CHAPTER 14 DRAINS AND SWALES

14.1 INTRODUCTION

This chapter provides guidelines for the design of open drainage system, such as lined drains and grassed swales. These facilities, along with stormwater inlets are components of the minor drainage system designed to collect minor flood flows from roads, properties and open space, and convey them to the major drainage system.

It should be noted that fully lined drains are not encouraged anymore in local practice while grass lined ones as encouraged. Developers and designers shall seek approval from the local regulatory authority if such needs arise. Much of procedures and experience that deal with open drainage system have been established in Malaysian practice since late 1970s.

14.1.1 Design Storm

Drains and swales should have the capacity to convey the flow up to and including the minor system design ARI.

14.1.2 Drainage Reserves

Most open drains will be located within road reserve and therefore do not require a separate reserve to allow access for maintenance. However, open drains and swales located outside of road reserves, such as in public walkways and open space areas, should be provided with a drainage reserve in accordance with Figure 14.1.

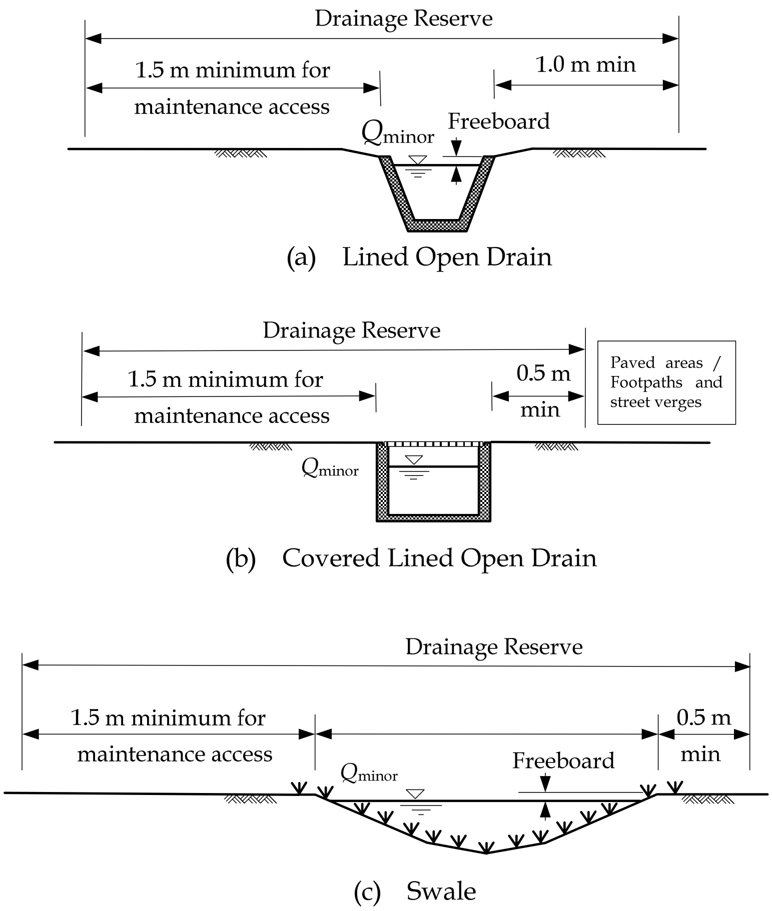


Figure 14.1: Drainage Reserve for Minor Drain and Swale

In new development areas, the edge of a swale should generally be located 0.5 m from the road reserve or property boundary. In existing areas, this alignment may be varied depending on the alignment and depth of existing underground services within the road verge. The designer should consult the local regulatory authority for appropriate alignments in existing areas.

14.2 STRUCTURAL AND COMPOSITE DRAIN

14.2.1 Description

A lined drain is highly resistant to erosion. This type of drain is expensive to construct, although it should have a very low maintenance cost if properly designed. Non-erodible lining should be used when stability cannot be achieved with a swale. Its principal disadvantages are high initial cost, susceptibility to failure if undermined by scour and the tendency for scour to occur downstream due to high flow velocities and acceleration of the flow on a steep slope or in critical locations where erosion would cause extensive damage.

A composite drain is combination of a grassed section and a lined drain that may be provided in locations subject to dry-weather base flows which would otherwise damage the invert of a grassed swale, or in areas with highly erodible soils. The composite drain components shall comply with the relevant design requirements specified for grassed swales and lined drains.

14.2.2 Lining Materials

Lined drains shall be constructed from materials proven to be structurally sound and durable and have satisfactory jointing systems.

Lined open drains may be constructed with any of the following materials:

- plain concrete;
- reinforced concrete;
- stone pitching;
- plastered brickwork; and
- precast masonry blocks.

Alternative drain materials may be acceptable. Proposals for the use of other materials shall be referred to the Local Authority for consideration on a case-by-case basis, especially for steep sloped high velocity applications.

14.2.3 Design Consideration and Requirements

The design should take into consideration of site conditions as described below.

(a) Drainage Area

Determination of drainage types (earth/concrete/composite) based on space availability, site suitability, environment conditions (aesthetic, conservation values, etc.) and maintenance advantages and disadvantages. Standardised locations for lined drains are provided to limit the negotiations needed when other services are involved.

(b) Roadway Reserves

The outer edge of a lined drain should be located 0.5 m (minimum) from the property boundary on the high side of road reserves to permit relatively short connections to service adjacent properties. Lined drains may also be located within road median strips.

The local regulatory authority should be consulted for standard alignments of public utility services within street verges.

Where there is significant advantage in placing a lined drain on an alignment reserved for another authority, it may be so placed provided that both the authorities agree upon the responsibility for maintenance of the stormwater conveyance. The other authority concerned shall provide written approval to release the reservation.

Curved alignments are preferred on curved roadways. However, in areas such as culs-de-sac and narrow street verges, straight alignments may be acceptable, where there are significant advantages in doing so.

(c) Privately Owned Lots

Municipal lined drains shall not be located within privately owned properties. Where lined drains are to be provided at the side or rear of private properties, they shall be placed within a separate drainage reserve in accordance with Figure 14.1(a) or Figure 14.1(b).

(d) Public Open Space

The location of lined drains within public land such as open space shall be brought to the attention of the local regulatory authority for consideration. As a guide, unless directed otherwise, lined drains shall be located as close as possible to the nearest property boundary with due consideration for public safety. Appropriate safety measures shall be provided to protect the public from being trapped within a drain during flash flooding.

14.2.4 Design Criteria

14.2.4.1 Geometry

The dimensions of lined open drains have been limited in the interests of public safety and to facilitate ease of maintenance. The minimum and maximum permissible cross-sectional dimensions are illustrated in Figure 14.2.

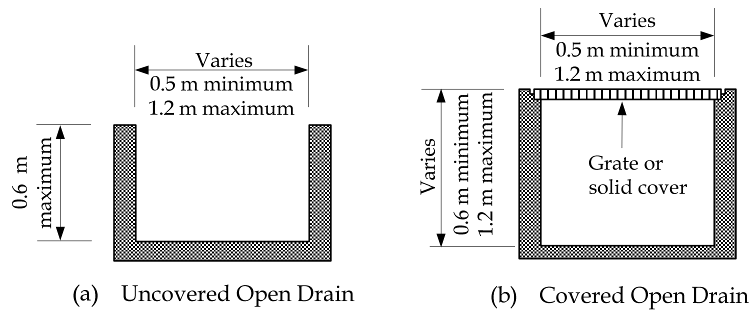


Figure 14.2: Dimension Limits for Open Lined Drains

The preferred shape for a composite drain is shown in Figure 14.3. The lined drain section is provided at the drain invert to carry dry-weather base flows and minor flows up to a those resulting from a 10 mm rainfall depth over the contributing catchment. The lining section shall be sized to provide additional flow capacity up to and including the design storm ARI.

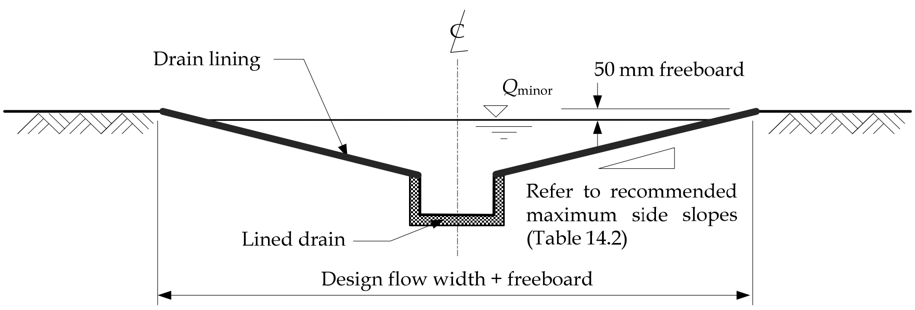


Figure 14.3: Recommended Composite Drain Cross Section

(a) Depth

The maximum depth for lined open drains shall be in accordance with Table 14.1. A reinforced concrete drain shall be provided for lined open drains that exceed 0.9 m in depth.

Table 14.1: Recommended Maximum Depths

Cover/Handrail Fence Condition	Maximum Depth (m)
Without protective covering	0.6
With solid or grated cover	1.2

(b) Width

The width of lined open drains may vary between a minimum width of 0.5 m and a maximum of 1.2 m.

(c) Side slope

The recommended maximum side slopes for lined open drains is indicated in Table 14.2.

Table 14.2: Recommended Maximum Side Slopes

Drain Lining	Maximum Side Slope
Concrete, brickwork and blockwork	Vertical
Stone pitching	1.5(H):1(V)
Grassed/vegetated, rock riprap	2(H):1(V)

14.2.4.2 Freeboard

The depth of an open lined drain shall include a minimum freeboard of 50 mm above the design storm water level in the minor drain.

14.2.4.3 Velocities and Longitudinal Slope

To prevent sedimentation and vegetative growth, the minimum average flow velocity for minor drain shall not be less than 0.6 m/s. The maximum flow velocity in open drain should be restricted to a maximum of 2 m/s. However, for flow velocities in excess of 2 m/s and less than 4 m/s, drains shall be provided with a 1.2 m high handrail fence, or covered with metal grates or solid plates for the entire length of the drain for public safety.

As longitudinal slope increase the velocity increases proportionally. Open drains longitudinal slope should be constant and no steeper than 0.2%. Drop structures may be required to reduce the longitudinal slope in order to control flow velocities.

14.2.4.4 Roughness Coefficients

Lined drain materials for proposed systems typically include concrete, stone pitching, riprap, gabions, brickworks and precast masonry. The suggested Manning's roughness coefficients for these drain materials are indicated in Chapter 2 (Table 2.3).

14.2.4.5 Drainage Sumps

Drainage sumps (with a minimum size of 450 mm x 450 mm) shall be provided along covered drains with a maximum interval spacing of every 100 m and a minimum depth from drain invert is 600 mm.

14.2.4.6 Safety Requirements

Open drains in locations exposed to pedestrian access or sited close to carriageway shall be covered if the drain exceeds 0.6 m in depth. The type of drain cover used will depend on the expected live loadings and whether or not the drain is required to accept surface flow. The acceptable types of drain covering are as follows:

(a) Precast Reinforced Concrete Covers

Drains not subject to traffic loads or inflow of surface runoff may be covered using precast reinforced concrete covers. Covers should be sized such that the weight is limited to what can be easily lifted by two workmen to gain access for maintenance.

(b) Metal Grates and Solid Plates

Drains subject to vehicular traffic loads or inflow of surface runoff shall be covered using metal grates or solid plates. Metal covers shall be designed in accordance with the latest editions of relevant Malaysian Standards or equivalent.

(c) Cover Levels

Covers for lined open drains shall be set at the finished cover levels given in Table 14.3.

Table 14.3: Cover Levels

Location	Cover Level
Paved areas	Flush with finished surface
Footpaths and street verges	Flush with finished surface
Elsewhere	100 mm above the surface to allow for top soiling and grassing

(d) Handrail Fence

The maximum depth for cover or handrail fence condition shall be in accordance with Table 14.1.

Adequate safety measures such as 1.2 m high handrail fence shall be provided at populated areas or areas exposed to pedestrian access. Vertical drops should be avoided. Fencing or railings may also need to be considered if side slopes are to be steeper than 3(H):1(V) in the design.

14.2.5 Design Procedure

The preliminary sizing estimation procedure for minor drain is given below:

Step 1: Estimate the design discharge, Q_{minor} based on the design minor ARI using suitable methods from those outlined in Chapter 2 (Section 2.3).

Step 2: Estimate Manning's n of the lining material.

Step 3: Select the design cross-section. Determine the depth and the minimum base width for the proposed system. Determine the proposed drain capacity using Manning's Equation.

Step 4: Compare the estimated drain capacity with the calculated design discharge, Q_{minor}. If the drain capacity is found to be inadequate, then the drain cross section should be modified to increase the capacity. Likewise a reduction in the cross section may also be required if the drain is not to be overdesigned. In the case of any modifications to drain cross section, repeat Step 3.

Step 5: Calculate the average flow velocity from $V = Q/A$ and check that it is within the maximum and minimum velocity criteria for the open drain. If not, adjust the drain dimensions and return to Step 3.

Step 6: Determine the flow depth, y and check if y is within required limits for the open drain type. If not, adjust the drain dimensions and return to Step 3.

Step 7: Add the required freeboard. If required, calculate the top width of drain for drains with sloping sides.

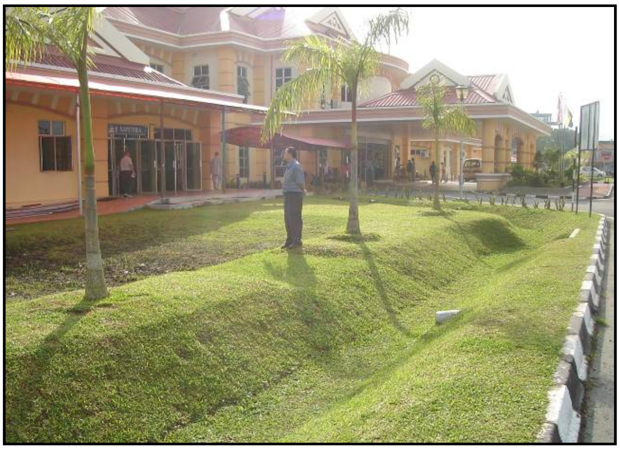
Step 8: Calculate the width of the drainage reserve.

14.3 SWALES

14.3.1 Description

Swales are broad and shallow channels designed to store and/or convey runoff at a non-erosive velocity, as well as enhance its water quality through infiltration, sedimentation and filtration. Swales may be covered by dense vegetation, usually grass to slow down flows and trap particles and remove pollutant.

(a) Universiti Tun Hussein Onn Malaysia



(b) Taiping Health Clinic (Type 2)

Figure 14.4: Grassed Swales in Malaysia

14.3.2 Advantages

- easy to incorporate into landscaping;
- good removal of urban pollutants;
- reduces runoff rates and volumes;
- low capital cost;
- maintenance can be incorporated into general landscape management; and
- good option for small area retrofits.

14.3.3 Disadvantages

- not suitable for steep areas;
- limited to small areas;
- risks of blockages in connecting pipework/culverts;
- sufficient land may not be available for suitable swale designs to be incorporated; and
- standing water in vegetated swales can result in potential safety, odour, and mosquito problems.

14.3.4 Design Consideration and Requirements

14.3.4.1 Drainage Area

Grassed swales engineered for enhancing water quality cannot effectively convey large flows. Therefore, swales are generally appropriate for catchments with small, flat impermeable areas. If used in areas with steep slopes, grassed swales must generally run parallel to contours in order to be effective.

14.3.4.2 Space Requirement

Grassed swales must be effectively incorporated into landscaping and public open spaces as they demand significant land-take due to their shallow side-slopes. Grassed swales are generally difficult to be incorporated into dense urban developments where limited space may be available (CIRIA, 2007).

14.3.4.3 Location and Site Suitability

Swales should be integrated into the site planning and should take account of the location and use of other site features. The siting of a swale should be such that the topography allows for the design of a channel with sufficiently mild slope and cross-sectional area to maintain non-erosive velocities. Swales should not be sited on unstable ground and ground stability should be verified by assessing site soil and groundwater conditions. Maintenance access should be easy and good growth of vegetation should be ensured by siting swales in areas that receive sufficient sunlight (CIRIA, 2007).

14.3.4.4 Site Slope

Grassed swales are usually restricted to sites with significant slopes, though careful planning should enable their use in steeper areas by considering the contours of the site (CIRIA, 2007). The longitudinal terrain slope should not exceed 2% as low runoff velocities are required for pollutant removal and to prevent erosion. Longitudinal slopes can be maintained at the desired gradient and water can flow into swales laterally from impermeable areas.

14.3.4.5 Subsurface Soils and Groundwater

Where grassed swales are designed to encourage infiltration, the seasonally high groundwater table must be more than 1 m below the base of the swale. Where infiltration is not required, the seasonally high groundwater level should be below any underdrain provided with the swales (CIRIA, 2007).

14.3.5 Design Criteria

14.3.5.1 Alignment

Standardised alignments for grassed swales are provided to limit the negotiations needed when other services are involved, such as privately owned lots and public open space.

Municipal grassed swales shall not be located within privately owned properties. If grassed swales are to be provided at the side or rear of private properties, they shall be placed within a separate drainage reserve of minimum dimensions in accordance with Figure 14.1. The location of swales within public land such as open space should generally conform to natural drainage paths wherever practical. The designer should consult with the local regulatory authority for appropriate alignments with due consideration for public and aesthetic amenity.

14.3.5.2 Geometry

The preferred shapes for swales are shown in Figure 14.5. The depth shall not exceed 1.2 m. A ‘vee’ or triangular shaped section will generally be sufficient for most applications; however, a trapezoidal or parabolic swale shape may be used for additional capacity or to limit the depth of the swale. Swales with trapezoidal cross sections shall be recommended for ease of construction. A parabolic shape is best for erosion control, but is hard to construct.

For a trapezoidal shape, the bottom width should be between 0.5 m and 3.0 m. The 0.5 m minimum bottom width allows for construction considerations and ensures a minimum filtering surface for water quality treatment. The 3.0 m maximum bottom width prevents shallow flows from concentrating and potentially eroding channels, thereby maximizing the filtering by vegetation.

Side slope shall not be steeper than 2(H):1(V) while side slope 4(H):1(V) or flatter is recommended for safety reason. However, side slope of 2(H):1(V) in residential areas are strongly discouraged. The larger the wetted area of the swale, the slower the flow and the more effective it is in removing pollutants.

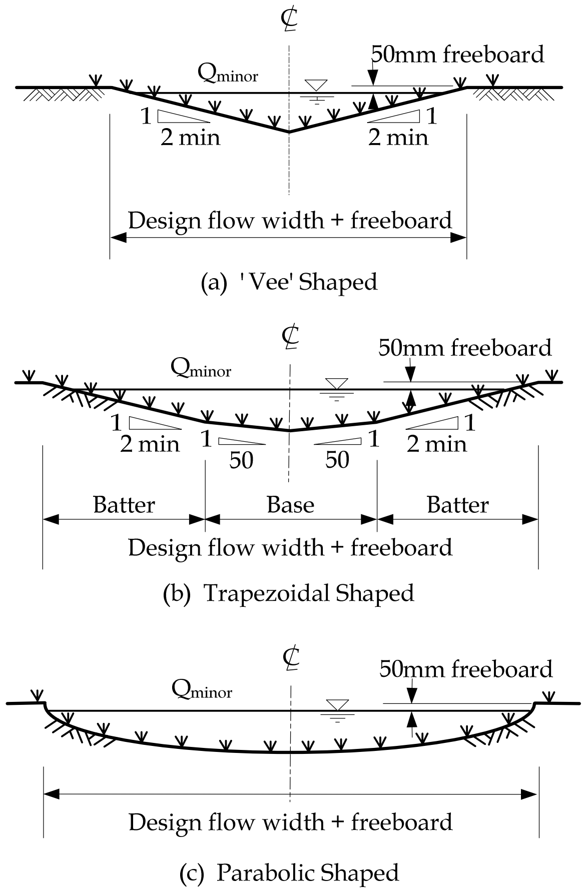


Figure 14.5: Recommended Swale Cross Sections

14.3.5.3 Longitudinal Slope

Slope of swales should normally be between 0.1% (1 in 1000) and no greater than 0.5% (1 in 200). Underdrains may be required for slopes below 0.2% (1 in 500), while drop structures such as rock check dams in the channel may be required for slopes greater than 0.2% to reduce the drainage longitudinal slope such that the design flow velocities do not exceed the permissible limits.

14.3.5.4 Freeboard

The depth of a swale shall include a minimum freeboard of 50 mm above the design stormwater level (based on maximum design flows) in the swale to allow for blockages.

14.3.5.5 Velocities

Maximum acceptable flow rate velocities for conveyance of peak design flow (maximum flood flow design) along the swale shall not exceed the recommended maximum scour velocity for various ground covers and values of soil erodibility, or ideally be less than 2 m/s, unless additional erosion protection is provided.

14.3.5.6 Grass Cover

A dense planting of grass provides the filtering mechanism responsible for water quality treatment in swales. Therefore, the grass species chosen for lining of grassed swales must be sturdy, drought resistant, easy to establish, and able to spread and develop a strong turf layer after establishment. A thick root structure is necessary to control weed growth and erosion.

Grass is by far the most effective choice of plant material in swales, however not all grass species are best for vegetative cover. The grasses recommended for permanent seed mixes shall be selected for those in Annex 1.

Compacted soils will need to be tilled before grass seeding or planting. At least 100 mm thick of good quality topsoil is required. General guidelines for establishing an effective grass lining shall be in accordance with Annex 1.

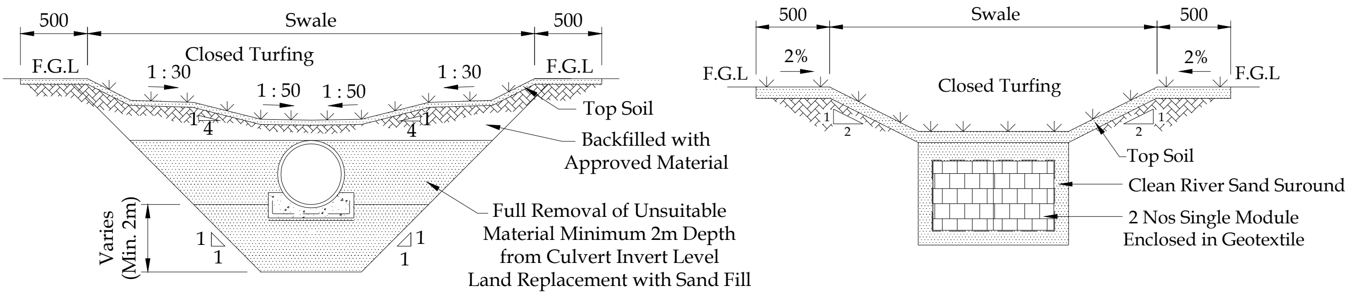
14.3.5.7 Roughness Coefficients

The roughness coefficient, *n*, varies with the type of vegetative cover, longitudinal slope and average flow depth. The *n* value must be adjusted for varying flow depths. Manning's roughness coefficients for swales are provided in Chapter 2 (Table 2.3).

14.3.5.8 Underdrain

A swale should have the capacity to convey the peak flows from the design minor ARI without exceeding the maximum permissible velocities. If this is not practical or there is insufficient space for a swale, designer should consider dividing the flow into surface and subsurface conduits where underground pipedrains or drainage modules can be provided (Figure 14.6). Underdrains can also be placed beneath the channel to prevent ponding.

It is important for biofiltration swales to maximise water contact with vegetation and the soil surface. Gravely and coarse sandy soils will not provide water quality treatment unless the bottom of the swale is lined to prevent infiltration. (Note: sites that have relatively coarse soils may be more appropriate for stormwater quantity infiltration purposes after runoff treatment has been accomplished). Therefore, the bed of a biofiltration swale shall consist of a permeable soil layer above the underdrain material.



(a) Underground Pipedrain (b) Drainage Module

Figure 14.6 Example of Underdrains Provided in the Subsurface of a Swale

A composite swale is a combination system of underground pipedrain and swale. The underdrain caters to the minor storm event for transporting runoff from roadway and other inlets to the outfalls and receiving waters. Drainage sumps shall be provided along swales with a maximum interval spacing of every 100 m. The design of underground pipedrain system should conform to the design criteria as shown in Chapter 15.

14.3.5.9 Low Flow Provision Channel

For swales that will be subjected to dry weather flows, an underdrain or surface invert should be provided.

14.3.5.10 Water Quality Treatment and Flood Flow Design

Swales should be sized as both a treatment facility to slow the stormwater as much as possible to encourage pollutant removal, and as a conveyance system to pass the peak hydraulic flows of the design storms.

(a) Design Water Quality Flow Depth

The sizing calculations for water quality treatment design should check flow velocity, depth and residence times during water quality design storm (3-month ARI). To be effective, the depth of the stormwater during treatment must not exceed the height of the grass. A grass height of 150mm or more and a flow depth of less than 150mm should be selected for the water quality design storm (Figure 14.5). Grasses over that height tend to flatten down when water is flowing over them, which prevents sedimentation. To attain this height requires regular maintenance.

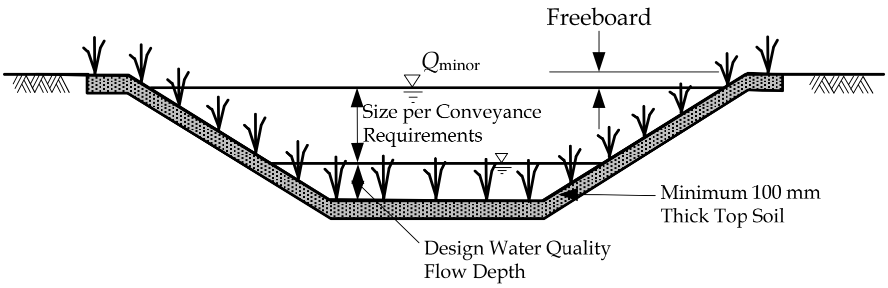


Figure 14.5: Water Quality Treatment and Flood Flow Design for Swale

The velocity of runoff shall not exceed 0.5 m/s along a swale during the water quality design storm to avoid flattening of the vegetation; however, lower velocities are preferable. Design calculation should allow the water quality storm and capacity check for the design storm.

(b) Length

The flow velocity shall not exceed 0.5 m/s along a swale of 60 m length during the water quality design storm. Swales are recommended to have a minimum length of 60 m, which can be achieved by specifying a wide-radius curved path where the available land is not adequate for a linear swale (Sharp bends should be avoided to reduce erosion and to provide for erosion protection). If a shorter length must be used, designers should increase the swale cross sectional area by an amount proportional to the reduction in length below 60 m, to obtain the same water residence time. The recommended minimum residence time is 2 minutes.

14.3.5.11 Safety

Public safety should be maintained by providing sufficient conveyance capacity and appropriate flow depth and velocity to satisfy design requirements for adjacent pedestrian access; the safety of children and adults wading in the swale should be considered.

14.3.5.12 Erosion Protection

Once the maximum flow depth calculations have been performed and safety has been considered, erosion protection calculations should be performed. For any design storm event, the flow velocities are required to be less than 2 m/s, although higher velocities may be allowed if erosion protection is provided.

14.3.6 Design Procedure

The following design steps are recommended when designing grassed swales:

Step 1: Estimate the design discharge, Q_{minor} based on the design ARI for conveyance within the swale based on the site specific characteristics such as catchment area, topography and impervious area.

Step 2: Adopt a trial swale cross section. Calculate the swale geometry for either a triangular, trapezoidal or parabolic swale shape.

Step 3: Determine the Manning's roughness coefficient (*n*) value based on the type of swale vegetation, longitudinal slope (S) based on-site conditions and average depth of flow for the design flow rate (Q_{minor}).

Step 4: Calculate a peak flow (*Q*) and determine the flow depth, velocity and flow rate for the trial swale using Manning's equation.

Step 5: Compare *Q* with the Q_{minor}. Perform iterations through Steps 2 to 4 by changing flow depth, *D* until $Q \geq Q_{minor}$.

Step 6: Check the minimum swale length (*L*)

Step 7: Check the flow velocity for the design flowrate. If this is greater than 2.0 m/s, increase the flow width or reduce the depth of flow. Allow higher velocities if erosion protection is provided.

Step 8: Evaluate water quality parameters. The water quality flow depth should be a maximum of 150 mm. Adjust the swale geometry and re-evaluate as needed.

Step 9: Evaluate the swale geometry for the water quality design storm (40 mm rainfall depth over the contributing catchment), peak discharge velocity and capacity.

Step 10: Check that the flow velocity does not exceed 0.5 m/s along the swale during the water quality design storm for the design flow rate.

Step 11: Establish a construction sequence and construction specifications.

Step 12: Establish maintenance and inspection requirements.

REFERENCES

1. Chow V.T. (1959). *Open Channel Hydraulics.* McGraw-Hill Book Company, New York, USA.
2. Construction Industry Research and Information Association or CIRIA. (2007). *The SUDS Manual*. CIRIA Report C697. London, UK.

APPENDIX 14.A EXAMPLE – LINED DRAIN

Problem:

Determine the size of a lined rectangular drain to convey a 5-year ARI minor system design flow from a proposed 5 hectare bungalow development in Kuala Lumpur. The post-development time of concentration, t_c at the development outlet is estimated to be 20 minutes.

Solution:

Reference	Calculation		Output
	Determine design flows for the drain:		
Equation 2.2	$i = \dfrac{\lambda T^{\kappa}}{(d+\theta)^{\eta}}$		
	where: i = the average rainfall intensity (mm/hr) for selected ARI (T) and storm duration (d);		
Table 1.1	T = average recurrence interval, ARI (years);	=	5-year ARI
	d = storm duration (hours); $0.20 \le d \le 72$and	=	20 minutes
	λ, κ, θ and η = fitting constants dependent on the raingauge location		
Appendix 2.B Table 2.B2			

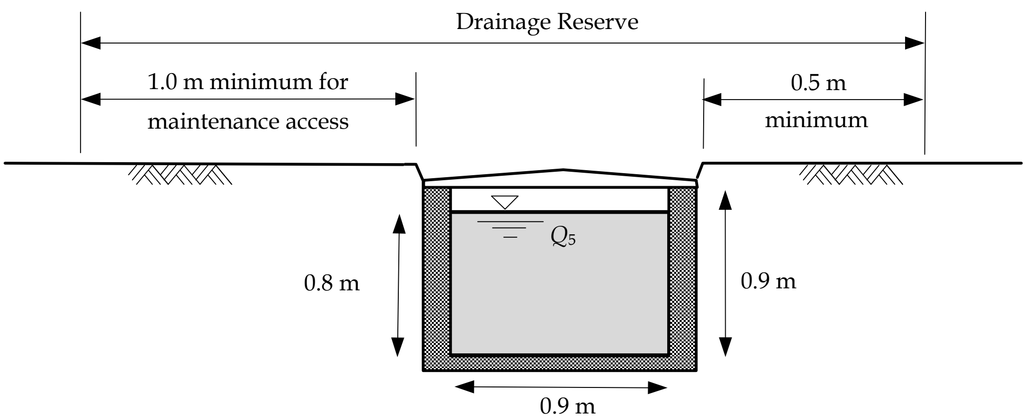
Location & Station ID	ARI, T (years)	Storm duration d	Derived Parameters			
			λ	κ	θ	η
Puchong Drop, KL (3015001)	5	0	69.650	0.151	0.223	0.880

	$i = \dfrac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} = \dfrac{69.650(5)^{0.151}}{\left(\left(\dfrac{20}{60}\right)+0.223\right)^{0.880}}$	=	148.79 mm/h
Equation 2.3	$Q = \dfrac{C.I.A}{360}$		
	where: Q = peak flow (m³/s);		
Table 2.6	C = dimensionless runoff coefficient;	=	0.65
	I = average rainfall intensity over time of concentration, t_c (mm/hr); and	=	148.79 mm/h
	A = drainage area (ha).	=	5 ha
	$Q_5 = \dfrac{0.65 \times 148.79 \times 5}{360}$	=	1.34 m³/s
	Calculate size of lined drain section		
Table 2.3	Manning's n for concrete lining	=	0.015
	Assuming:		
	Drain longitudinal slope	=	0.4% (1 in 250)
	Width, B	=	0.90 m
	Side slope, Z	=	0

Reference	Calculation	Output
	$Q = v \times A$	
	where : $v = \frac{1}{n} S_o^{1/2} R^{2/3}$;	
	$A = (B + ZD)D = 0.90D$	
	$P = B + 2D\sqrt{1+Z^2} = 0.90 + 2D$	

D (m)	A (m^2)	P (m)	R (m)	v m/s	Q (m^3/s)
0.60	0.540	2.10	0.26	1.70	0.921
0.70	0.630	2.30	0.27	1.78	1.120
0.80	0.720	2.50	0.29	1.84	1.324
0.85	**0.765**	**2.60**	**0.29**	**1.87**	**1.427**
Check					OK

Reference	Calculation	Output
		(>Q_5=1.34m^3/s)
Section 14.2.4.2	Allowing a minimum freeboard =	50 mm
	Hence, required depth, $D_{minimum}$ =	0.85 m
	Provided dimension of lined drain (Refer to precast concrete manufacturers): =	0.90 m
	Width, *B* =	0.90 m
	Depth, *D* =	1.89 m/s
	Velocity, *v* =	1.530 m^3/s
	Discharge, *Q*	
	The drain dimensions are 0.90 m wide x 0.90 m deep, which is within the recommended limits.	
Section 14.2.4.3	Check flow velocity for lined drain =	1.89 m/s (0.6<v<2 m/s); ...OK
Section 14.2.4.1	Depth between 0.6 m and 1.2m, lined drain shall be covered.	
	Service opening shall be provided along open drain with maximum interval spacing at every 100 m	



Proposed Lined Drain Design Dimensions

APPENDIX 14.B EXAMPLE – COMPOSITE DRAIN

Problem:

Determine the size of a composite drain to convey a 5-year ARI minor system design flow from a proposed 2 hectare bungalow development in Kuala Lumpur. The post-development time of concentration, t_c at the development outlet is estimated to be 25 minutes.

Solution:

Reference	Calculation	Output
	Determine design flows for the composite drain:	
Equation 2.2	$i = \dfrac{\lambda T^{\kappa}}{(d+\theta)^{\eta}}$	
	where: i = the average rainfall intensity (mm/hr) for selected ARI (T) and storm duration (d);	
Table 1.1	T = average recurrence interval, ARI (years); =	5-year ARI
	d = storm duration (hours); $0.20 \le d \le 72$; and =	25 minutes
	λ, κ, θ and η = fitting constants dependent on the raingauge location.	
Appendix 2.B Table 2.B2	(see table below)	
	$i = \dfrac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} = \dfrac{69.650(5)^{0.151}}{\left(\left(\dfrac{25}{60}\right)+0.223\right)^{0.880}}$ =	131.59 mm/h
Equation 2.3	$Q = \dfrac{C.I.A}{360}$	
	where: Q = peak flow (m^3/s);	
Table 2.6	C = dimensionless runoff coefficient; =	0.65
	I = average rainfall intensity over time of concentration, t_c (mm/hr); and =	131.59 mm/h
	A = drainage area (ha). =	2 ha
	$Q_5 = \dfrac{0.65 \times 131.59 \times 2}{360}$ =	0.475 m^3/s
14.2.4.1	For dry-weather base flows and minor flows up to a 10 mm rainfall depth,	
	Assume storm duration =	25 minutes
	Hence, the design flows are:	
	$Q_{dry-weather} = \dfrac{0.65\,x\left(\dfrac{10}{25/60}\right)x2}{360}$ =	0.087 m^3/s

Table 2.B2 (within calculation):

Location & Station ID	ARI, T (years)	Storm duration d	Derived Parameters λ	κ	θ	η
Puchong Drop, KL (3015001)	5	25	69.650	0.151	0.223	0.880

Reference	Calculation		Output
	Calculate size of lined drain section (dry-weather base flows):		
Table 2.3	Manning's n for concrete lining	=	0.015
	Assuming:		
	Drain longitudinal slope	=	0.5% (1 in 200)
	Drain width, *B*	=	0.60 m
	Side slope, *Z*	=	0
	$Q = v \times A$		
	Where :		
	$v = \frac{1}{n} S_o^{1/2} R^{2/3}$;		
	$A = (B + ZD)D = 0.60D$		
	$P = B + 2D\sqrt{1+Z^2} = 0.60 + 2D$		

D (m)	*A* (m^2)	*P* (m)	*R* (m)	*v* m/s	*Q* (m^3/s)
0.15	0.090	0.90	0.10	1.02	0.091
0.20	**0.120**	**1.00**	**0.12**	**1.15**	**0.138**
0.25	0.150	1.10	0.14	1.25	0.187
0.30	0.180	1.20	0.15	1.33	0.240

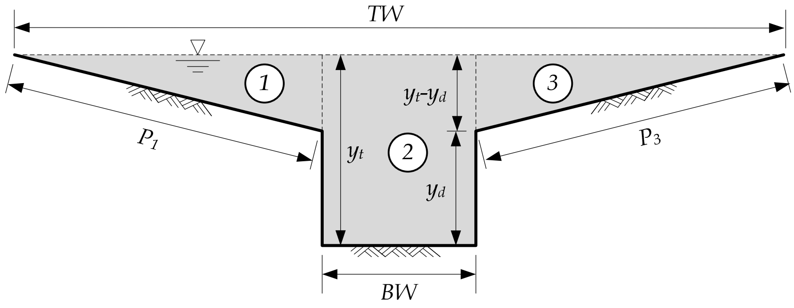
(>0.087 m^3/s)

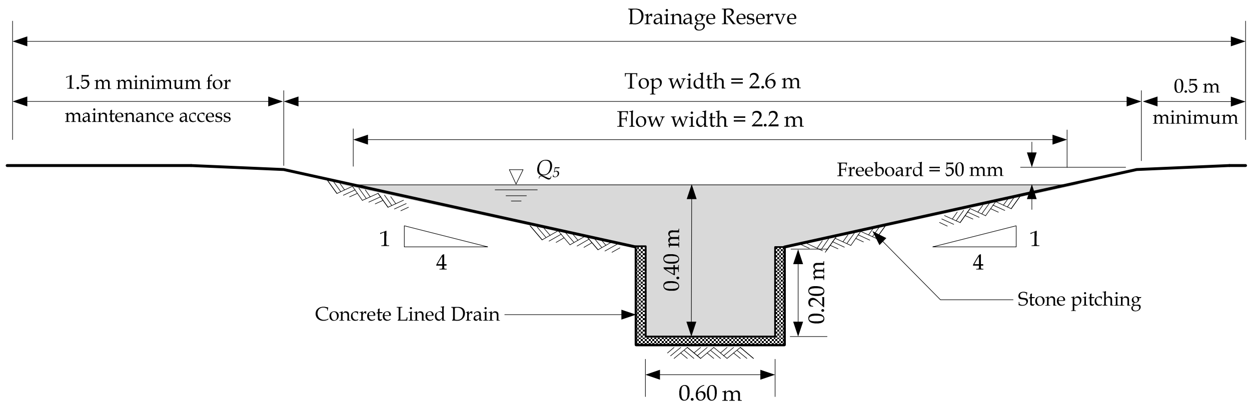
Reference	Calculation		Output
	Provided dimension of lined drain:		
	Drain width, *B*	=	0.60 m
	Depth, *D*	=	0.20 m
	Velocity, *v*	=	1.15 m/s
	Discharge, *Q*	=	0.138 m^3/s
	The drain dimensions are 0.60 m wide x 0.20 m deep, which is within the recommended limits.		
Section 14.2.4.3	Check flow velocity for lined drain.		(0.6<v<2 m/s); …OK
	Calculate size of total drain section:		
Table 2.3	Manning's n for concrete lining	=	0.015
	Manning's n for stone pitching	=	0.035

y_t (m)	*TW* (m)	*BW* (m)	y_d (m)	y_t - y_d (m)	$A_{1\&3}$ (m^2)	$P_{1\&3}$ (m)	$R_{1\&3}$	$V_{1\&3}$ (m/s)	$Q_{1\&3}$ (m^3/s)
0.50	3.0	0.6	0.2	0.30	0.36	2.47	0.146	0.559	0.201
0.45	2.6	0.6	0.2	0.25	0.25	2.06	0.121	0.495	0.124
0.40	**2.2**	**0.6**	**0.2**	**0.20**	**0.16**	**1.65**	**0.097**	**0.427**	**0.068**

y_t (m)	*TW* (m)	*BW* (m)	A_2 (m^2)	P_2 (m)	R_2	V_2 (m/s)	Q_2 (m^3/s)	$Q_{total} = Q_{1\&3} + Q_2$ (m^3/s)
0.50	3.0	0.6	0.30	1.00	0.300	2.113	0.634	0.835
0.45	2.6	0.6	0.27	1.00	0.270	1.969	0.532	0.655
0.40	**2.2**	**0.6**	**0.24**	**1.00**	**0.240**	**1.821**	**0.437**	**0.505**

(>Q_5 = 0.475 m^3/s); …OK

Reference	Calculation		Output
			
	Flow Segments for Calculating Composite Roughness		
Section 14.2.4.2	Allowing a minimum freeboard	=	50 mm
	Provided dimension of composite drain:		
	Top width, *TW*	=	2.6m
	Bottom width, *BW*	=	0.6 m
	Depth, y_t	=	0.45 m
	Discharge, *Q*	=	0.655 m^3/s (>Q_5); …OK



Composite Drain Design Dimensions

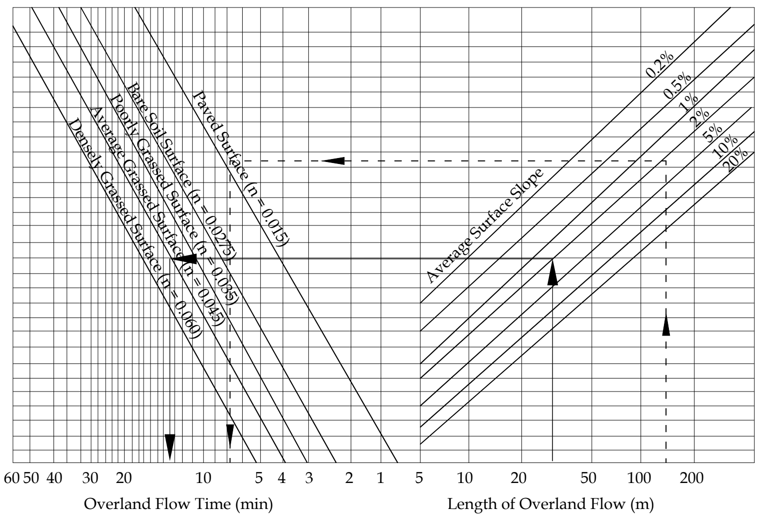
APPENDIX 14.C EXAMPLE – SWALES

<u>Problem:</u>

Determine the size of a grassed swale to convey a 10-year ARI minor system design flow from the project "Cadangan Mendirikan Sebuah Klinik Kesihatan Taiping – 2 Tingkat (Jenis KK2), Daerah Larut & Matang, Perak Darul Ridzuan".

<u>Solution:</u>

Reference	Calculation		Output
Relevant Layout Plan	Development project area**:**	=	2.51 ha
	Sub-catchment area, A	=	0.2325 ha
	Type of landuse	=	Open Spaces Grass
	Estimate time of concentration, t_c:		
Table 2.1	Overland flow time, $t_o = (107.n.L^{1/3}) / S^{1/2}$	=	1.1 minutes
	Where: t_o = Overland sheet flow travel time (minutes);		
	L = Overland sheet flow path length (m);	=	34.4 m
	n = Manning's roughness value for the surface; and	=	0.045
	S = Slope of overland surface (%).	=	2 %
Design Chart 2.A1			



Reference	Calculation		Output
	Time of travel over surface, t_o	=	12.5 minutes
	Say, t_o	=	12.5 minutes
Table 1.1	Design of average recurrence interval (ARI)	=	10-year ARI
Equation 2.2	$i = \dfrac{\lambda T^{\kappa}}{(d+\theta)^{\eta}}$		
	where:		
	i = the average rainfall intensity (mm/hr) for selected ARI (T) and storm duration (d);		
Table 1.1	T = average recurrence interval, ARI (years);	=	5-year ARI
	d = storm duration (hours); $0.20 \le d \le 72$; and	=	12.5 minutes
	λ, κ, θ and η = fitting constants dependent on the rain gauge location		

Reference	Calculation	Output

Appendix 2.B
Table 2.B2

Location & Station ID	ARI, T (years)	Storm duration d	Derived Parameters			
			λ	κ	θ	η
Bukit Larut, Taiping (4511111)	10	12.50	87.236	0.165	0.258	0.842

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} = \frac{87.236(5)^{0.165}}{\left(\left(\frac{12.50}{60}\right)+0.258\right)^{0.842}}$$ = 242.47 mm/h

Runoff Estimation:

Equation 2.3 — Design Flow, $Q = \frac{C.I.A}{360}$

Where: Q = peak flow (m³/s);
Table 2.6 — C = runoff coefficient; = 0.40
I = average rainfall intensity over time of concentration, t_c (mm/hr); and = 242.47 mm/hr
A = drainage area (ha). = 0.2325 ha

Design Flow, $Q_{10} = \frac{0.40 \times 242.47 \times 0.2325}{360}$ = 0.063 m³/s

Sizing for Swales:

Swale cross-section = Trapezoidal
Table 2.3 — Manning's roughness coefficient, n = 0.035
Section 14.3.5.2 — Swale longitudinal slope, S = 0.2%
Side slope, Z = 3

Depth, D (m)	Bottom width, BW (m)	Side slope, Z (m)	Top width, TW (m)	Area, A (m²)	Wet. Perimeter, P (m)	Hydraulic radius, R (m)	Velocity, v (m/s)	Discharge, Q (m³/s)
0.10	0.60	3	1.20	0.09	1.23	0.07	0.22	0.020
0.20	**0.60**	**3**	**1.80**	**0.24**	**1.86**	**0.13**	**0.32**	**0.078**
0.25	0.60	3	2.10	0.34	2.18	0.15	0.37	0.124
0.30	0.60	3	2.40	0.45	2.50	0.18	0.41	0.182
0.40	0.60	3	3.00	0.72	3.13	0.23	0.48	0.344

(>0.063 m³/s)

Section 14.2.4.2 — Provide a minimum freeboard = 50 mm

Hence, required swale depth, D = 0.25 m

Provided dimension of swale:
Bottom width, BW = 0.6 m
Top width, TW = 1.80 m
Velocity, v = 0.37 m/s
Discharge, Q = 0.124 m³/s

Reference	Calculation	Output
Section 14.3.5.5	Check flow velocity for swale =	(<2 m/s); …OK

Water Quality Storm Design:

For water quality storm up to a 3-month ARI flow,

Appendix 2.B Table 2.B2

Location & Station ID	ARI, T (years)	Storm duration d	Derived Parameters			
			λ	κ	θ	η
Bukit Larut, Taiping (4511111)	0.25	12.50	83.3964	0.3189	0.1767	0.8166

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} = \frac{87.236(5)^{0.165}}{\left(\left(\frac{12.50}{60}\right)+0.258\right)^{0.842}}$$ = 116.85 mm/h

Hence, the design flows are:

$$Q_{water\ quality} = \frac{0.40 \times 116.85 \times 0.2325}{360}$$ = 0.030 m³/s

Calculate flow depth and velocity for the water quality flow:

Table 14.5

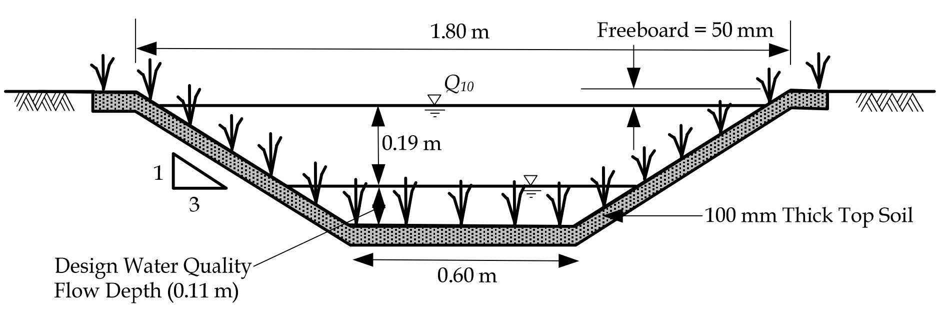
Swale cross-section = Trapezoidal

Manning's roughness coefficient, n = 0.035

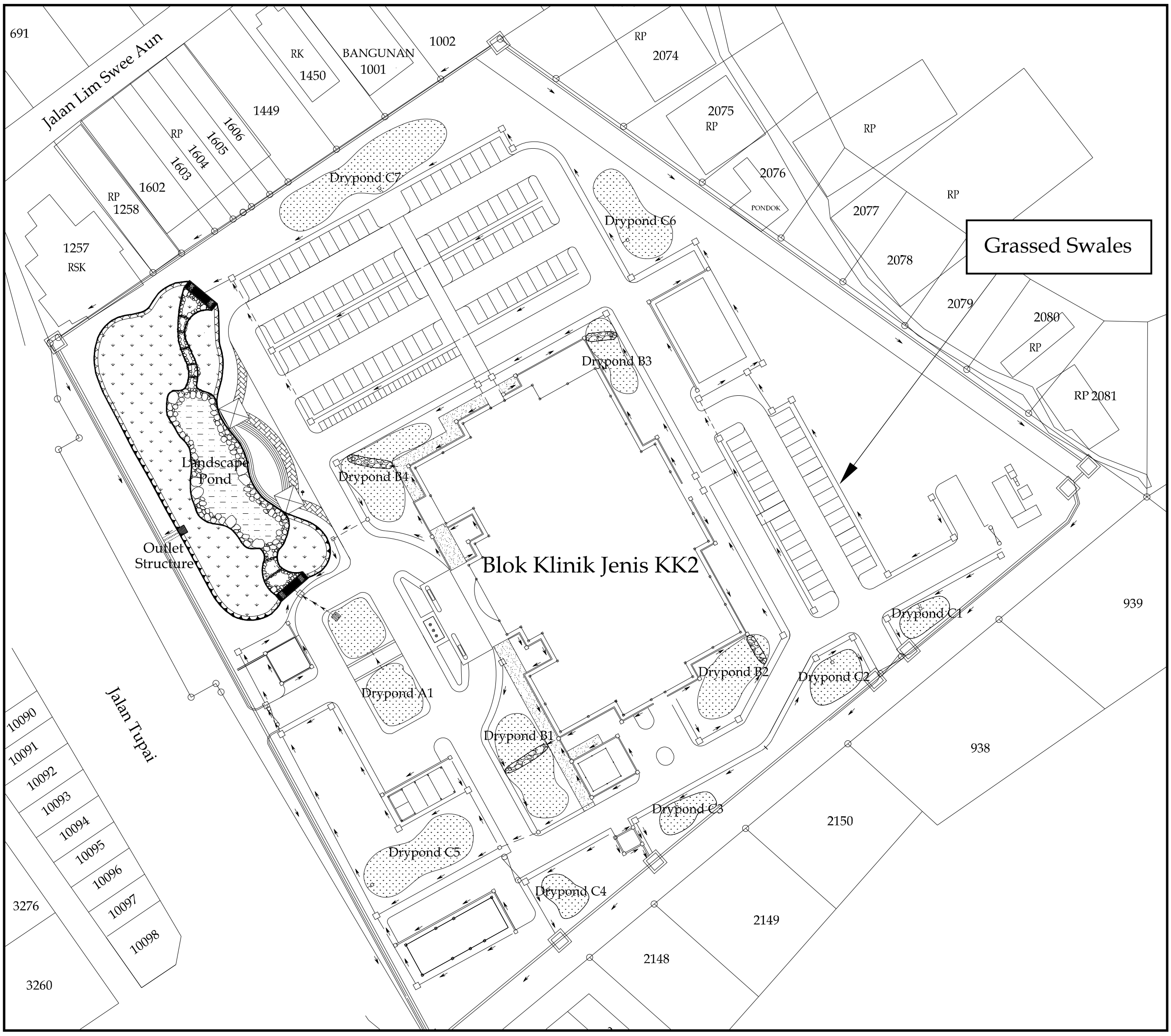
Depth, D (m)	Bottom width, BW (m)	Side slope, Z (m)	Top Width, TW (m)	Area, A (m²)	Wet. perimeter, P (m)	Hydraulic radius, R (m)	Velocity, v (m/s)	Discharge, Q (m³/s)
0.11	0.60	3	1.26	0.10	1.30	0.08	0.23	0.024
0.12	0.60	3	1.32	0.12	1.36	0.08	0.24	0.028
0.13	**0.60**	**3**	**1.38**	**0.13**	**1.42**	**0.09**	**0.26**	**0.033**
0.14	0.60	3	1.44	0.14	1.49	0.10	0.27	0.038

(> 0.030 m³/s)

Reference	Calculation	Output
Section 14.3.5.10	Check water quality flow depth; D =	0.13 m (≤ 150 mm); …OK
	Check velocity for water quality flow depth; v =	0.26 m/s (< 0.5 m/s); …OK



Grassed Swale Design Dimensions



Layout Plan

Examples of Grassed Swales at Project Area

Back To Top