if the check dams reduce slope to 5%).
9. Plant specifications must be on the approved plans. Grasses tend to be the superior choice of vegetation as they are resilient, somewhat stiff, dense, provide abundant surface area and can sprout through thin deposits of sand and sediments.
10. Pretreatment should be provided when high sediment inputs to swales or filter strips are likely.

9.9.2 Important inspection aspects related to construction

Construction activities should be phased to ensure the greatest practical amount of plant cover during the course of construction. If permanent swales and filter strips are installed during site construction, they either must be protected from construction site runoff or restored for long term use once site construction is completed. The following important aspects of construction should be noted:

Plate 9-6: Swale needing maintenance due to high sediment loads

1. Stake out site location for the swale or check dam to allow for dimensions, shapes, and slopes to be verified per the design plans.
2. Ensure that lateral slopes are completely level to avoid any tendency for the flow to channelize.
3. Ensure that inlets, outlets, and other auxiliary structures such as check dams or flow bypasses, are installed as specified.
4. Make sure that vegetation complies with planting specifications. Ensure that vegetation becomes uniformly dense for good filtration and erosion protection. Grass can be established by seeding or using sod. Seeding is generally preferred due to its lower cost and the greater flexibility it allows in selecting grass species. The method of vegetative stabilization should be discussed and approved at a preconstruction meeting.
5. Place the swale or filter strip so that no portion will be in the shade of buildings or trees throughout the entire day, as this will cause poor plant growth.
6. Make sure that construction runoff is not entering the swale or check dam. If it is, require removal of sediments and re-establish vegetation upon the completion of construction.
7. Ensure that measures are in place to divert runoff while vegetation is being established. If runoff is probable and cannot be diverted, ensure that adequate erosion control measures are in place.
8. Inspect liners, underdrains, riprap, and check dam spacing, if these are included in the approved plan.
9. Make sure that any level spreaders are completely level and stable enough to remain level during their operation.
10. Check for proper installation of pretreatment devices, if required.
11. Ensure that kerb cuts and their locations are as specified.

9.9.3 As-built plans

Where consent conditions require, there may be a requirement for an As-Built Plan to verify that construction was done in accordance with the approved consent.

The As-built plans should verify that:

1. Dimensions of the swale(s) match the design dimensions
2. Check dams and level spreaders constructed according to plan and are level
3. Inlets and outlets are constructed correctly
4. Lateral slopes are completely level
5. Longitudinal slopes are within design range
6. Flow bypasses are installed correctly.
7. Kerb cuts are installed correctly
8. Vegetation complies with planting specification and is suitably dense
9. Topsoil is adequate in composition and placement

9.10 Operation and maintenance

Plate 9-7: Woody vegetation may reduce grass filtering effectiveness

Physical filtration by vegetation is an important contaminant removal mechanism of swales and filter strips. Another may also be infiltration of stormwater runoff into the surrounding surface and subsurface soils.

Swales and filter strips are mainly susceptible to impaired performance from excess sediment smothering vegetation. Oils and greases can also be a serious concern as they can kill vegetation. These impacts could occur very quickly if large amounts of these contaminants are introduced in a short time frame.

Because the effectiveness of swales and filter strips depends on vegetative filtering of dispersed flow, as well as on infiltration of runoff into underlying soils, their maintenance focuses on:

> maintaining dispersed flow through the swale or filter strip
> maintaining a thick growth of vegetation
> preventing undesired overgrowth vegetation from taking over the site
> removal of accumulated sediments
> debris removal

Maintenance of dispersed flow through the swale or filter strip is critical for its ongoing treatment effectiveness. Concentrated flow travels at a higher velocity than does dispersed flow, and may transport contaminants straight through the practice instead of being removed by it.

Maintaining a dense growth of vegetation to enhance swale or filter strip performance requires periodic vegetation mowing by owners or operators. This must be correctly done. Mowing grass too short will damage the grass, increase runoff flow velocities, and thereby decrease pollutant removal effectiveness. If the grass grows too tall, it may be flattened during storms, also decreasing treatment effectiveness. Mowing during winter months when soils may be saturated could rut the swale or filter strip and concentrate flows.

Inspections must be done to ensure that the desired vegetation remains in the facility. The invasion of undesired vegetation can occur if site conditions promote its growth. In some situations the replacement of the planted vegetation by a volunteer species may be beneficial, but only if the invasive species provides equal or increased water quality benefits and is accepted by the property owners. If site slopes are very flat, the swale or filter strip could become dominated by wetland plants. The dense growth of wetland plants may be desired for stormwater treatment and also will reduce the typical mowing costs associated with them. In this situation, the maintenance file should document the shift in the plant community and provide guidelines for how to take care of the modified site condition.

Sediments accumulate in swales and filter strips and their removal may be their most expensive maintenance aspect. After sediment removal, it is essential to restore the slope and elevations to the originally constructed condition and re-establish the vegetation. Erosion control in the contributing drainage area will be necessary to prevent scour of the facility until there is once again a dense stand of vegetation.

Sediment may also impede effective performance by clogging inlets and preventing the entry of design storms into the practice. If stormwater backs up into the upstream drainage area, it may overflow to an area not intended to accept additional flow and may cause erosion and site instability.

As with other practices, debris removal is an ongoing maintenance need for all swales and filter strips. Debris, such as vegetative cuttings or garden/yard dumpings, if not removed can block inlets or outlets, cause flow to become concentrated and can be unsightly. Inspection and removal of debris should be done on a monthly basis, but debris should be removed whenever it is observed on site.

It is also important to know when you don't have to do maintenance. The original plan for the site provides the best information at that time on the design and construction of the swale or check dam, but over time the facility may change in appearance and function. These changes may not necessarily be bad. Having a knowledgeable inspector conduct regular inspections may be one way to allow a practice to evolve into an improved facility with reduced maintenance costs. The emergence of wetland plants in a swale or filter strip or the growth of native vegetation may improve its value and performance.

9.11 Case study

A swale is to be constructed in a road median strip in a residential subdivision that is located in Kumeu. The catchment area at the bottom of the swale is 2.0 hectares. The imperviousness is 40%, and the soils are clay.

<u>Hydology</u>
Water quality design storm is 1/3 of the 2 year-24 hour rainfall (81 mm) = 27 mm

Peak flow calculation:
Peak rainfall rate = 16.2 x 27 mm/24 hours = 18.2 mm/hour

Impervious area:
$I_a = 0$ and $S = 25.4(1000/CN - 10)$ mm = 5.2 mm
At peak rainfall, Runoff/Rainfall = $(P_{24} - 2I_a)(P_{24} - 2I_a + 4S)/P_{24} - 2I_a + 2S)^2 = 0.923$
Peak runoff rate = 18.2 mm/hour x 0.923 x 0.8 hectares = 0.037 m^3/s

Pervious area:
$I_a = 5$ mm and $S = 25.4(1000/CN - 10)$ mm = 89.2 mm
At peak rainfall, Runoff/Rainfall = $(P_{24} - 2I_a)(P_{24} - 2I_a + 4S)/(P_{24} - 2I_a + 2S)^2 = 0.264$
Peak runoff rate = 18.2 mm/hour x 0.264 x 1.2 hectares = 0.016 m^3/s

Combined peak runoff flow rate = 0.037 + 0.016 = 0.053 m^3/s
Correction for attenuation in the catchment:
Peak flow rate in swale = 0.89 x 0.053 m^3/s = 0.047 m^3/s

<u>Design steps</u>
1. Vegetation cover - grass, 50 - 150 mm tall, slope - 4%, design depth of flow 100 mm for water quality storm
$d > 60$ mm $n = 0.013\, d^{-1.2} / (0.75 + 25s)$

2. Mannings n = 0.118

3. swale shape - trapezoidal with side slope Z = 3

4. Calculate the bottom width
$n = 0.118$ $d = 100$ mm
$Q = .047\ m^3/s$ $s = .04$
$Z = 3$
$b = (Qn / d^{1.67} s^{0.5}) - Zd$
$b = 1.2$ m

calculate top width

$T = b + 2dZ$
$T = 1.3$ m

5. Calculate the cross-sectional area A

$A = bd + Zd^2$
$A = .15\ m^2$

6. Calculate the flow velocity

$V = Q/A$
$V = 0.31$ m/s which is less than the maximum allowed 0.8 m/s - good

7. Calculate the Swale length

$L = Vt$ (60 sec/min)(9 min.)
$L = 168$ metres for full water quality treatment

Since b is less than the maximum value, it may be possible to reduce L by increasing b. If reducing L to 100 metres is desired, then:

$V = L/60t = 0.185$ m/s
$A = Q/V = 0.25\ m^2$
$b = (A - Zd^2)/d = 2.2$ metres which is slightly greater than the allowable 2 m
If L was increased to 110 m, the bottom width would be allowable at the maximum 2 m width.

Once the water quality treatment calculations have been completed the design can be adjusted to accommodate additional flow from larger storms if the swale is to accept those events. This will necessitate increasing the freeboard of the swale. Calculate the Q for the larger event and ensure that flow velocities are less than 1.5 m/sec. unless erosion protection is provided.

9.12 Bibliography

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Swale and filter strip Inspection forms

Construction and operation and maintenance inspection forms

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (**Under Section 332 of the Resource Management Act 1991)**	Investigating Officer: Date: Time: Weather: Rainfall over previous 2-3 days? Person contacted during visit: Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

SWALE & FILTER STRIP CONSTRUCTION INSPECTION FORM	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

Swale & Filter Strip Components:

Items Inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
PRE-CONSTRUCTION	Y	N			12. Flow bypasses installed correctly	Y	N		
1. Runoff diverted	Y	N			13. Pretreatment devices installed	Y	N		
2. Facility area cleared	Y	N			14. Curb cuts installed per plans	Y	N		
3. Facility location staked out	Y	N			**VEGETATION**	Y	N		
4. Facility not in heavily shaded area	Y	N			15. Complies with planting specification	Y	N		
EXCAVATION					16. Topsoil adequate in composition & placement	Y	N		
5. Size & location	Y	N							
6. Lateral slopes completely level	Y	N			17. Adequate erosion control measures in place	Y	N		
7. Longitudinal slopes within design range	Y	N			**FINAL INSPECTION**				
CHECK DAMS & LEVEL SPREADERS					18. Dimensions	Y	N		
					19. Check Dams & level spreaders	Y	N		
8. Dimensions, spacing, & materials	Y	N			20. Proper outlet	Y	N		
9. Compaction	Y	N			21. Effective stand of vegetation & stabilisation	Y	N		
10. Level spreaders are completely level	Y	N			22. Construction generated sediment removed	Y	N		
STRUCTURAL COMPONENTS									
11. Inlets & outlets installed correctly	Y	N							

OFFICERS REMARKS:

ACTION TO BE TAKEN:

No action necessary. Continue routine inspections?   Y / N

Correct noted site deficiencies by
____

1st Notice:
____

2nd Notice:
____

Submit plan modifications as noted in written comments by
____

Notice to Comply issued
____

Final inspection, project completed
____

Officers signature: ____________________________

Consent Holder/Engineer/Agent's signature: ____________________________

Auckland Regional Council TE RAUHITANGA TAIAO	**STORMWATER COMPLIANCE INSPECTION ADVICE** (Under Section 332 of the Resource Management Act 1991)	Investigating Officer:
		Date:
		Time:
		Weather: Rainfall over previous 2-3 days?
		Person contacted during visit:
		Page 1 of 2

Site Name:		File No:	
Consent Holder:		Consent No:	
Engineer:		Catchment:	

SWALE AND FILTER STRIP FACILITY MAINTENANCE INSPECTION CHECKLIST	: 9	Needs immediate attention Not Applicable	V	Okay	;	Clarification Required

"As builts"	Required Y / N	Available Y / N	Adequate Y / N	Approx. check to verify vol(s). Y / N
"Operation & Maintenance Plan"	Required Y / N	Available Y / N	Adequate Y / N	
"Planting Plan"	Required Y / N	Available Y / N	Adequate Y / N	

Swale And Filter Strip Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency		Checked		Maintenance Needed		Inspection Frequency
DEBRIS CLEANOUT	Y	N	Y	N	**M**	**CHECK DAMS / ENERGY DISSIPATORS / SUMPS**	Y	N	Y	N	
1. Swales and filter strips and contributing areas clean of debris											
2. No dumping of yard wastes into swales or filter strips											
3. Litter (branches, etc) have been removed											
VEGETATION					**M**						
4. Plant height not less than design water depth											
5. Fertilised per specifications											
6. No evidence of erosion											
7. Grass height not greater than 250mm											
8. Is plant composition according to approved plans											
9. No placement of inappropriate plants											
DEWATERING					**M**						
10. Swales and filter strips dewaters between storms											
11. No evidence of standing water											

Inspection Frequency Key A = Annual, M = Monthly

OFFICERS REMARKS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N Compliance with other consent conditions? Y / N

Comments: ____

Dates by which maintenance must be completed: / /

Dates by which outstanding information as per consent conditions is required by: / /

Officers signature: _______________________________

Consent Holder/Engineer/Agent's signature: _____________________________