CHAPTER 12 EROSION AND SEDIMENT CONTROL

12.1 INTRODUCTION

Uncontrolled land disturbance, deforestation and construction activities, exposed to rainfall and runoff, cause excessive erosion and sedimentation particularly in tropical environment including Malaysia. The effect has been in obvious water quality deterioration of a number of watercourses and receiving waters due to severe siltation. Therefore, comprehensive control is required to regulate and manage the processes and to mitigate the impacts of erosion and sedimentation.

This Chapter provides relevant guidance and procedures for reduction and control of erosion and sedimentation so that developmental/construction activities can be planned and executed in a judicious manner with minimum land, water quality and environmental degradation. The contents include preventive methods, micro model-based erosion estimates, BMPs design procedures and control plan preparation.

The amount of soil eroded from land development and sediment delivered to waterways is very large, majority transported to the sea, while the rest deposited in floodplains, rivers, lakes and reservoirs. Sediment is always the number one pollutant in waterways, where siltation and nutrients impair more kilometres of rivers and streams than any other pollutant. The economic costs of erosion and sedimentation are substantial, from resource damages on land and receiving waters as well as money spent for removal and/or dredging works (Gray & Sotir, 1996).

12.2 EROSION AND SEDIMENTATION PROCESSES

Soil erosion or surficial erosion is the detachment, entrainment, and transport of soil particles from ongoing land development and construction areas by the rainfall and runoff activities. Erosion occurs starting with raindrop splash. At the onset of runoff sheet, water collects into small rivulets, which may erode very small channels called rills. These rills may eventually coalesce into larger and deeper channels called gullies (Figure 12.1).

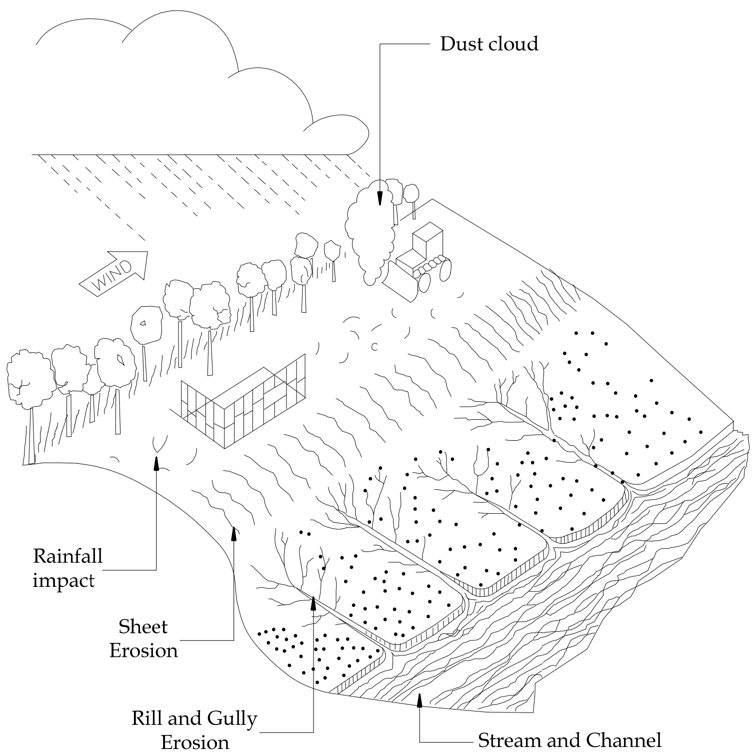


Figure 12.1: Types of Erosion Occurring at a Construction Site (CDM, 1993)

The mechanics of the erosion process is shown Figure 12-2 (Gray & Sotir, 1996). Drag or tractive forces exerted by the flowing stormwater runoff are resisted by inertia or cohesive forces between particles. The forces are measured by water velocity, discharge and soil particle shape and roughness. Erosion is initiated by drag, impact, or tractive forces acting on soil particles.

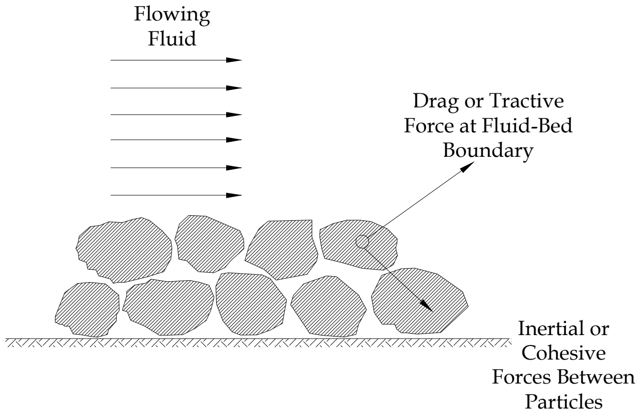


Figure 12.2: Mechanic of Erosion

Based on very limited database, it shows that the erosion rates from forest and agricultural land in a typical Malaysian tropic catchment are roughly 0.5 and 25 tons/ha/yr, while the erosion rates from construction sites have wider variations, ranging from approximately 1,000 to 10,000 tons/ha/yr. It is interesting to note that soil erosion rates from the tropical catchment in Malaysia is in the order of 10 to 20 times greater than those from catchments in the temperate climate (metropolitan areas of Washington D.C. and Baltimore, Maryland) (Chen, 1990). By comparing typical distribution patterns of rainfall intensities for tropical and temperate rainfall, it shows that the erosive power of the tropical rain is as much as 16 times greater than that of the temperate rain (Hudson, 1971).

Sedimentation is the build-up (aggradation) of sediment on the land surface or the bed of receiving waters. . Sedimentation leads to the rising of bed levels contributing to increased floods levels and escalates the destruction of aquatic habitats and fisheries (Figure 12.3). It is a dynamic process and is dependent upon the geomorphic and hydraulic characteristics of the drainage system and the nature of the receiving water body. The deposited sediment tends to remain in place sometimes for short periods of time, where subsequent rainstorms flush the sediment downstream and sometimes for very long times, the later being the case in estuaries and lakes. Sediment tends to be transported in pulses depending on the flow characteristics of the drainage systems.

a) On Flood Plain

b) In Receiving Waters

Figure 12.3: Impacts of Sedimentation

12.3 EROSION AND SEDIMENT CONTROL PRINCIPLES

There are primarily eight (8) principles of erosion and sediment control recommended (Figure 12.4). The following sub-sections provide detailed descriptions of these principles.

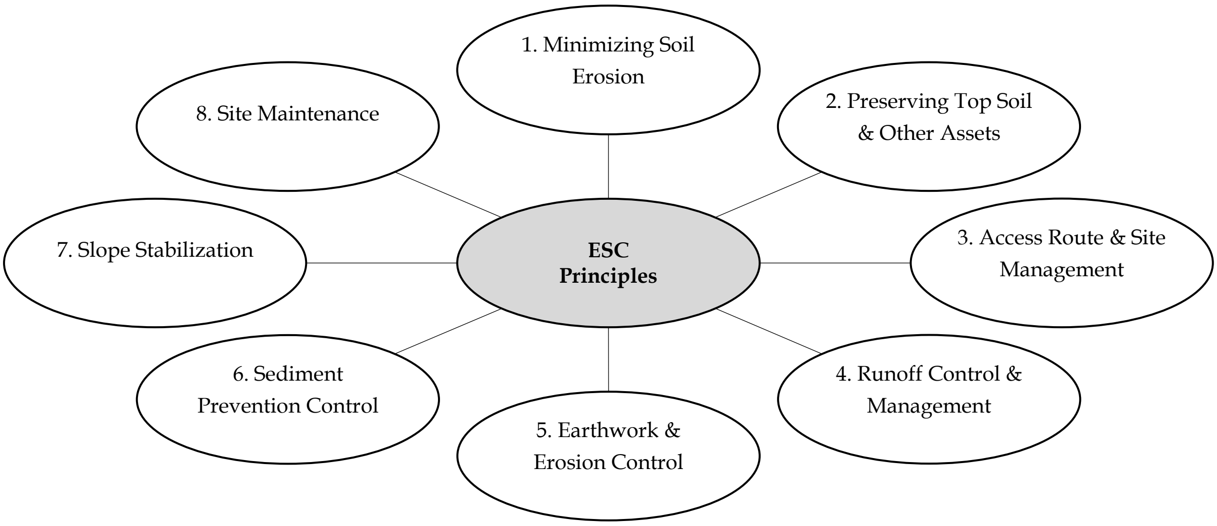


Figure 12.4: Principles of Erosion and Sediment Control

12.3.1 Minimising Soil Erosion

- Before development begins, preventative measures to minimise erosion shall be planned through the preparation of an ESCP.
- The working area for various facilities within a development site shall be reduced to less than twice the plan area of all buildings.
- The contractor shall regulate phases of earthwork and construction through proper development scheduling. All clearing, grading, and stabilisation operations shall be completed before moving onto the next phase. Major earthwork shall be scheduled to avoid wet seasons (monsoon).
- Existing vegetation shall be maintained to the maximum extent possible to filter runoff and provide erosion protection.
- Stream buffers shall be established, and natural waterway reserves should be delineated as recommended by Department of Irrigation and Drainage (DID) Malaysia.

12.3.2 Preserving Topsoil and Other Assets

- Sensitive ecological areas within a development site such as wetlands, natural springs, etc. shall be demarcated and preserved.
- All excavated topsoil shall be stockpiled, protected from erosion, and later used for revegetation.
- Vegetation of high ecological or social value should be identified, protected, and if required, transplanted.

12.3.3 Access Routes and Site Management

- All right-of-ways or access routes shall be shown on the ESCP and it shall be the responsibility of the developer to ensure that all vehicular traffic stays within the designated rights-of-way.
- Vehicle movements on access roads should be kept to a minimum with other areas off-limits to traffic.
- All movements of vehicles over unpaved areas should be kept to a minimum.
- Unpaved roads shall be sprayed with water to reduce dust pollution during dry periods.
- Access roads to the site shall be paved for at least 10 m into the site from any existing paved roads.
- Washing bays shall be provided to remove excessive sediment from out bound vehicles at all site access points.

12.3.4 Drainage Control and Runoff Management

Concentrated runoff often causes more erosion than sheet flows due to higher shear stress. Erosion control measures in locations of concentrated flow can have a major effect in reducing the risk of downstream sedimentation. Hence, proper runoff management during earthworks and construction can contribute greatly to erosion and sediment control. The following practices shall be followed:

- The main principle for establishing a good temporary drainage system in development sites is to direct runoff water so that it does not run across disturbed and unstable areas.
- Runoff from undisturbed areas and natural watercourses shall be diverted away from disturbed land using runoff management best management practices (BMPs) such as earth banks and diversion drains.
- Runoff from disturbed area shall be collected by a temporary (or permanent) drainage system and treated (using available sediment control BMPs), before being released (complying with Department of Environment (DOE) Malaysia environmental regulations) into natural watercourses.
- Temporary drainage system should be designed such that the system does not contribute to the sedimentation problems (stable channel design).
- No watercourse or reserve along a watercourse shall be disturbed until full plan details of the proposed works have been submitted to and approved by DID.
- Ineffective drainage controls shall be noted (especially during wet weather) and promptly corrected.

12.3.5 Earthworks and Erosion Control

- Generally, slopes should not be steeper than 2(H):1(V), or as designed by an experienced geotechnical engineer through slope stability analysis.
- All earthworks shall be stabilised as early as possible to minimize the rates of soil erosion using structural stabilisation or erosion control BMPs.
- Inactive working areas (areas not anticipating any construction activity in upcoming 30 days) shall be stabilised within 7 days with proper stabilization techniques.

12.3.6 Sediment Prevention and Control

- Sediment control BMPs shall be designed and provided at all construction/earthwork sites. These BMPs function by creating impoundments, resulting in sediment settling out from runoff.
- Permanent water quality control measures such as ponds and gross pollutant traps can be constructed and temporarily used as sediment basins, provided they are satisfactorily maintained and cleaned out after development to ensure efficient operation as designed.
- Sediment traps and other temporary control measures should only be removed and dismantled when the permanent vegetative cover and control measures are satisfactorily established.

12.3.7 Slope Stabilisation

- All critical areas along streams must be marked on the ESCP and the recommended methods of stabilisation indicated.
- There shall be no obstruction or interference with natural waterways. Where a road is to be cut across a river or stream, bridges and culverts as prescribed by the enforcement authority shall be constructed and maintained according to specifications.
- For hilly land (greater than 12° or 20%) terracing shall be built and maintained. Cover plants shall be established on the slopes of the platforms and walls of the terrace immediately after commencement of earthworks.
- Slope steeper than 35° or 70% shall not be worked and should instead be identified, stabilised and maintained.

12.3.8 Site Maintenance

- A maintenance programme shall be prepared to include plans for the removal and disposal of unwanted sediments, the repair of structural damages, and improvement or modification of BMPs (based on engineer's recommendation).
- Regular inspections should also be planned for on a fixed interval as well as before and after each storm event.
- All erosion and sediment control measures shall be constructed and maintained by the developer.
- Final discharge(s) from the development site shall comply with ambient standards for TSS (150 mg/l and below (DOE, 1996)) and turbidity for the designated beneficial use of the receiving water.

12.4 DESIGN GUIDELINES FOR EROSION AND SEDIMENT CONTROL BMPs

This section describes specific erosion and sediment best management practices (BMPs) for common construction activities. These BMPs can be further categorized into three types, i.e. erosion control BMPs, runoff management BMPs and sediment control BMPs, based on the natural functions and design objectives of each facility.

Erosion control BMPs emphasise the provision of cover protection to soil, while runoff management BMPs are temporary facilities provided to minimise channel erosion at construction sites. Over time, excessive sediments will be produced downstream of construction sites and they will have to be trapped by providing sediment control BMPs. The design of these BMPs as part of a functioning ESCP will help to ensure that runoff discharges from construction sites have minimal effects on natural watercourses.

While erosion control BMPs can be applied without detailed design, runoff management BMPs and sediment control BMPs shall be properly designed to ensure the facilities provided are able to cope with the on-site demand. This section introduces the Universal Soil Loss Equation (USLE) to be used to assess site erosion risk for preparation of an ESCP, and the Modified Universal Soil Loss Equation (MUSLE) to be used to estimate load for BMPs design.

12.4.1 Soil Loss and Sediment Yield Estimation

12.4.1.1 Soil Loss

The Universal Soil Loss Equation (USLE) is a semi-empirical equation used to assess soil losses (sheet & rill erosion) under different cropping systems and land management practices (Wischmeier and Smith, 1978). The USLE is given as,

$$A = R.K.LS.C.P \qquad (12.1)$$

where,

A = Annual soil loss, in tonnes/ha/year;

R = Rainfall erosivity factor, an erosion index for the given storm period in MJ.mm/ha/h;

K = Soil erodibility factor, the erosion rate for a specific soil in continuous fallow condition on a 9% slope having a length of 22.1 m in tonnes/ha/(MJ.mm/ha/h);

LS = Topographic factor, which represents the slope length and slope steepness. It is the ratio of soil loss from a specific site to that from a unit site having the 9% slope with a slope length of 22.1 m when other parameters are held constant;

C = Cover Management factor, which represents the protective coverage of canopy and organic material in direct contact with the ground. It is measured as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled land under clean-tilled continuous fallow (bare soil) conditions. This is the factor that indicates the effect of erosion control facilities in an ESCP; and

P = Support practice factor, which represents the soil conservation operations or other measures that control erosion, such as contour farming, terraces, and strip cropping. It is expressed as the ratio of soil loss with a specific support practice to the corresponding loss with up and-down slope culture. This is also the factor that indicates the effect of sedimentation control facilities in an ESCP.

This equation produces the annual soil loss (erosion rate) of a site, and hence is very useful in assessing erosion risk of a development site. By assessing different site conditions (pre-, during, and post- construction), Engineer can quantify how erosion risk changes throughout the course of development, and consequently design proper BMPs to reduce soil loss. Using the same equation, an engineer is able to predict the effect of BMPs implementation as well. The assessment of soil loss is required and should be documented in a written report, submitted as part of an ESCP for approval. An example of calculations using this equation is given in Appendix 12.C.

(a) Rainfall Erosivity Factor (R)

The rainfall erosivity factor relates soil loss to rainfall parameters. When other functions are held constant, soil losses are directly proportional to a rainstorm parameter: The total storm energy (E) times the maximum 30-minute intensity (I_{30}). The average annual total of the storm (EI_{30}) in a particular locality is represented by the rainfall erosivity factor, R, for that locality. The relation is expressed in Equation (12.2). Detailed calculations of R factors can be found in *Guideline for Erosion and Sediment Control in Malaysia* (DID, 2010).

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right] \tag{12.2}$$

where;

E = Total storm kinetic energy (MJ/ha);

I_{30} = Maximum 30 minute rainfall intensity;

j = Index for the number of years used to compute the average;

k = Index of the number of storms in each year;

n = Number of years to obtain average R; and

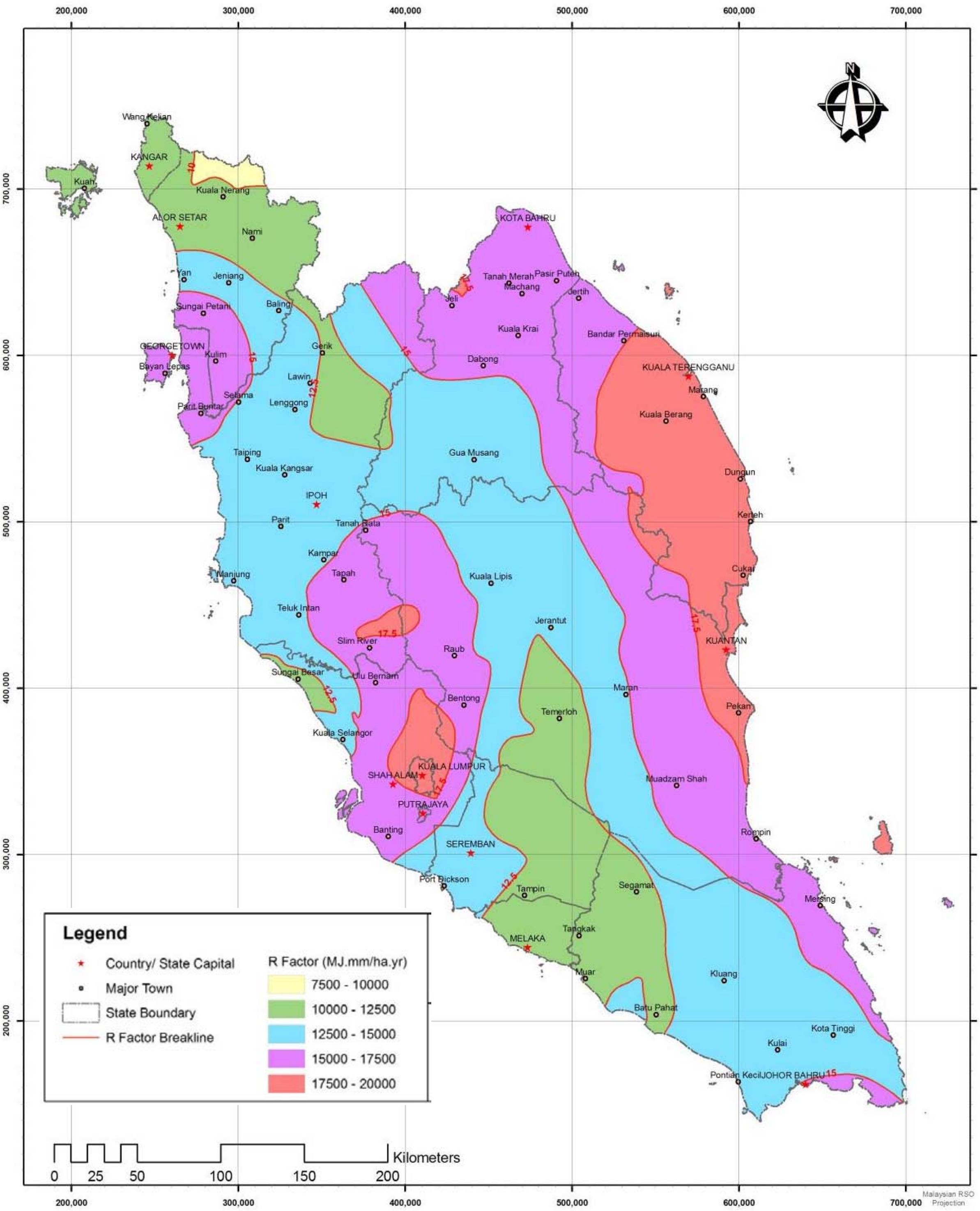
m = Number of storms in each year.

Hourly rainfall data from 241 rain gauge stations for the past 10 years were used to produce R factors for major locations in Peninsular Malaysia. The isoerodent map is given in Figure 12.5. For East Malaysia, the maximum R Factor, 20,000 MJ.mm/ha/yr shall be adopted. Soil loss prediction for a fraction of a year can be estimated using a Monthly Modification Factor (M) given in Table 12.1 below.

Table 12.1: Modification Factor (M) for Regions in Peninsular Malaysia

Region*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northern	0.030	0.033	0.073	0.100	0.070	0.077	0.083	0.087	0.123	0.163	0.097	0.063
Central	0.064	0.054	0.088	0.102	0.070	0.066	0.074	0.064	0.084	0.114	0.130	0.090
Eastern	0.085	0.045	0.055	0.050	0.070	0.055	0.055	0.070	0.085	0.100	0.140	0.190
Southern	0.120	0.045	0.090	0.075	0.065	0.060	0.060	0.060	0.075	0.095	0.110	0.145

*Note: Northern Region - Perlis, Kedah, Pulau Pinang
Central Region - Perak, Selangor, Wilayah Persekutuan Kuala Lumpur, Negeri Sembilan, Melaka
Eastern Region - Terengganu, Kelantan
Southern Region - Johor, Pahang



* Note: The highest value found in Peninsular Malaysia (20,000) shall be applicable for the entire East Malaysia.

Figure 12.5: Rainfall Erosivity Map for Peninsular Malaysia

(b) Soil Erodibility Factor (K)

Soil erodibility defines the resistance of the soil to both detachment and transport. It is an important index to measure soil susceptibility to water erosion, and an essential parameter for soil erosion prediction. The soil-erodibility factor (*K*) represents the effect of soil properties and soil profile characteristics such as soil texture, aggregate stability, shear strength, infiltration capacity, and organic and chemical contents on soil loss.

Equation 12.3 (Tew, 1999) has been found to give the most satisfactorily estimation of *K* factors for Malaysian soil series, and is therefore recommended for the calculation of *K* factors in Malaysia. Percentage of soil particle class can be obtained through standard laboratory analysis of site samples, while soil structure code and permeability class can be obtained from Table 12.2.

$$.K=\left[10\times10^{-4}\left(12\text{-}OM\right)M^{1.14}+4.5\left(S\text{-}3\right)+8.0\left(P\text{-}2\right)\right]/100 \qquad (12.3)$$

where,

M = (% silt + % very fine sand) x (100 - % clay);
OM = % of organic matter;
S = soil structure code; and
P = permeability class.

Table 12.2: Soil Structure Code and Permeability Class for Various Soil Textures

Soil Texture	Permeability Code[1]	Hydrologic Soil Group[2]	Soil Structure Code[3]
Heavy Clay	6	D	4
Clay	6	D	4
Silty Clay Loam	5	C	4
Sandy Clay	5	C	4
Sandy Clay Loam	4	C	4
Clay Loam	4	C	4
Loam	3	B	2
Silty Loam	3	B	3
Loamy Sand	2	A	1
Sandy Loam	2	A	2
Sand	1	A	1

Note: 1 – National Soil Survey Handbook (NRCS, 2005)
2 – National Engineering Handbook (NRCS, 2007)
3 – Field Manual for Describing Soils in Ontario (Ontario Centre for Soil Resource Evaluation, 1993)

(c) Slope Length and Steepness Factor (LS)

The rate of soil erosion by water is very much affected by both slope length (*L*) and slope steepness (*S*) in terms of gradient/ percent slope. By definition, the factor *L* is a ratio of field soil loss to that from a 72.6-foot slope, the value of L may be expressed as $(\lambda/\psi)^m$, where λ is the field slope length in feet (or m), Ψ is 72.6-foot (or 22.13 m) and the exponent *m* in this expression is not the same for all location. The slope-steepness factor (*S*) reflects the influence of slope gradient on erosion. It is the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions. *LS* factor can be obtained directly from Table 12.3. Linear interpolation is allowed for values obtained from the table.

(d) Cover Management (C) and Practice Support (P) Factors

Crop Management, *C* factor and Practice Support, *P* factor are two management factors that can be used to control soil loss at a specific site. The *C* factors, which represent various types of covers introduced to protect bare ground from rain splash and sheet erosion, are important to reduce soil erosion at a construction site or disturbed land. If erosion has already taken place then the *P* factor is needed to stop the silt and sediment in flowing water from running off the site. Combining both the techniques for *C* and *P* factors, it is possible to minimize erosion at a construction site and reduce sediment loading to downstream receiving water bodies.

Recommended *C* and *P* values of commonly found erosion (normally associated with *C* factor) and sediment (normally associated with *P* factor) control BMPs are given in Tables 12.4 and 12.5, respectively.

Table 12.3: *LS* Factor for Various Slopes and Slope Lengths

Slope Steepness, *S* (%)	Slope Length, λ (m)											
	2	5	10	15	25	50	75	100	150	200	250	300
0.1	0.043	0.052	0.059	0.064	0.071	0.082	0.089	0.094	0.102	0.108	0.113	0.117
0.5	0.055	0.067	0.076	0.083	0.092	0.106	0.114	0.121	0.131	0.139	0.146	0.151
1.0	0.057	0.075	0.093	0.105	0.122	0.150	0.170	0.185	0.209	0.228	0.243	0.257
2.0	0.089	0.117	0.144	0.163	0.190	0.234	0.264	0.288	0.325	0.354	0.379	0.400
3.0	0.100	0.144	0.190	0.224	0.275	0.362	0.426	0.478	0.563	0.631	0.690	0.742
4.0	0.135	0.195	0.257	0.302	0.371	0.489	0.575	0.646	0.759	0.852	0.932	1.002
5.0	0.138	0.218	0.308	0.377	0.487	0.688	0.843	0.973	1.192	1.376	1.539	1.686
6.0	0.173	0.273	0.387	0.474	0.612	0.865	1.059	1.223	1.498	1.730	1.934	2.119
8.0	0.255	0.404	0.571	0.699	0.903	1.277	1.564	1.806	2.212	2.554	2.855	3.128
10.0	0.353	0.559	0.790	0.968	1.250	1.767	2.165	2.499	3.061	3.535	3.952	4.329
15.0	0.525	0.909	1.378	1.757	2.388	3.619	4.616	5.486	6.997	8.315	9.506	10.605
20.0	0.848	1.470	2.228	2.841	3.860	5.851	7.463	8.869	11.311	13.442	15.368	17.145
25.0	1.249	2.164	3.279	4.183	5.683	8.613	10.986	13.055	16.651	19.788	22.623	25.239
30.0	1.726	2.991	4.533	5.782	7.855	11.906	15.185	18.046	23.017	27.353	31.272	34.887
40.0	2.911	5.045	7.646	9.752	13.250	20.083	25.614	30.440	38.824	46.139	52.749	58.846
50.0	4.404	7.631	11.567	14.753	20.044	30.382	38.749	46.050	58.733	69.798	79.798	89.023
60.0	6.204	10.751	16.296	20.784	28.239	42.802	54.590	64.875	82.744	98.333	112.420	125.416
70.0	8.312	14.404	21.833	27.846	37.833	57.344	73.138	86.917	110.856	131.741	150.615	168.026
80.0	10.728	18.590	28.177	35.938	48.827	74.008	94.391	112.174	143.070	170.025	194.383	216.854
90.0	13.451	23.309	35.329	45.060	61.221	92.793	118.350	140.648	179.386	213.182	243.723	271.898
100.0	16.482	28.560	43.289	55.212	75.014	113.700	145.016	172.337	219.803	261.214	298637	333.159

Table 12.4a: Cover Management, *C* Factor for Forested and Undisturbed Lands

Erosion Control Treatment	C Factor
Rangeland	0.23
Forest/Tree	
25% cover	0.42
50% cover	0.39
75% cover	0.36
100% cover	0.03
Bushes/ Scrub	
25% cover	0.40
50% cover	0.35
75% cover	0.30
100% cover	0.03
Grassland (100% coverage)	0.03
Swamps/ mangrove	0.01
Water body	0.01

Note: The values are compiled from Layfield (2009), Troeh et al. (1999), Mitchell and Bubenzer (1980), ECTC (2006) and Ayad (2003).

Table 12.4b: Cover Management, *C* Factor for Agricultural and Urbanized Areas

Erosion Control Treatment	C Factor
Mining areas	1.00
Agricultural areas	
Agricultural crop	0.38
Horticulture	0.25
Cocoa	0.20
Coconut	0.20
Oil palm	0.20
Rubber	0.20
Paddy (with water)	0.01
Urbanized areas	
Residential	
Low density (50% green area)	0.25
Medium density (25% green area)	0.15
High density (5% green area)	0.05
Commercial, Educational and Industrial	
Low density (50% green area)	0.25
Medium density (25% green area)	0.15
High density (5 green area)	0.05
Impervious (Parking lot, road, etc.)	0.01

Note: The values are modified from Layfield (2009) and Troeh et al. (1999).

Table 12.4c: Cover Management, *C* Factor for BMPs at Construction Sites

Erosion Control Treatment	C Factor
Bare soil / Newly cleared land	1.00
Cut and fill at construction site	
Fill Packed, smooth	1.00
Freshly disked	0.95
Rough (offset disk)	0.85
Cut Below root zone	0.80
Mulch	
plant fibers, stockpiled native materials/chipped	
50% cover	0.25
75% cover	0.13
100% cover	0.02
Grass-seeding and sod	
40% cover	0.10
60% cover	0.05
≥90% cover	0.02
Turfing	
40% cover	0.10
60% cover	0.05
≥90% cover	0.02
Compacted gravel layer	0.05
Geo-cell	0.05
Rolled Erosion Control Product:	
Erosion control blankets / Turf reinforcement mats	0.02
Plastic sheeting	0.02
Turf reinforcement mats	0.02

Note: The values are compiled from Layfield (2009), Troeh et al. (1999), Mitchell and Bubenzer (1980), ECTC (2006), Israelsen et al (1980), Weischmeier and Smith (1978), and Kuenstler (2009).

Table 12.5: Support Practice, *P* Factor for BMPs at Construction and Development Sites

Support/ Sediment Control Practice		P Factor
Bare soil		1.00
Disked bare soil (rough or irregular surface)		0.90
Wired log / Sand bag barriers		0.85
Check Dam		0.80
Grass buffer strips (to filter sediment laden sheet flow)		
Basin slope (%)		
0 to 10		0.60
11 to 24		0.80
Contour furrowed surface (maximum length refers to downslope length)		
Slope (%)	Maximum Length (m)	
1 to 2	120	0.60
3 to 5	90	0.50
6 to 8	60	0.50
9 to 12	40	0.60
13 to 16	25	0.70
17 to 20	20	0.80
> 20	15	0.80
Silt fence		0.55
Sediment containment systems (Sediment basin/Trap)		0.50
Berm drain and Cascade		0.50
Terracing		
Slope (%)		
1 to 2		0.12
3 to 8		0.10
9 to 12		0.12
13 to 16		0.14
17 to 20		0.16
> 20		0.18

Note: The values are compiled from Layfield (2009), Troeh et al. (1999), Mitchell and Bubenzer (1980), ECTC (2006), Israelsen et al (1980), Weischmeier and Smith (1978) and Kuenstler (2009)

12.4.1.2 Sediment Yield

The Modified Universal Soil Loss Equation (MUSLE) is recommended for sediment yield estimation of a catchment as a result of a specific storm event (Williams, 1975). The estimated amount of sediment storage volume is used in sediment basin/ trap design. This empirical relationship is expressed by the following equation for individual storm event:

$$.Y = 89.6\left(VQ_p\right)^{0.56}(K.LS.C.P) \tag{12.4}$$

where,

Y	=	Sediment yield per storm event (tonnes);
V	=	Runoff volume (m^3);
Q_p	=	Peak discharge (m^3/s); and
K, LS, C, P	=	USLE factors.

Runoff volume and peak discharge can be estimated using procedures described in Chapter 2 of this manual. The most common application would be the Rational Method. Soil Loss factors namely, *K*, *LS*, *C* and *P*, can be determined using equations and recommendations specified in Section 12.4.1.1.

Equation 12.4 is used to produce an event-based sediment yield, i.e. the amount of sediment expected at the end drainage point from the designated site. Hence, it is useful to predict (in mass) the amount of sediment for sizing and maintenance of sediment control BMPs. Many of these BMPs have a designated sediment storage zone. Using the MUSLE, the amount of sediment from a design water quality storm can be estimated. An example of calculations using this equation can be found in Appendix 12.D. Its application in BMPs design is shown in Appendix 12.E and Appendix 12.F.

12.4.2 Erosion Control BMPs

12.4.2.1 Seeding and Planting

(a) Description

Seeding of grasses and planting of trees, shrubs, and ground covers provide long-term stabilisation of soil (Figure 12.6). For example, vegetation may be established along landscape corridors and buffer zones where they may act as filter strips. Additionally, vegetated swales, mild slopes and stream banks can also serve as appropriate areas for seeding and plantings. In general, vegetation is the most suitable and most cost-effective cover for any disturbed or bare soil. However, it should be noted that this BMP has limitations. Seeding and planting on steep slopes can be difficult and may require the help of geo-mats. Vegetation will require proper irrigation during drier days and is slow to stabilise. Excessive use of fertilisers can also worsen stormwater pollution issues.

Maintenance wise, seeding and planting should not require costly or too much of regular maintenance, apart from regular watering during drier months to help plant establish. Fertilizers and pesticide may be required depending on plant selection, although the use of native species normally minimise such needs. Pruning or mowing may be required from time to time, as is weed removal. Eroded areas would require re-vegetation or reinforcement with other BMPs.

a) Turfing in Progress

b) Completed Hydroseeding

Figure 12.6: Examples of Turfing and Stabilised Hydroseeding

(b) Design and Application Criteria

- Suppliers must be consulted to confirm appropriate method of seeding and seed species to ensure successful germination and provide an effective measure;
- Seeding is effective on mild slopes typically (H) 2:(V) 1 or flatter;
- For interim erosion control measures, the contractor must ensure no sediment is entrained off the area and must provide at minimum temporary seeding of native or non-invasive species;
- A minimum 150 mm of top soil should be applied to all areas subjected to permanent landscaping;
- All containerized nursery stock should be kept alive and healthy prior to planting;
- Botanist advice shall be acquired for specific site and plant requirements; and
- Personnel for maintenance should be adequately trained in gardening skills.

12.4.2.2 Mulching

(a) Description

Mulching is a temporary ground cover that protects the soil from rainfall impacts, increases infiltration, conserves moisture around vegetation, prevents compaction and cracking of soil, and aids the growth of seedings and plantings by holding the seeds, fertilisers, and topsoil in place until growth occurs. Figure 12.7 shows the examples of mulching works.

Mulching can be used either to temporarily or permanently stabilise cleared or freshly seeded areas. Types of mulches include organic materials, straw, wood chips, bark or other wood fibres. A variety of mats of organic or inorganic materials and chemical stabilisation may be used with mulches. Mulching requires periodical and after storm inspections. Effort should be made to replace or reinforce eroded mulch.

Figure 12.7: Examples of Mulch Application

(b) Design and Application Criteria

The choice of mulch should be based on the size of the area, site slopes, surface conditions (such as hardness and moisture), weed growth, and availability of mulch materials.

- Mulch may be used with netting to supplement soil stabilisation;
- Binders may be required for steep areas, or if wind or runoff is a problem;
- Types of mulch, binders, and application rates should be recommended by manufacturer; and
- Mulch should not be applied in areas subjected to concentrated flows, as it is highly erodible.

12.4.2.3 Geotextiles and Mats

(a) Description

Mattings made of natural or synthetic material, are often used to temporarily or permanently stabilise soil (Figure 12.8), reduce erosion from rainfall impact, hold soil in place, and absorb and hold moisture near the soil surface. Additionally, mattings may be used alone or with mulch during the establishment of protective cover on critical slopes. This technique is suitable for protection of steep slopes or stream channels with high shear force, as the mats provide structural support to hold soil (in many cases containing seeds or seedlings) together.

Geotextiles and mats require inspection for loose matting, which should be re-anchored or rejoined. Once stabilised, this BMP will require minimal maintenance. It should be noted that matting is relatively more costly than other erosion control BMPs. Its effectiveness heavily relies on the skill of installation workers. The use of synthetic matting such as plastic sheet can increase runoff rates in downslope areas and shall be avoided or only used as emergency or very temporary protection.

Figure 12.8: Example of Geotextile Applications for Erosion Control

(b) Design and Installation Criteria

The application of geotextile does not require professional design for most uses. If hydrostatic pressure is a concern for stability of a retaining wall, contractor should consult a professional experienced in the selection of geotextile fabric. Matting for conveyance systems such as swales or channel banks shall fulfil hydraulic requirements of the conveyance system as described in Chapter 1.

Geotextiles should be installed according to manufacturer's specifications. Among some aspects of installation to be emphasised are: toes and anchors should be sufficiently secure against uplift, overlap span should be sufficient, jointing methods used are to be those recommended by the manufacturer and performed to specification by skilled workers, and backfilling materials are chosen so as to not to damage the mats.

Due to differences in manufacturing materials, techniques, product properties, site constraints, and working environments, methods of installation may vary significantly.

12.4.3 Runoff Management BMPs

Runoff management is a process to control the direction, volume and velocity of the transport medium and safely convey stormwater so that its potential for erosion is reduced. Runoff management BMPs help to direct stormwater away from exposed soils. Transport control should direct the flow to areas where the sediment can be trapped and removed. The primary mechanisms used to control runoff include: reducing the amount of runoff, detaining runoff (reducing velocity), diverting runoff, and dissipating the energy of runoff. The runoff management BMPs introduced here are temporary structures specifically designed to support runoff management during construction. Whenever appropriate, permanent structures such as open channels, engineered waterways, and permanent culverts can be constructed at early stages of construction to manage runoff during construction.

12.4.3.1 Earth Bank

(a) Description

A temporary earth bank is a temporary berm or ridge of compacted soil used to divert runoff or channel water to a desired location, thereby reducing the potential for erosion and off-site sedimentation. Earth banks may also be used to divert runoff from off-site and from undisturbed areas away from disturbed areas, sheet flows away from unprotected or unstable slopes, and polluted runoff into sediment control or permanent stormwater BMPs. Earth banks require minimal maintenance, but should be checked after major storms to repair failed, overtopped or eroded areas. Figure 12.9 provides an engineering drawing for an earth bank.

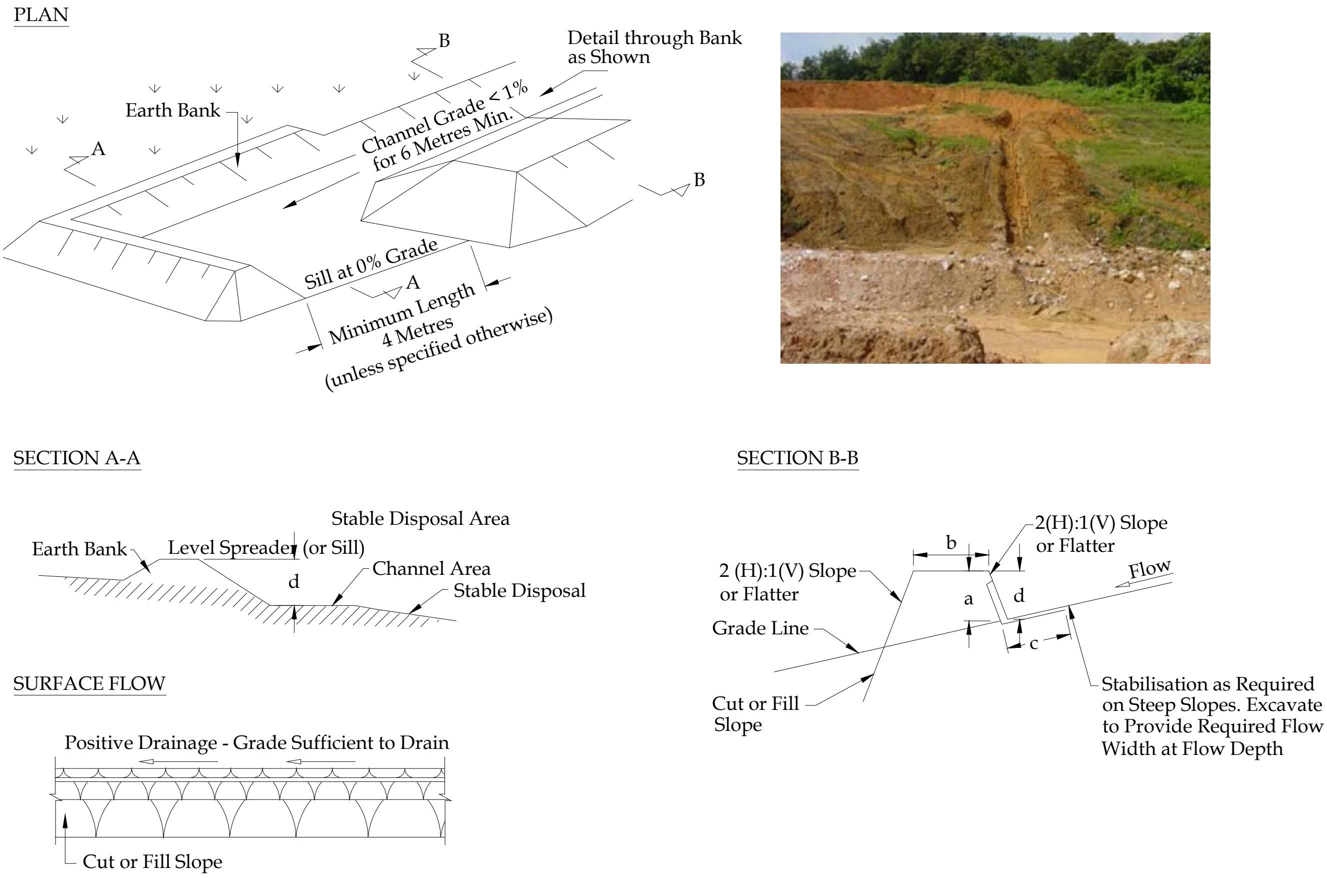


Figure 12.9: Example of an Earth Bank

(b) Design Criteria

Table 12.10: Design Criteria for Temporary Earth Bank

Parameter	Requirement
Design Storm	2-year ARI
Catchment Area	Not more than 4 ha
Dimension	Side Slope: 2(H):1(V) or flatter Height: Minimum of 450 mm Top Width: Minimum of 600 mm
Flood Protection	Ensure upstream/ downstream flooding condition not aggravated
Scour Protection	Proper scour protection to be provided on the face contacted by flowing water
Embankment Material	95% compaction by earth moving machinery

12.4.3.2 Diversion Channel

(a) Description

Temporary diversion channels (Figure 12.10) may be used to divert off-site runoff around the construction site, divert runoff from stabilised areas around disturbed areas, and to direct runoff into sediment control BMPs. Diversion channels should be installed when the site is initially graded and remain in place until permanent BMPs are installed and/or slopes are stabilised. Diversion channels should be regularly checked to prevent clogging, unexpected sediment built-up or channel erosion, overtopping, and cover failure, preferably after every storm. Any defects shall be repaired immediately.

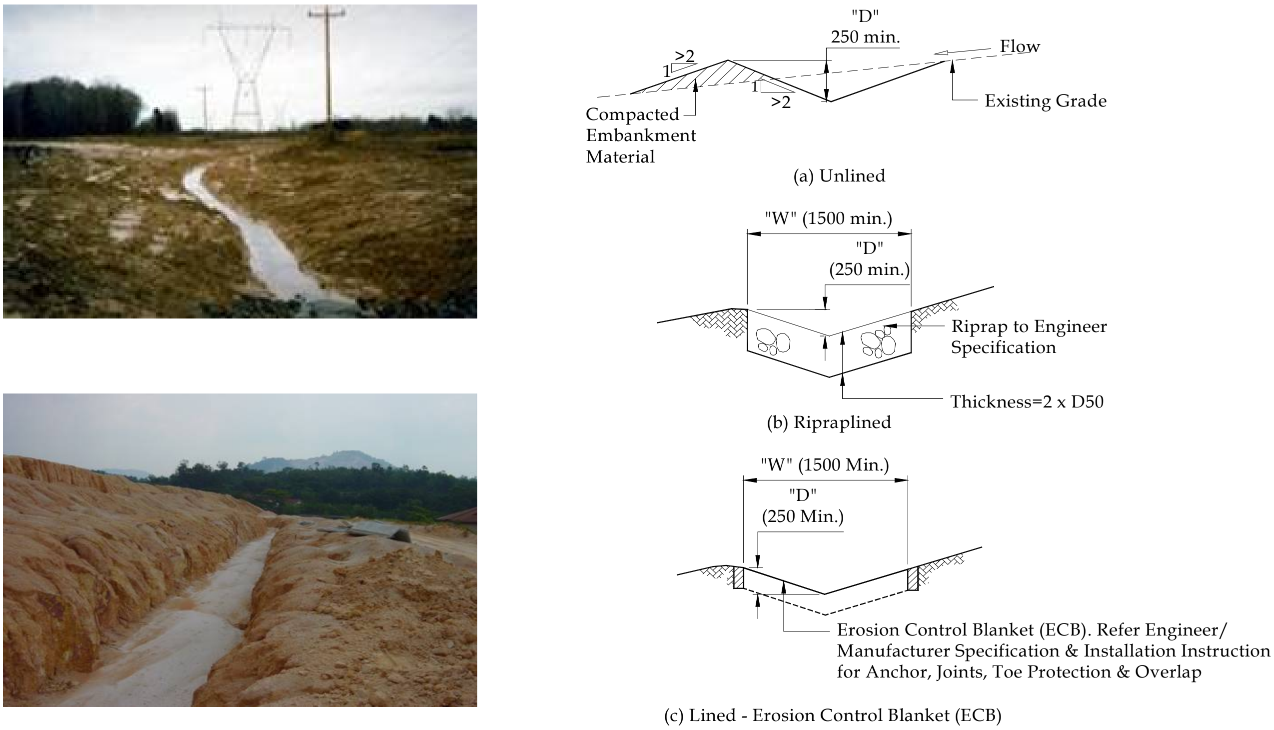


Figure 12.10: Diversion Channels

(b) Design Criteria

Table 12.11: Design Criteria for Temporary Earth Bank

Parameter	Requirement
Design Storm	2-year ARI
Dimension	Side Slope (if applicable): 2(H):1(V) or flatter
Flood Protection	Ensure upstream/ downstream flooding condition not aggravated.
Hydraulic Criteria	Shall be designed as described in Chapter 14 (Drains and Swales) of this manual.
Scour Protection	• Inlet and outlet protection shall be provided • Channel bed and banks can be stabilised using various erosion control methods such as turf, riprap or geo-mats. • Perform checking of maximum shear and velocity
Embankment Material	95% compaction by earth moving machinery

(c) Installation and Application Criteria

Diversion channels are only effective if they are properly installed. As diversion channels are mainly made of earth and soil, it is extremely important that this BMP is properly stabilised by proper earth compaction and surface cover. The side slope and top width criteria should be met to prevent erosion and slope failure.

12.4.3.3 Drainage Outlet Protection

(a) Description

Drainage outlet protection (Figure 12.11) is a physical device consisting of rock, grouted riprap, or concrete rubble that is placed at the outlet of a culvert, conduit, or channel to prevent scour caused by high flow velocities, and to absorb flow energies to produce non-erosive velocities. Energy dissipaters using ripraps or gabions are commonly used as temporary outlet protection. This BMP should be provided wherever discharge velocities and energies at the outlets of culverts, conduits, or channels are sufficient to erode the downstream reach. In cases where loose rocks or rip rap are used, it is important to carry out regular inspections to avoid material wash-off during large storm event. Lost materials should be immediately replaced. Materials used should be selected based on channel stability design.

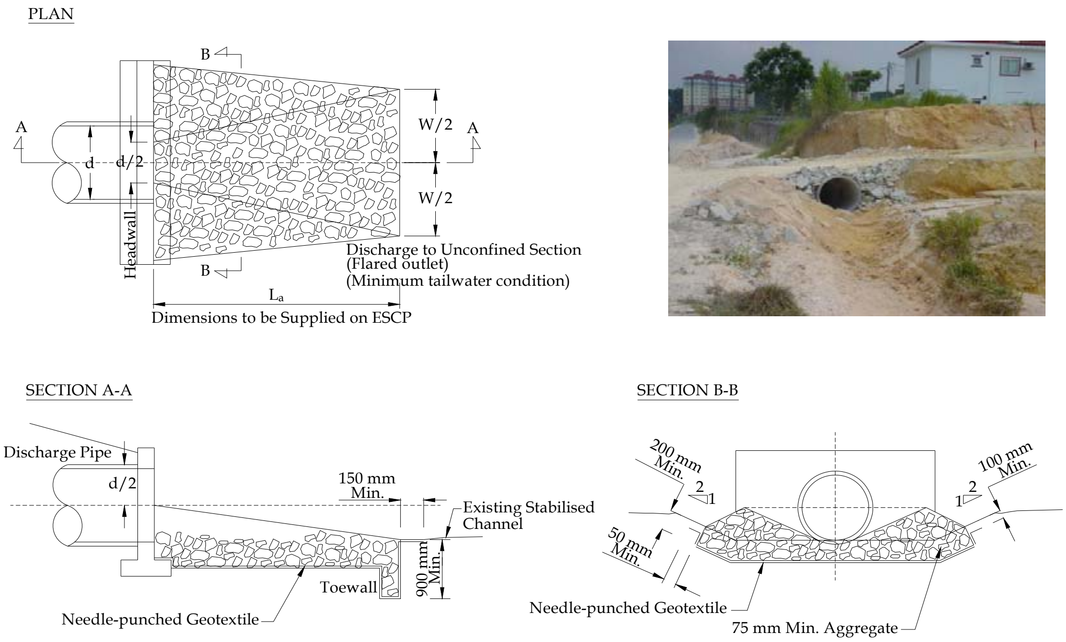


Figure 12.11 Drainage Outlet Protection

(b) Design Criteria

The hydraulic design of drainage outlet protection shall comply with erosion and scour protection recommended in Chapter 20 of this manual. The designed structure shall also be checked for seepage and structural stability. Rock outlet protection is effective when the rock is sized and placed properly. Rock size should be increased for high velocity flows.

12.4.3.4 Temporary Waterway Crossing

(a) Description

A temporary access waterway crossing is a culvert placed across a waterway to provide access for construction purposes for a period of less than one year. The purpose of a temporary crossing is to provide a safe, erosion-free access point across a waterway for vehicles. The concept of temporary crossing is slightly different from a permanent culvert, where it is supposed to convey only minor events and dry weather flows. During major events, the crossing will act as spill crest where larger flows overtop and overspill from the top of crossing while still contained in the conveyance system. Caution should be exercised when applying this BMP as it is a in-stream construction.

The crossing, though temporary might have adverse effect on upstream flooding if overlooked in design. Over a large watercourse, this may be an expensive undertaking for a temporary structure. Weekly inspection and maintenance is required to check for structural failure, debris removal, inlet and outlet protection maintenance etc.

(b) Design Criteria

The design of temporary crossings should generally comply with specifications outlined for culverts design in Chapter 18 of this manual and further incorporate the following design criteria as shown in Table 12.12.

Table 12.12: Design Criteria for Temporary Crossings

Parameter	Requirement
Design Storm	2-year ARI
Dry Weather Flow	To be prepared to allow existing natural flow regime
Overspill	All flow greater than 2 year ARI shall safely bypass the crossing
Flood Protection	Ensure upstream/ downstream flooding condition not aggravated
Hydraulic	Refer Culvert Design in Chapter 18
Scour Protection	Inlet and outlet protection shall be provided

12.4.4 Sediment Control BMPs

Sedimentation control BMPs trap sediment on the site in selected locations and minimize sediment transfer off the site. Sedimentation controls are generally passive systems that rely on filtering or settling of soil particles out of the water or air. Sedimentation control BMPs treat soil as waste products and work to remove it from the drainage system. Sediment control BMPs are the last line of defence against erosion and sedimentation before sediment reaches natural watercourses.

12.4.4.1 Silt Fences

(a) Description

A silt fence (Figure 12.12) is a temporary sediment barrier consisting of filter fabric stretched across and attached to supporting posts, entrenched, and, depending upon the strength of the fabric used, backed by a wire fence for support. This measure does not filter runoff, but acts as a linear barrier creating upstream ponding that allows soil particles to settle out, thereby reducing the amount of soil leaving a disturbed area. This BMP is relatively effective at retaining suspended solids coarser than 0.02 mm. Silt fences are simple to construct, relatively inexpensive and easily moved as development progresses.

Silt fence can be considered an on-site control as it caters to small overland sheet flow. It is most effective in securing site perimeter, protecting topsoil stock pile, and intercepting sheet flow along slope contours. Silt fence requires regular inspection and maintenance as it is easily damaged. Sediment built-up behind fence should be regularly removed. The fence is also not suitable for areas dominated by very fine (clayey) soil particles. The selection of material pore size is important and suppliers or manufacturers shall be consulted on this matter.

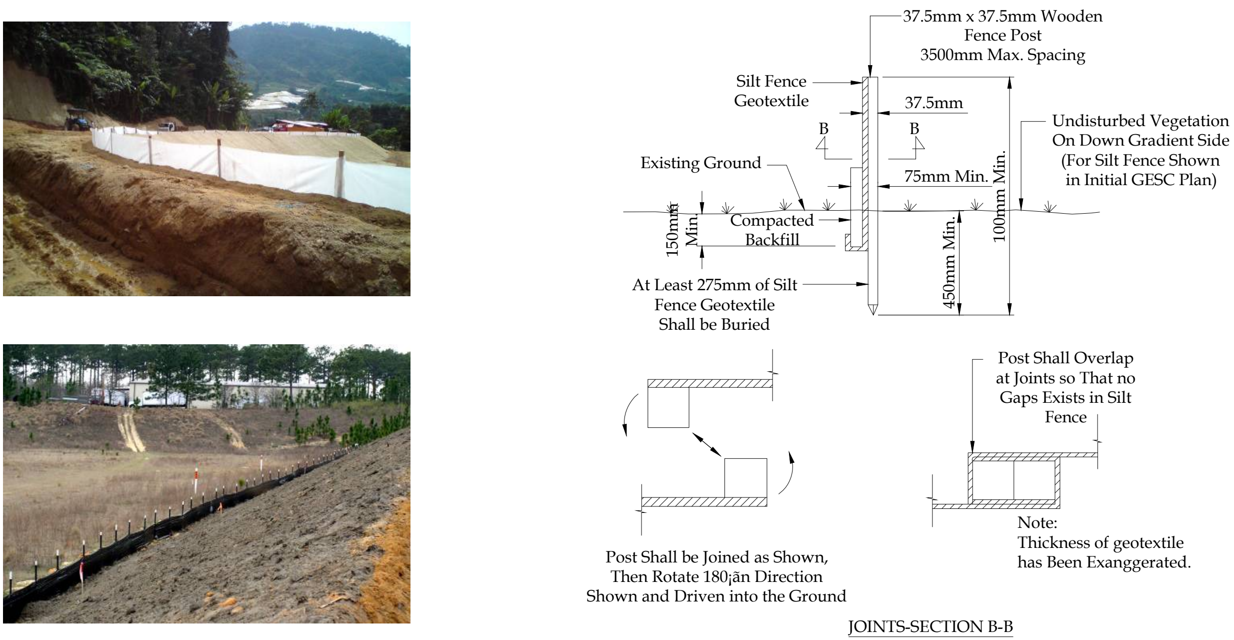


Figure 12.12: Silt Fence Application

(b) Design Criteria

Table 12.13: Design Criteria of Silt Fence

Parameter	Requirement
Design Storm (Both Quantity & Quality)	First 50 mm of rainfall over the contribution (equivalent impervious) catchment
Maximum Contributing Area	0.4 ha
Hydraulic	For any point along the fence, • Concentrated flow shall not exceed 50 L/s • Maximum water depth shall not exceed 600 mm
Sitting of facility	• Fences SHALL NOT be installed in areas receiving concentrated flow, i.e. streams or ditches • Maximum length of each fence segment shall not exceed 30 m • The at least 1 m from ends of each segment shall be turned uphill to prevent runoff flowing around the fence
Slope	• Slope draining to fence shall be 1(H):1(V) or flatter • Length of path draining to fence shall not exceed 60 m
Storage Area	Storage area to be provided behind fence Approximately 280 m² per ha of contributing area is required

(c) Installation and Application Criteria

- Designers should leave an undisturbed or stabilised area immediately downslope of the fence;
- Designers should select filter fabric which retains 85% of the soil, by weight, based on sieve analysis, but is not finer than an equivalent opening size of 70 (US Standard Sieve) or about 210 µm;
- Sediment fences should remain in place until the disturbed area is permanently stabilised;
- Posts should be spaced a maximum of 3.5 m apart and driven securely into the ground a minimum of 450 mm;
- A trench should be excavated approximately 200 mm wide and 300 mm deep along the line of posts and upslope from the barrier;
- The use of joints should be avoided. When joints are necessary, filter cloth should be spliced together only at a support post, with a minimum 150 mm overlap and both ends securely fastened to the post;
- The trench should be backfilled with 20 mm minimum diameter washed gravel or compacted native material;
- The ends of the filter fence should be turned uphill to prevent stormwater from flowing around the fence; and
- Designers should provide an undisturbed or stabilized outlet suitable for sheet flow.

12.4.4.2 Check Dams

(a) Description

A check dam (Figure 12.13) is a small temporary dam constructed across a diversion channel or swale. Check dams reduce the velocity of concentrated stormwater flows, thereby reducing erosion of the diversion channel or swale and promoting sedimentation behind the dam. Small barriers consisting of rocks or earth berms are suitable as for check dams. Many commercial products such as gabions and sand bags can also be used effectively as check dams.

Check dams are primarily used in small channels in steep terrain where velocities exceed 0.6 m/s. This BMP acts to prevent erosion by reducing the velocity of channel flow in small intermittent channels and temporary swales. In areas with high velocity, deep sump may be provided immediately upstream of the check dam to capture excessive sediment. Check dams are not to be used as a stand-alone substitute for other sediment control BMPs simply because trapping efficiency in check dams are relatively low, and high flows could potentially re-suspend settled sediment. Maintenance is therefore required to remove trapped sediment and to check for structural stability on regular basis. Check dams should only be placed in small open channels, and never on a flowing river or natural stream.

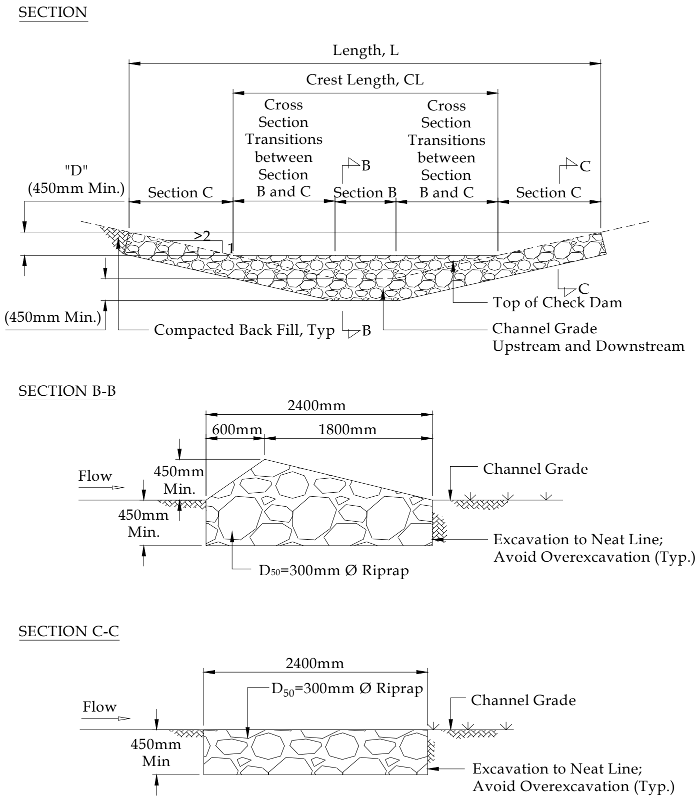


Figure 12.13: Check Dams

(b) Design Criteria

Table 12.14: Design Criteria of Check Dam

Parameter	Requirement
Design Storm	2-year ARI, unless specified otherwise by Authorities
Overspill	All flow greater than 2 year ARI shall safely bypass the crossing
Flood Protection	Ensure upstream/ downstream flooding condition not aggravated
Dimension	• Height (centre) of dam shall not exceed 1 m • For rock check dam: - Upstream slope: 2(H):1(V) or flatter - Downstream slope: 4(H):1(V) or flatter • Centres of the dam shall be notched to centre to promote concentrated flow (approx. 0.15 m) • Outer sides of dam shall be at least 0.5 m higher than centre to avoid undermining • Spill crest shall be of at least 100 mm in width parallel to flow
Intervals	A series of check dams can be placed such that the height of each subsequent check dam must be equal or lower than the base of the check dam before it
Geotextile	Check dam with height more than 450 mm shall be laid with geotextile to avoid seepage and structural failure
Scour Protection	• Structure shall withstand the shear force induced by a 2-year ARI flow. Materials (rocks, earth, and gabion) must be selected to meet this requirement • Additional scour protection downstream of check dam shall be provided if deemed necessary

12.4.4.3 Sediment Traps

(a) Description

A sediment trap is a small temporary ponding area, usually with a gravel outlet, formed by excavation and construction of an earthen embankment (Figure 12.14). The purpose of the trap is to detain runoff from disturbed areas for a long enough period of time to allow majority of the coarser suspended soil particles in the runoff to settle out. It is intended for use on small catchments (2 ha) areas with no complex drainage features, where construction will be completed in a reasonably short period of time.

This practice is one of the most efficient and cost effective methods of sediment control. When possible, sediment traps should be constructed as a first step in any land-disturbing activity. Sediment trap should never be location on-stream. In areas near to public, safety fence should be provided. It should be noted that since sediment traps are only effective in trapping coarse sediment, a chemical binder or coagulant may be required for fine particle trapping. The sediment trap requires monitoring during each storm event. It should drain within 36 hours after a storm event, failing which, mechanical dewatering is required. Regular maintenance should include sediment removal (after sediment is 300 mm thick), as well as structural and outlet protection inspection.

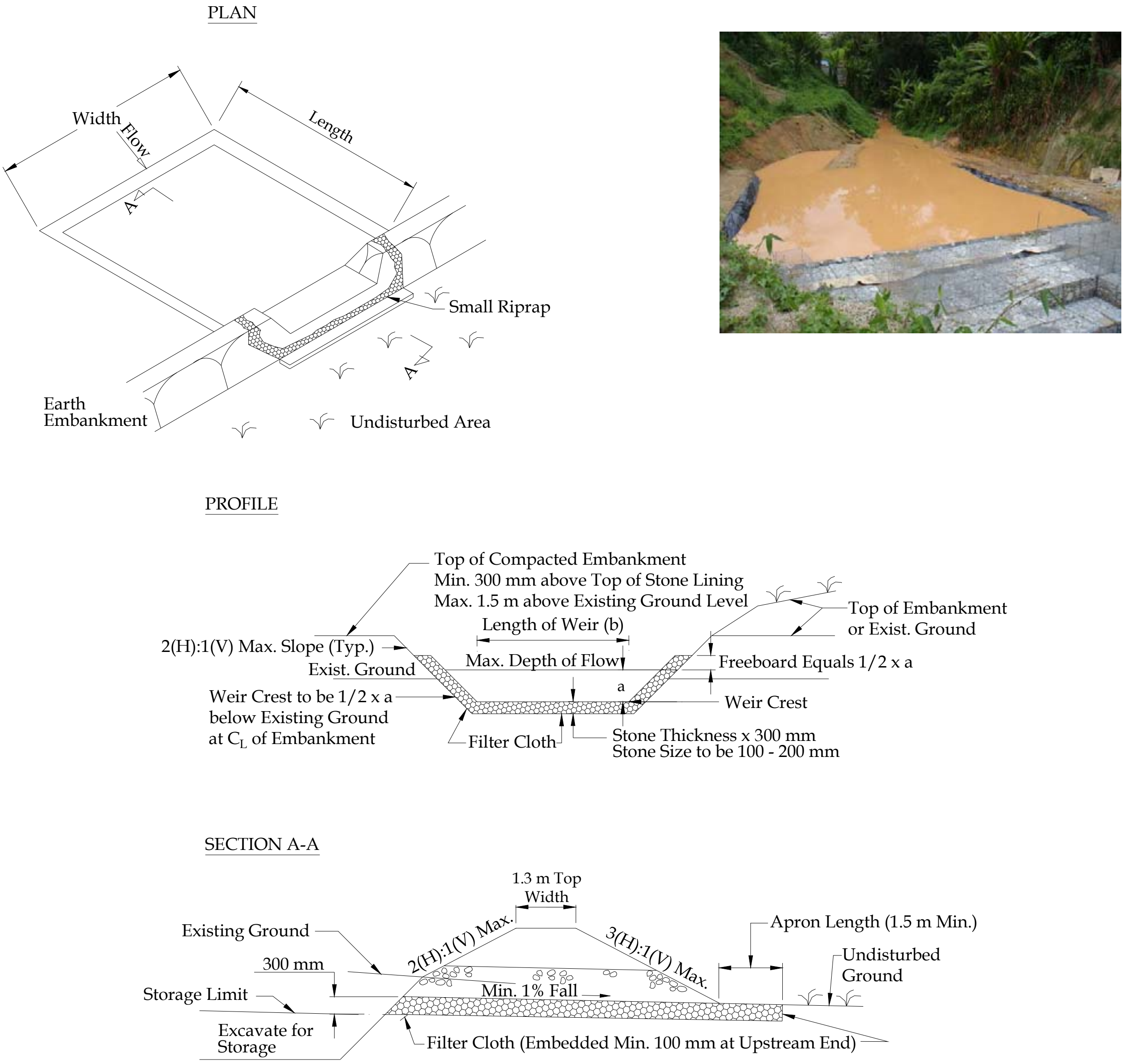


Figure 12.14: Example of a Sediment Trap

(b) Design Criteria

Table 12.15: Design Criteria of Sediment Traps for Sediment Control

Parameter	Requirement
Runoff Quantity Design	Up to 10-year ARI
Runoff Quality Design	First 50 mm rainfall over contributing (equivalent impervious) catchment
Overspill	All flow up to 10-year ARI shall safely bypass the trap
Runoff Retention	All flow up to runoff quality design flow shall be retained within basin. Extended drawdown can be permitted by authority when deem necessary.
Flood Protection	Ensure upstream/ downstream flooding condition not aggravated
Maximum Contributing Area	2 ha
Storage Volume	• Total Storage: 125 m^3/ ha of contributing area • Permanent Pool: half of total storage
Basin Dimension	• Minimum length to width ratio: 2:1 • Minimum depth of 1 m • Depths exceeding 2 m are not recommended. In unavoidable circumstances, provide perimeter fencing for safety
Embankment	• Inside embankment: 2(H):1(V) or flatter • Outside embankment: (3(H):1(V) or flatter • Maximum embankment height should not exceed 1.5 m
Lining Materials	Suitable size rocks or rip rap
Erosion Protection	Outlet protection shall be provided for the emergency spillway

(c) Installation and Application Criteria

- Traps should be located where sediment can be easily removed (Access roads are to be provided if required).
- The outlet of the trap must be stabilised with rock, vegetation, or another suitable material.
- The fill material for the embankment must be free of roots and other woody vegetation as well as oversized stones, rocks, organic material, or other objectionable matter. The embankment may be compacted with suitable equipment during construction.
- The spillway installation is critical to prevent failure of the structure during high flows and all specifications provided by the designer must be implemented.

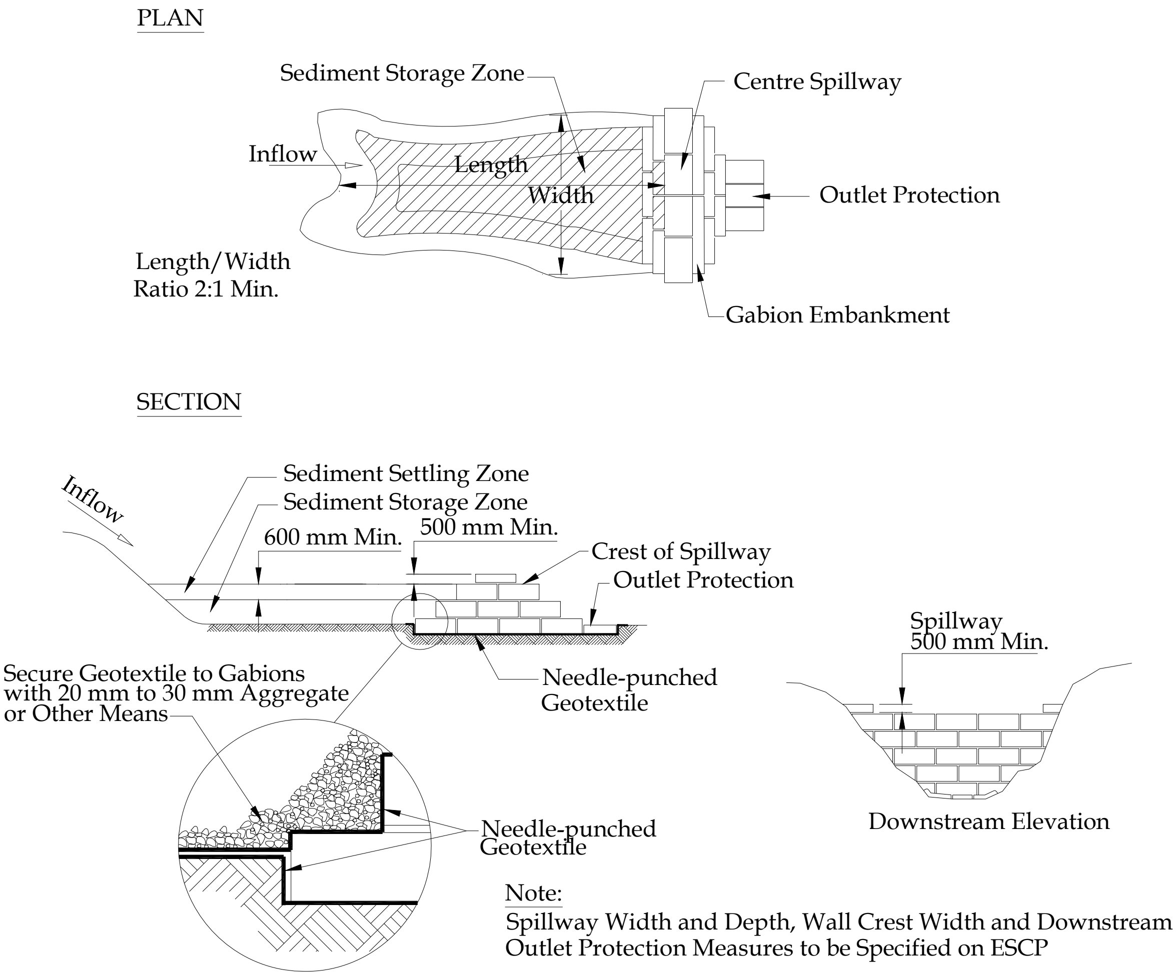
12.4.4.4 Sediment Basins

(a) Description

A sediment basin (Figure 12.15) typically consists of an impoundment, a dam, a riser pipe outlet, and an emergency spillway. It functions in the same way as a sediment trap but caters to a larger catchment. The basin is a temporary measure (with a design life of 12 to 18 months) and is to be maintained until the site area is permanently protected against erosion or a permanent detention basin or water quality control structure is constructed.

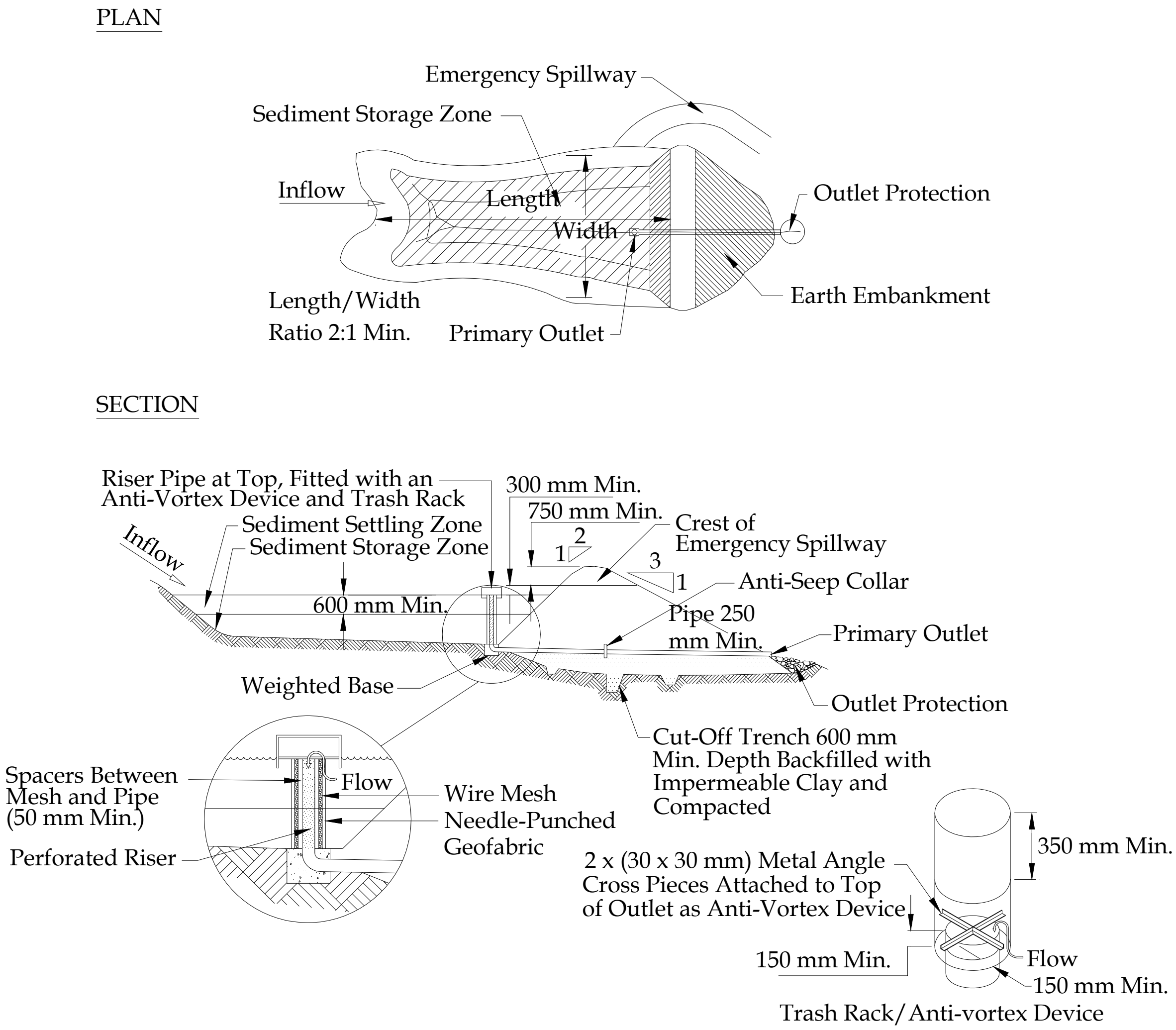
Sediment basins are suitable for nearly all types of construction projects. Wherever possible, they should be constructed before land clearing and grading work begins. The type of basin is to be determined using Table 12.16 below. The basin must not be located in a stream or natural waterway but should be located to trap sediment-laden runoff before it enters any stream. It is a common and encouraged practice to locate this structure at the location where permanent stormwater BMPs (mostly ponds) will be located. Like a sediment trap, sediment basin may pose a safety hazard and should be properly fenced if required by the local regulatory authority. Large sediment basins (dams higher than 3 m) shall be subject to Federal and/or State dam safety criteria.

Maintenance of sediment basins is similar to sediment trap maintenance. Removal of accumulated sediment should be carried out once the sediment storage zone is full. The basin must be able to drain in 36 hours of a rain event, failing which, mechanical dewatering is required. Regular inspections are to be carried out to ensure structural stability and functionality of the inlet, outlet and outlet protection works. If the basin is located at the final discharge point from site, periodic water quality samples shall be collected and tested for total suspended solids (TSS) and turbidity to comply with DOE water quality regulations.



a) Outlet Control-Gabion Spillway

Figure 12.15: Sediment Basins



b) Outlet Control-Riser

Figure 12.15: Sediment Basins (cont'd)

Table 12.16: Sediment Basin Types and Design Considerations

Category	Soil Description	Hydrological Soil Group	Basin Type	Design Considerations
I	Coarse-grained sand, sandy loam: less than 33% <0.02 mm	A	Dry	Settling velocity, sediment storage
II	Fine-grained loam, clay: more than 33% < 0.02 mm	B	Wet	Storm impoundment, sediment storage
III	Dispersible fine-grained clays: more than 10% of dispersible material	C, D	Wet	Storm impoundment, sediment storage, assisted flocculation

(b) Design Criteria

Table 12.17: Design Criteria of Sediment Basin for Sediment Control

Parameter	Requirement
Basin Type	Refer Table 12.16
Runoff Quantity Design	Up to 10-year ARI
Runoff Quality Design	First 50 mm rainfall over contributing (equivalent impervious) catchment
Runoff Control	• All flow up to runoff quality design shall be retained within the trap • The basin should drain within 24 hours (dry)/ 36 hours (wet) after the water quality design storm. • The primary outlet/riser should be used to control stormwater runoff. • The Emergency spillway should safely conveying flows up to 10-year ARI
Flood Protection	Ensure that upstream/ downstream flooding conditions do not aggravate possible failure of the embankment.
Minimum Contributing Area	2 ha
Storage Volume	Total Storage: Refer Table 12.18 (dry) or Table 12.19 (wet) Settling zone volume: half of total storage Sediment zone volume: half of total storage
Basin Dimension	• Minimum length to width ratio: 2:1 • Maximum length to settling depth ratio: 200:1 • Minimum settling zone depth: 0.6 m • Minimum sediment storage zone depth: 0.3 m
Embankment	Side slope: (2(H):1(V) or flatter
Erosion Protection	Outlet protection shall be provided for the emergency spillway
Sediment Trapping	90% of Total Suspended Solids Removal
Maintenance Frequency	Determined by dividing sediment storage capacity by the amount of sediment collected in a water quality design storm

Table 12.18: Dry Sediment Basin Sizing Criteria

Parameter	Time of Concentration of Basin Catchment (minutes)				
	10	20	30	45	60
Surface Area (m^2/ha)	333	250	200	158	121
Total Volume (m^3/ha)	400	300	240	190	145

Table 12.19: Wet Sediment Basin Sizing Volume (m^3/ha)

Parameter	Site Runoff Potential	Magnitude of Design Storm Event (mm)				
		20	30	40	50	60
Settling Zone Volume	Moderate to high runoff	70	127	200	290	380
	Very high runoff	100	167	260	340	440
Total Volume	Moderate to high runoff	105	190	300	435	570
	Very high runoff	150	250	390	510	660

(c) Installation and Application Criteria

- Sediment basins must be installed entirely within the limits of the site.
- Basins must be constructed before clearing and grading work on the overall site begins.

- Basins must not be located in a stream.
- All basins should be located where failure of the embankment would not result in loss of life, damage to homes or buildings, or interruption of use or service of public roads or utilities.
- Local ordinances regarding health and safety must be adhered to.
- Large basins may be subject to State and/or Federal dam safety requirements.
- Sediment basins are attractive to children and can be very dangerous. Adequate safety precautions must be provided by restricting access to the site or to the basin with suitable fencing.
- Contractor shall securely anchor the outlet pipe and riser, and install anti-seep collars on the outlet pipe.
- Sediment basins may be capable of trapping smaller sediment particles if sufficient detention time is provided. However, they are most effective when used in conjunction with other BMPs to minimise the amount of sediment mobilised and carried to the basin.

12.5 PREPARATION OF EROSION AND SEDIMENT CONTROL PLAN (ESCP)

The ESCP is to be prepared by a qualified consultant to manage erosion and sediment processes during the phases of earthworks and subsequent construction. The ESCP is literally the master plan for construction site management in terms of erosion, runoff and sedimentation control.

In this section, the general requirements, the generic principles governing ESCPs, plan preparation stages, the content of ESCPs, and the performance evaluation stages are laid out..

12.5.1 General Requirements of ESCPs

ESCPs must be submitted to local regulatory authority for developments that involve an area of more than 1 ha. However, ESCPs can be requested by local regulatory authorities for any development sites (including those less than 1 ha) as a supporting plan, as empowered by the Street, Drainage, and Building Act (1974).

In order to obtain the permit so that scheduled work can be started on time, it is suggested that the ESCP should be submitted to related local regulatory authority at least 2 months in advance, or a longer period according to the requirements of local regulatory authority. Approval for ESCPs must be obtained from related local regulatory authority at least 14 calendar days before the beginning of construction activity.

Water quality design criteria for all temporary BMPs is to control the first 50 mm of rainfall from the contributing (equivalent impervious) catchment.

12.5.2 Content of an ESCP

A complete ESCP consisting of 3 major components, i.e., report, site plans and engineering drawings, as well as an inspection and maintenance plan, shall be submitted as one document for evaluation by the relevant authorities for approval. The report will describe the preparation of the ESCP including the concept, assessment, and design. Plans and drawings provide visual interpretation of the ESCP, and the inspection and maintenance plan outlines the steps required to implement the ESCP during site development.

12.5.2.1 Report

(a) Site Description

A written report shall be prepared to describe the site, especially the location, climate, topology and current land use. Information gathered through site investigations, consultation with local regulatory authorities or any reliable source shall be furnished in this report. The report shall provide a clear picture of the existing site condition. The proposed development shall also be narrated herein. Details on size of development, the purpose and proposed layout shall be included.

The planner shall also illustrate how the ESCP is planned to convert the development from the existing site condition. Items below provide some important points that shall be included. Local regulatory authorities may request other information to facilitate in evaluation process. If more than one phase of activity is planned, a description of the following items must be provided for each phase of major earthworks (bulk grading).

- Earthwork phases;
- Securing of site perimeter;
- Access points and traffic control;
- Management of stockpiles;
- Slope stabilisation;
- Erosion control measures;
- Runoff management on site;
- Sediment control measures; and
- General inspection and maintenance planning.

(b) Site Assessments

The ESCP planner shall carry out assessments to evaluate the site while planning the ESCP. The assessment shall be presented as part of the submission to the local regulatory authority. The methodology used and results of assessment shall be presented to facilitate evaluation of the ESCP. Two assessments are required, i.e. hydrological & hydraulic assessment, and soil loss assessment.

(i) Hydrological & Hydraulic Assessment Tasks

- The planner (or designer) shall perform hydrological and hydraulic assessments for pre-construction, during construction, and post-construction conditions at the site.
- If earthworks are planned in phases, during construction conditions shall include individual assessment of site conditions for each phase of earthworks.
- The assessment shall be performed to examine the required design storm criteria mentioned below, or as instructed by plan evaluator.

(ii) Soil Loss Assessment

- Perform soil loss assessment using USLE model (or any approved method agreed by evaluator) to assess the soil loss conditions for the site. The assessment shall prove that soil loss is adequately controlled with implementation of ESCP. The assessment shall account for soil loss estimation during pre-development, during construction (with and without ESCP) and post construction conditions.
- Each earthwork and/or construction phase shall be considered separately.
- Assessment shall be provided for each design points, as determined by the site condition.

(c) Engineering Design and Calculation

While most erosion control BMPs can be applied without design, other ESC BMPs components (i.e. runoff management BMPs, sediment control BMPs, and slope protection structures) must be provided with design calculation to justify their application. The design must state clearly the dimensions and location of the facilities. Calculations must prove that the proposed facilities will be able to serve the site in accordance to standard design procedures.

(d) Other Supporting Documents

The ESCP report shall be furnished with the following documents to facilitate plan evaluation by the relevant authorities (DID, 2010).

- Bill of Quantities (BQ); and
- Specification/ Installation Instruction of materials/ commercial product proposed.

The BQ should be prepared such that each individual ESC facility is billed independently. This is to ensure all proposed facilities are included in budget and that contractors shall have no construction/ maintenance/ financial constrain in carrying out the ESCP.

12.5.2.2 Site Plans & Engineering Drawings

Site Plans are simple illustrations of the project site, showing key physical ESC-related features including levels, slopes, ESC facilities, site management (access roads) etc. Site plans shall provide a clear impression and interpretation of all ESC controls designed for the site. Essentially, site plans shall be provided for 2 stages, i.e. pre-bulk grading and post bulk grading. Engineering drawings shall be prepared for all ESC BMPs proposed. Standard symbols/legend for indication of ESC BMPs as given in Appendix 12.A shall be followed.

(a) Pre-Bulk Grading Site Plan

The pre-bulk grading site plan shall clearly portray the existing land condition and the planned grading activity to transform the terrain into the final development levels. This shall include the following information:

- Pre development topology – drainage pattern, contour, and catchment delineation;
- Areas (with quantity) in which grading (cut & fill) will be performed;
- Specify grading phasing;
- Specify stockpile management (location, protection etc);
- Perimeter controls including buffer, hoarding and site perimeter drains;
- Delineate new catchment area based on graded topology (to be used for ESC facilities design);
- Identify and delineate waterway buffers; and
- Specify ESC facilities (size, location etc) to be implemented at this stage.

(b) Post-Bulk Grading Site Plan

The pre-bulk grading site plan shall clearly portray actual construction site condition after the major earth work or grading is completed. The plan shall essentially show the ESC practices to be implemented, which includes:

- The graded contour (topology after major earthworks);
- Project development phasing;
- Proposed drainage patters and catchment delineation; and
- Specify ESC facilities (size, location etc) to be implemented at this stage.

(c) Engineering Drawings

Engineering drawing shall be prepared for all ESC facilities selected for the site. This shall consists but not limited to,

- Typical engineering drawings for erosion control facilities such as erosion blanket;
- Detailed engineering drawings for temporary and permanent (if the permanent components are used as ESC facilities) runoff management facilities such as diversion drain and swales;
- Detailed engineering drawings for sediment control facilities such as check dams and sediment basin; and
- Detailed engineering drawings for slope stabilization such as terracing and retaining wall.

12.5.2.3 Inspection and Maintenance Plan

Every BMP installed on a construction site must be checked periodically and maintained sufficiently to ensure proper performance. An Inspection and Maintenance Plan should be prepared and implemented. The purpose of the plan is to;

- Clearly specify personnel assigned/responsible for BMP inspection and maintenance;
- Determine maintenance requirements of any BMP and subsequently present regular maintenance schedule; and
- Determine and present methods/ procedures/ checklist/ record logs to be used for in-house BMPs inspections.

The plan shall provide the following details in regards of inspection and maintenance:

- *Schedule for Inspection and Maintenance* – a Gantt Chart indicating the scheduled date for regular inspection and expected facilities maintenance. Major maintenance such as servicing of sediment basin, must be included.
- *State responsibility of stakeholders* – a list of contacts to summarise person (or party) in charge of all ESCP aspects (from design, construction, maintenance, inspection, and operation).
- *Record Keeping* – The database used in record keeping shall be specified. Methods used to store engineering drawings, ESCP plans, inspection results & maintenance log etc, shall be clearly stated. If applicable, example of templates can be provided.

12.5.3 ESCP Preparation Stages

The ESCP must be prepared before construction begins, ideally during the project planning and design stages. It may be completed at the end of the design stage or early in the construction stage, as shown in Figure 12.16. Implementation of the ESCP begins when construction begins, typically before the initial clearing and grading operations since these activities usually increase erosion potential on the site. During construction, the ESCP should be referred to frequently and refined by the consultant and contractor as changes occur in construction operations, which have significant effects on the potential of pollutants discharge.

The ESCP may be very dynamic for large, complicated projects to be constructed in multiple stages over a long period of time. Planning, design, and construction of these projects may be occurring simultaneously. In such cases, it may be useful to prepare the ESCP in sections, with each section covering a stage or portion of the project and an overview section generally discussing the entire project.

The following sections give guidance on how to incorporate ESCP preparation into the planning, design, and construction stages of a project.

12.5.3.1 Planning Phase

The planning phase is the source of most information needed for the ESCP. Conceptual and preliminary erosion and sediment control planning is also made at this phase via the normal review process with the local regulatory authority. Four activities which occur during planning that are important to the preparation of an ESCP are as follows:

- Assessing site conditions;
- Developing a base plan(s);
- Selecting post-construction measures; and
- Establishing long-term maintenance agreements.

ESCP preparation begins as early as planning phase of a development. Once the basic site condition is ascertained (i.e. topology, hydrology, development layout etc), erosion risk assessment can be carried out as the first step of ESCP preparation. The objective of the assessment is to determine the existing erosion risk and how the risk will be affected by the development. The additional information on erosion and hydrology from assessments will then allow Engineer to select and plan the post-construction (permanent) stormwater BMPs. In the process, a maintenance agreement shall be established at this stage regarding to the party in-charge of post-construction operation and maintenance of the selected BMPs

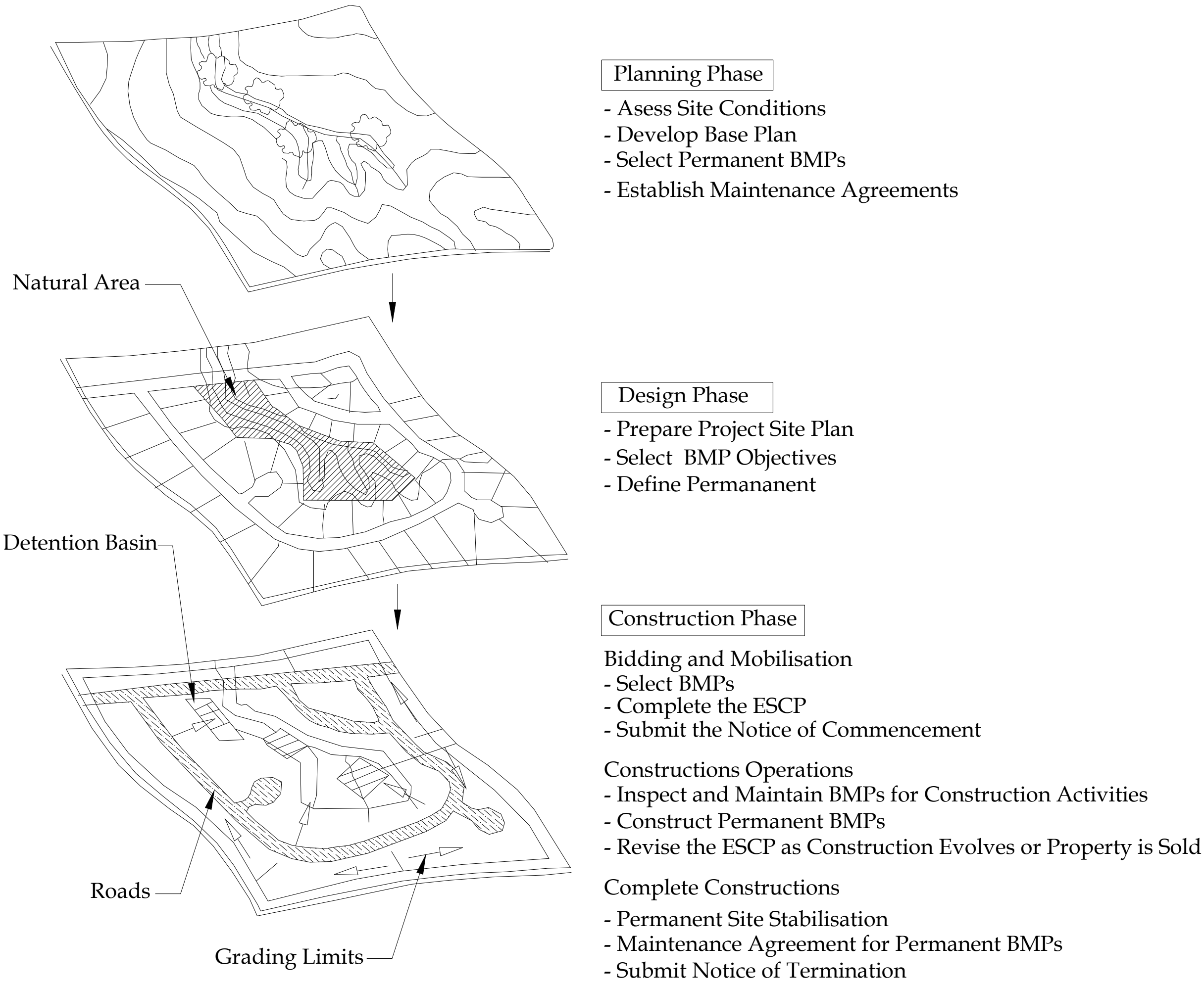


Figure 12.16: Plan Preparation Stages for ESCP (CDM, 1993)

12.5.3.2 Design Phase

There are three principal activities that are typically incorporated into the ESCP during the design phase, i.e. Preparation of Site Plan, Define Objectives for Control Measures, and Designing Permanent Control Measures. During the preparation of site plan, numerous studies will be produced to provide information for detailed design of the development. The site plan will then contain final information on drainage, grading, structural and landscape layouts. Hence the plan forms the foundation for ESCP planning. Based on the grading plan, proper earthwork and construction phasing can be planned, while the drainage and landscape plan will aid in selection and placing of temporary ESC BMPs.

During the final project design process, the consultant will prepare detailed grading plans, paving and drainage plans, landscape plans, and other plans as necessary for the successful construction of the project. These plans provide the construction design requirements, specifications, and other construction documents necessary for the construction bidding, permitting, and inspection. For the ESCP to be compatible with the other engineering plans, the most practical process may be for the consultant to develop BMPs objectives for the construction period based on contractor activities and the grading and drainage plans for the site.

This step can occur as part of the preparation of the grading and drainage plan and be included in the bid package and/or construction documents for consideration of the potential contractors. This allows the developer to explicitly address unique site conditions, which may affect the stormwater pollution control during construction. Alternatively, the developer could require the contractor to prepare such a plan to justify the selection of BMPs.

12.5.3.3 Construction Phase

ESCP is heavily involved in construction phase of a development. This involvement can be further divided into bidding and mobilization stage, construction operation stage, and construction completion stage. During bidding and mobilization, ESCP plan should be completed with erosion and sediment control for each development phases being properly laid out. Contractor(s) selected by developer should be able to initiate construction activity. Physical setup for ESCP implementation including BMPs construction, record keeping system, and personnel training should take place as soon as development starts.

During construction operation, the developer should ensure that the selected contractor is responsible for implementing the BMPs according to the ESCP. Because site conditions will inevitably vary during construction, the ESCP should be revised as necessary, with any changes highlighted on the ESCP copy maintained at the construction site. The inspection and maintenance plan (part of ESCP) will play a major role in ensuring all BMPs are implemented as planned and that the overall ESCP is servicing the development at a satisfactory level throughout the entire project.

Upon completion of construction, it is the responsibility of the developer and contractor to ensure that:

(a) All treatment techniques or structures that are no longer required are removed using method approved by authorities;

(b) Sediment and other unwanted materials are disposed off in an approved manner;

(c) Slopes, embankments, vegetation and planting areas have been properly established;

(d) Site access is returned to its original condition or approved final layout depending on site-specific circumstances;

(e) All permanent structures constructed to serve as part of ESCP are restored to its designed condition;

(f) All safety standards are conformed and that site is safe to be occupied;

(g) All drainage ways, pond areas, and reserves are properly gazetted in the final site plan; and

(h) Standard operation procedure (SOP) or maintenance plan for stormwater structures is produced whenever deemed necessary by authorities.

12.5.4 Performance Evaluation of ESCP

The final step in the preparation of an ESCP is to develop a program to monitor how well the BMPs work and to evaluate whether additional BMPs are required. To meet these objectives, ESCP implementer is required to conduct site inspection and monitoring, systematic record keeping and regular review and modification (if necessary) on the ESCP.

12.5.4.1 Site Inspection & Monitoring

An inspector should be identified and specified in the submitted ESCP. The inspector is responsible to plan for regular inspection, monitoring, and record keeping of the ESCP. This person shall provide any on-site details on the implementation and performance of ESCP to relevant authorities or participate in joint inspection with local regulatory authorities whenever required.

Site inspections should be carried out on two bases. Inspection should be carried out on a fixed interval (e.g. weekly, fortnight, monthly). On top of that, event-based inspection should be carried out before and after storm events.

Inspection shall gauge and monitor the performance of the components of ESCP, and should cover construction management as well as erosion and sediment control BMPs. For contractor activity BMPs, inspection would include:

- looking for evidence of spills and resulting clean-up procedures (e.g. supplies of spill cleanup material);
- examining the integrity of containment structures;
- verifying the use of employee education programmes for the various activities;
- noting the location of activity (e.g. outdoor vs. indoor, concrete vs. grass);
- verifying adequacy of trash receptacles; and
- verifying waste disposal practices (e.g. recycle vs. hazardous waste bins).

For sediment and erosion control BMPs, the monitoring program should consist of regular inspection to determine the following:

- Changes in drainage patterns. Ensure all runoff, i.e. disturbed or natural flows are well managed. Changes of drainage pattern due to earthwork must be accounted for in ESCP. In the event of drainage pattern change in unanticipated manner, appropriate modification on ESCP shall be performed to rectify situation;
- Installation of BMPs. Installation of BMPs shall be as per designed. Any site adjustment shall be referred back to the consultant for approval;
- Site stabilization. Inactive areas (no activity for more than 30 days) must be stabilized with erosion control BMPs or structural method within 7 days;
- Effectiveness of BMPs. Indicators of underperformed BMPs include structural failure, sediment outside of control area, formation of rills and gullies, runoff overspill (flash flood), murky site discharge, etc.; and
- Maintenance of BMPs. All BMPs required to be serviced in accordance to design specification. Routine maintenance shall include vegetation watering, replacement of protection materials (vegetation, silt fence, rip rap etc), structural repair, and sediment removal from sediment control BMPs.

12.5.4.2 Record Keeping

- Results of the inspection shall be recorded in the site inspection checklist form and in inspection log book. Particulars such as date of the inspection, the inspectors and important results or observations must be included. Significant changes such as additional BMPs, change in capacity/structure, location etc, shall also be involved.
- All records are to be retained for at least 3 years by the developer.
- It is suggested that details of incidents such as spills or BMPs failures (flood, structural collapse or drain clogging) be kept. This information can be particularly useful during review of BMPs.
- Photographs may be useful and powerful description of incidents and proof.

12.5.4.3 Plan Review and Modification

During the course of construction, unexpected schedule changes, phasing changes, staging area modifications, off-site drainage impacts, and repeated failures of designed controls may affect the implementation and performance of ESCP. These changes must be made known and the ESCP revised accordingly. During the preparation and review of the modified ESCP, construction may continue with temporary modifications to the erosion and sediment control BMPs. Revisions to the ESCP are also required when the properly installed systems are ineffective in preventing silt transport off the site. Modifications to the ESCP shall be carried out by qualified engineers, preferably the same party which design the ESCP initially.

REFERENCES

1. Ayad, M.H.A.Q. (2003). Soil *Erosion Risk Prediction with RS and GIS for the Northwestern Part of Hebei Province, China.* Pakistan Journal of Applied Sciences. Vol. 3 (10-12).

2. Camp Dresser & Mckee (1993). *California Stormwater Best Management Practice Handbooks*. Prepared for Stormwater Quality Task Force, California State Water Resources Control Board and American Public Works Association, USA.

3. Chen, CN (1990). *Methodology for Erosion Control in Urbanising Watersheds*, Proceedings Urban Planning and Stormwater Management, UTM Press Johor Bahru, Malaysia.

4. Department of Environment or DOE (1996). *Guidelines for Prevention and Control of Soil Erosion and Siltation in Malaysia* Ministry of Science, Technology and Environment. Malaysia.

5. Department of Irrigation and Drainage or DID (2000). *Urban Stormwater Management Manual for Malaysia* Ministry of Natural Resources and Environment, Malaysia.

6. DID (2010). *Guideline for Erosion and Sediment Control in Malaysia.* Ministry of Natural Resources and Environment Malaysia.

7. Erosion Control Technology Council or ECTC (2006). *Rolled Erosion Control Products Specification Chart* http://www.ectc.org/ECTC_RECP_Temporar.pdf

8. Gray, DH & Sotir, RB (1996). *Biotechnical and Soil Bioengineering Slope Stabilization*, John Wiley & Son, New York.

9. Fifield, J.S. (2004). *Designing for Effective Sediment and Erosion Control on Construction Sites* 2nd Eds. Forester Communications, Santa Barbara, California, USA.

10. Hudson, N. (1971). *Soil Conservation* Cornell University Press, Ithaca, New York.

11. Israelsen, C.E., C.G. Clyde, J.E. Fletcher, E.K. Israelsen, F.W. Haws, P.E. Packer and E.E. Farmer (1980). *Erosion control during highway construction, Manual on Principles and practices* National Cooperative Highway Research Program Report 221. Transportation Research Board, National Research Council, Washington, DC, USA

12. Kuenstler W (2009). *C factor: Cover-Management* www.techtransfer.osmre.gov/NTTMainSite/Library/hbmanual/rusle/chapter5.pdf

13. Layfield (2009). Erosion Management Factors.

    http://geomembranes.com/shared/resview.cfm?id=18&source=technotes

14. Md Nasir Md Noh (2006). *The storm water management manual for Malaysia (MSMA): A tool for soil and water conservation practice for agriculture area.* Proceedings 3rd Asian Regional Conference, PWTC, September 10-16.

15. Mitchell, J.K. and G.D. Bubenzer. (1980). *Soil loss estimation, soil erosion* (M.J. Kirby and R.P.C. Morgan, Eds.) John Wiley and Sons.

16. National Resources Conservation Service or NRCS (2005) *Part 614: Applying Soil Taxonomy* National Soil Survey Handbook, United States Department of Agriculture, Washington, DC, USA.

17. NRCS (2007) *Part 630: Hydrology* National Engineering Handbook, United States Department of Agriculture, Washington, DC, USA.

18. Ontario Centre for Soil Resource Evaluation (1993). *Field Manual for Describing Soils in Ontario* Ministry of Agriculture, Food and Rural Affairs, Ontario, Canada.

19. Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., and Yoder, D.C. (1997). *Predicting Soil Loss by Water: A Guide to Conservation Planning with the Revised Soil Loss Equation (RSULE)*. Handbook, Vol. 703. US Department of Agriculture, Washington, DC, USA.

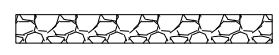
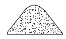
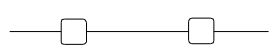
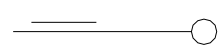
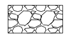
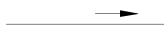
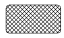
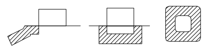
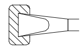
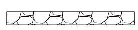
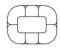
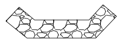
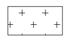
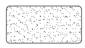
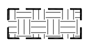
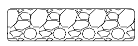
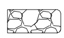
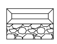
20. Tew, K.H. (1999). *Production of Malaysian Soil Erodibility Nomograph in Relation to Soil Erosion issues* VT Soil Erosion Research and Consultancy, Selangor, Malaysia

21. Troeh, F.R., Hobbs, J.A., Donahue, R.L. (1999). *Soil and Water Conservation for Productivity and Environmental Protection* 3rd Eds. Prentice Hall, New Jersey, USA.

22. Williams J.R. (1975). *Sediment routing for agricultural watersheds*. Water Resour. Bull. 11:965–974.

23. Wischmeier W.H., and Smith, D.D. (1978). *Predicting Rainfall Erosion Losses*. Agricultural Handbook 537. USDA, Washington, DC.

APPENDIX 12.A BMPs LEGEND AND PLAN SYMBOLS

Item	BMPs Names	Legend	Symbol
1	Check Dam	CD	
2	Compost Blanket	CB	
3	Compost Filter Berm	CFB	
4	Concrete Washout Area	CWA	
5	Construction Fence	CF	
6	Dewatering	DW	
7	Diversion Ditch	DD	
8	Drainage Outlet Protection	OP	
9	Earth Bank	EB	
10	Erosion Control Blanket	ECB	
11	Inlet Protection	IP	
12	Limits Of Construction	LOC	
13	Materials Storage Area	MSA	
14	RRB For Culvert Protection	RRC	
15	Reinforced Check Dam	RCD	
16	Reinforced Rock Berm	RRB	
17	Sand Bag Barrier	SBB	
18	Sediment Control Log	SCL	
19	Sediment Basin	SB	
20	Sediment Trap	ST	
21	Seeding And Mulching	SM	
22	Silt Fence	SF	
23	Stabilized Staging Area	SSA	
24	Stockpile Area	SPA	
25	Surface Roughening	SR	
26	Temporary Slope Drain	TSD	
27	Temporary Stream Crossing	TSC	
28	Terracing	TER	
29	Vehicle Tracking Control	VTC	
30	VTC With Wheel Wash	WW	

APPENDIX 12.B EXAMPLE – MODEL ESCP PREPARATION

Problem:

This example illustrates a proper ESCP Plan prepared for a agricultural land development in Cameron Highlands. The information from this example is repetitively used in the following examples to demonstrate engineering analysis and design for ESCP.

The proposed development on Lot 1587, Blue Valley, Cameron Highland is to transform the undeveloped into a high-tech hydroponic farm. The initial development covers over 28ha of steep terrain. The current example concentrate on one of the subdivided plot (Plot 1, hereafter referred to as the site) of the development, which only covers 2.74 ha of land. The challenge in this project is to transform the steep and undulating terrain into almost flat platforms to house the hydroponic greenhouse structures. In the final design, rainwater from the roofs of the greenhouses will be partially stored in underground on-site-detention tanks, and will be recycled for irrigation use.

Solution:

The ESCP must be prepared before construction begins, during the project planning and design phase. It was completed at the end of the design phase or early in the construction phase. In this project, once the final design platform, building footprint and infrastructures alignment are obtained, the design of earthwork and ESCP then took place.

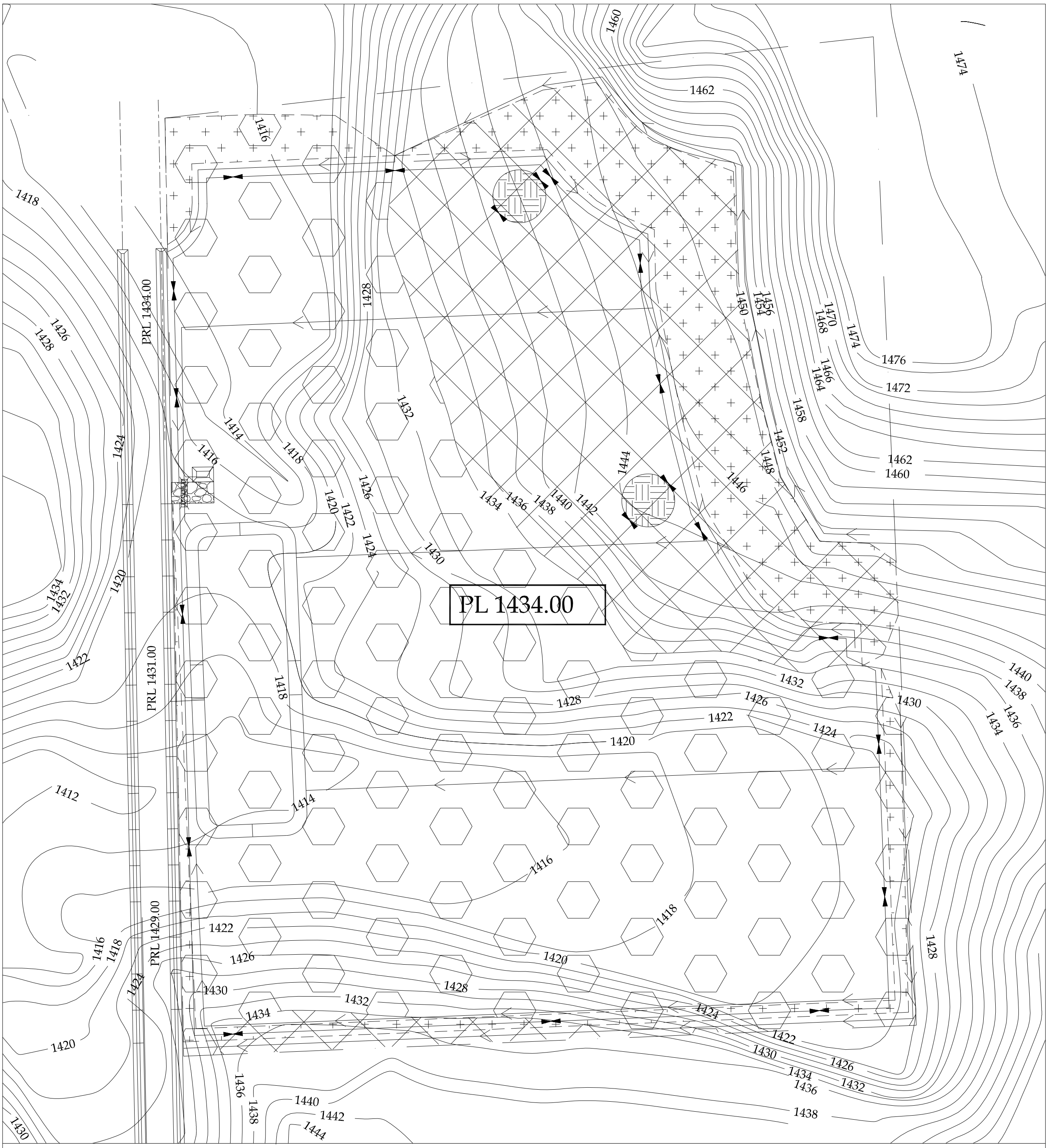
First, the erosion risk analysis is carried out to determine annual soil loss for existing and during construction condition at site. Then, preliminary ESC BMPs are tested to achieve required soil loss control on a site-scale basis. This assessment is presented in Appendix 12.C.

The ESCP prepared for the site is based on the 8 ESC principles given in this manual which include:

- Minimizing Soil Erosion – The north-eastern corner of the site consists of very steep slope, which is unsuitable for development. Therefore the area is being preserved as natural green. In order to further reduce erosion, earthwork is carried out in two phases. In the first phase, the proposed sediment basin is first constructed, together with the site access. Earthwork will progress by filling the access entrance, basin area advancing into the north-eastern area. Temporary diversion drains will be constructed as planned as earthwork progresses further into the site. The slope is trimmed and cut to desired terrace and platform level. As the first phase earthwork is completed and stabilized, second phase begins by continuing filling of the southern side of the site. Diversion drain is supplied to convey runoff from undisturbed land into the service drain, away from disturbed site. Additional diversion drain is constructed to convey runoff into sediment basin as required.
- Preserving Top Soil – Topsoil removed from site clearing are stockpiled and protected from erosion within the site for reuse in landscaping and erosion control turfing.
- Access Route – Access Route is provided near to the sediment basin. A fully paved (10m) access point is used as the only entry point to the site and is equipped with a washing bay.
- Drainage Control – Generally, runoff from undisturbed areas are diverted into service drain directly without additional treatment. Runoff from disturbed areas is collected by a diversion channel network which will be treated by sediment basin before being discharged into service drain.
- Erosion Control – Erosion control are provided via vegetation. At terraced slope, hydroseeding are provided. After earthwork is completed, areas not involved in construction are to be provided with close turfing.
- Sediment Prevention – Sediment control BMPs are provided via silt fence and sediment basin. The site perimeter is temporarily secured by using silt fence to avoid sediment leakage from site prior during earthwork. Runoff from the entire disturbed area is collected and treated by a wet sediment basin. Design of sediment basin is presented in Appendix 12.E.

- Slope Stabilization – All steep slopes in the site are provided with proper engineering stabilization. Terracing is provided for high slopes, with proper cut-off and cascade drains. All slope surfaces are protected with hydroseeding.
- Maintenance – The entire ESCP is designed with maintenance in mind. All structures are designed for minimal maintenance requirements. Detailed BMPs maintenance requirements and overall site maintenance are provided together with the ESCP report.

The final ESCP are presented in two layout plans, i.e. Pre-bulk Grading and Post-bulk Grading plans. In the pre-bulk grading plan (Figure 12.B1), the cut and fill areas are delineated, including areas to be preserved. In this plan, the temporary ESC BMPs to be implemented during the earthwork are presented. The post-bulk grading plan (Figure 12.B2) presents the ESC after major earthwork is completed. First of all the treated slope is converted into grassed terrace slope with proper cut-off and cascade drains. Runoff from this area are combined with flow from undisturbed areas and diverted away from site. The plan also include proposed building footprint of the development. Some runoff management structures such as culvert crossing are converted into permanent structures at this stage of development.



LEGEND

Note:
All Dimensions are in meters

Fill	Site Access Point with Wash Bay
Cut	Temporary Waterway Crossing
Silt Fence	Stockpile
Site Boundary	Sediment Basin
Diversion Channel (Disturbed Flow)	Terracing with Hydroseeding
Diversion Channel (Natural Flow)	

Figure 12.B1: Pre-Bulk Grading ESCP

LEGEND

Note:
All Dimensions are in meters

	Fill		Site Access Point with Wash Bay
	Cut		Temporary Waterway Crossing
	Silt Fence		Stockpile
	Site Boundary		Sediment Basin
	Diversion Channel (Disturbed Flow)		Terracing with Hydroseeding
	Diversion Channel (Natural Flow)		

Figure 12.B2: Post-Bulk Grading ESCP

APPENDIX 12.C EXAMPLE – SOIL LOSS ESTIMATION WITH USLE

Problem:

Using details from the development project mentioned in Appendix 12.B, a soil loss assessment is to be carried out to determine the erosion risk at site. The assessment shall examine erosion risk before development took place, during earthwork without control and during earthwork with control to justify effective BMPs selected for the site.

Solution:

<table>
<tr><th>Solution</th><th>Calculation</th><th>Output</th></tr>
<tr><td>

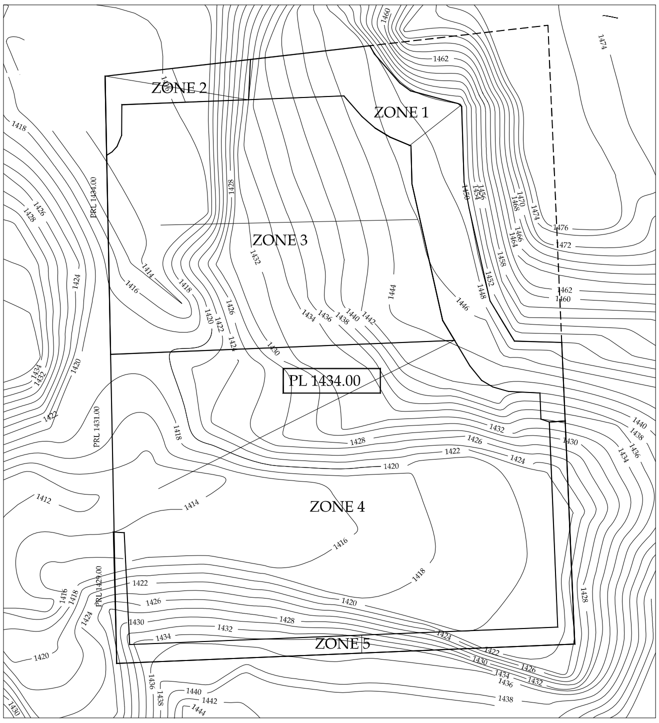
Figure 12.5

Equation 12.3

Table 12.2</td><td>
In order to provide better assessment of the various conditions at site, the site is divided into 5 zones, which are considered to be homogenous in terms of erosion risk. The zone delineations are given in Figure 12C.1. Universal Soil Loss Equation (USLE) will be used to assess the erosion risk of the site under three conditions, i.e. existing (undisturbed), disturbed and uncontrolled (no ESC), and disturbed but controlled (with ESC). The example below shows step by step guide to obtain necessary USLE parameters for the Zone 3 under existing condition. The procedures to obtain USLE parameters for other zones and development conditions are exactly the same as that shown in this example.
(1) Determination of Rainfall Erosivity, R Factor:
R factor for the area of Tanah Rata (Pahang) falls in the range of 15,000 to 17,500 MJ.mm/ha.hr.yr. For evaluation purpose, the higher limit is used, therefore,
R Factor = 17,500 MJ.mm/ha.hr.yr
(2) Determination of Soil Erodibility, K Factor :
In determining the K factor of the develop area, soil data obtained from hand auger method for the site is used. The soil samples are tested for grain analysis and the results are converted to 100% of sand, sit, clay and organic matter (excluding larger particles), as shown in Table 12C.1.
Table 12.C1: Summary of Laboratory Test Result of Soil Data
<table>
<tr><th rowspan="2">Hand Auger No.</th><th rowspan="2">Sample Number</th><th rowspan="2">Depth (m)</th><th colspan="3">Particle Size Distribution (%)</th></tr>
<tr><th>Clay</th><th>Silt</th><th>Sand</th></tr>
<tr><td>HA 1</td><td>A
B</td><td>0.5
1.0</td><td>12.83
15.94</td><td>35.99
42.11</td><td>51.19
41.95</td></tr>
</table>
<table>
<tr><th>Hand Auger No.</th><th>Sample Number</th><th>Structure Code (S)</th><th>Permeability Code (P)</th><th>K Factor</th></tr>
<tr><td>HA 1</td><td>A
B</td><td>2
2</td><td>3
3</td><td>0.0244
0.0266</td></tr>
</table>
For existing (undisturbed) condition, erosion took place on ground surface and hence the concerned soil layer is Sample A. For disturbed condition (uncontrolled and controlled), the site has been disturbed and hence Sample B (representing soil at 1m depth) is used, assuming earth work removed the top soil and exposed the lower soil layer. Therefore,
K Factor = 0.0244
</td><td>

R = 17,500 MJ.mm/ha.hr.yr

K = 0.0244</td></tr>
</table>

Reference	Calculation	Output
	(3) Determination of *LS* Factor: In order to obtained LS factor, the horizontal slope length (m) and slope steepness (%) needs to be determined through elevation information available on site. For existing condition, the contours from topographic maps or survey works can be used. For disturbed conditions, designed platform levels can be used. It is reminded that the assessment evaluate the average soil loss and hence, the determination of slope length and slope steepness shall not be based on most critical, but values that represents the average of the entire zone. Referring to Figure 12C.1 the length and slope for Zone 3 (existing condition) can be worked out as below,	
	 Figure 12.C1: Zone Delineation and Slope Length for Development Site	
	Horizontal slope length, λ = 105m	λ = 105m
	Slope steepness, s = (1446-1413)/105 x 100 = 31%	s = 31%
Table 12.3	Matching λ and s in Table 12.3, the value for LS factor can be obtained using linear interpolation. Therefore,	
	LS Factor = 19.7	*LS* = 19.7
Table 12.4	(4) Determination of *C* Factor: For existing condition, the entire site is covered with thick forest, and hence 100% forest coverage was selected. Therefore,	
	C Factor = 0.03	*C* = 0.03

Reference	Calculation	Output
Table 12.5	(5) Determination of CP Factor: For existing condition, no management support practice is provided (undisturbed site) and therefore, *P* Factor = 1.00	*P* = 1.00
Equation 12.1	(6) Determination of Soil Loss: Estimation of soil loss for Zone 3 can then be completed: *A* = 17,500 x 0.0244 x 19.7 x 0.03 x 1.00 = 252 tonne/ha/yr	*A* = 252 tonne/ha/yr

Using same procedure, the soil loss for other zones and development conditions can be determine, as shown in Table 12C.2. It can be observed that uncontrolled land disturbance can cause significant increase in erosion risk. Annual soil loss for Zone 1, 2 and 5 increase due to the increase in elevation factors where cut and fill has cause dramatic increment in elevation difference compared to existing condition. However, the ESCP provides corrective measures to mitigate the situation by providing terracing practise and hydroseeding. For Zone 3 and 4, soil loss are significantly reduced even in uncontrolled condition compared to exiting condition because of the flatten land for development. Eventually, the implementation of ESCP manages to minimise increment of soil loss to a satisfactory level.

Table 12.C2: Summary of Soil Loss Assessment for Development Site

Condition	Parameters	Zone				
		1	2	3	4	5
Existing	*R*	17,500	17,500	17,500	17,500	17,500
	K	0.0244	0.0244	0.0244	0.0244	0.0244
	LS	2.2836	16.6415	19.6936	14.9137	3.4415
	C	0.03	0.03	0.03	0.03	0.03
	P	1.00	1.00	1.00	1.00	1.00
	A (ton/ha/yr)	29	213	252	191	44
Earthwork-Uncontrolled	*R*	17,500	17,500	17,500	17,500	17,500
	K	0.0266	0.0266	0.0266	0.0266	0.0266
	LS	27.4147	50.6281	0.1224	0.1267	0.994
	C	1.00	1.00	1.00	1.00	1.00
	P	1.00	1.00	1.00	1.00	1.00
	A (ton/ha/yr)	12,762	23,567	57	59	463
Earthwork-Controlled	*R*	17,500	17,500	17,500	17,500	17,500
	K	0.0266	0.0266	0.0266	0.0266	0.0266
	LS	27.4147	50.6281	0.1224	0.1267	0.994
	C	0.05	0.05	1	1	0.05
	P	0.18	0.18	0.5	0.5	0.18
	A (ton/ha/yr)	115	212	28	29	4

APPENDIX 12.D EXAMPLE – SEDIMENT YIELD ESTIMATION

Problem:

The design of all sediment control BMPs requires the information on the quantity of sediment it is expected to trap. Therefore, determination of sediment yield for sediment basin catchment area is required for this site. The design rainfall is set to be 50mm as per requirement of this manual.

Solution:

Reference	Calculation	Output
	The catchment area for the proposed sediment basin includes Zone 1 (during pre-bulk grading only), Zone 3 and Zone 4. Therefore, the sediment yield from these 3 catchments should be determined for possible highest sediment yield condition, i.e. during the earthwork (pre-bulk grading plan). The Modified Universal Soil Loss Equation is used to determined the sediment yield for sediment basin.	
	1. Determination of Runoff Parameters	
	Runoff parameters required for sediment yield includes runoff peak discharge and runoff volume. Both parameters, however requires the knowledge of design rainfall.	
	(a) Design storm:	
	Zone 3:	
	Design Storm = 50 mm	
	Catchment Area, A = 1.84 ha	
Table 1.3	Time of Concentration, t_c = 20 minutes	
	Duration of storm, D = 60 minutes(Assume 1hour)	
Section 2.2.2	Intensity of design storm, I = 50 mm/h	
	Zone 4:	
	Design Storm = 50 mm	
	Catchment Area, A = 1.27 ha	
Table 1.3	Time of Concentration, t_c = 25 minutes	
	Duration of storm, D = 60 minutes(Assume 1 hour)	
Section 2.2.2	Intensity of design storm, I = 50 mm/h	
	(b) Calculate Peak Discharge:	
	Zone 3:	
	Rational Method	
Section 2.3.1	Runoff Coefficient, C = 0.50 (Bare soil)	
Table 2.6	Intensity of design storm, I = 50 mm/h	
	Catchment Area, A = 1.84 ha	
	$Q_p = C \times I \times A/360 = (0.5 \times 50 \times 1.84)/360 = 0.128\ m^3/s$	*Zone 3:* Q_p =0.128m^3/s
	Zone 4:	
	Rational Method	
Section 2.3.1	Runoff Coefficient, C = 0.50 (Bare soil)	
Table 2.6	Intensity of design storm, I = 50 mm/h	
	Catchment Area, A = 1.27 ha	

Reference	Calculation	Output
	$Q_p = C \times I \times A/360 = (0.5 \times 50 \times 1.27)/360 = 0.088 m^3/s$	*Zone 4:* $Q_p = 0.088 m^3/s$
	(c) Calculate Runoff Volume:	
Section 2.3.2	*Zone 3:* Rational Method Hydrograph Method (Type 2) Time of Concentration, t_c = 20 min Peak Discharge, Q_p = $0.128 m^3/s$	
	Therefore, $V = 0.5 \times (2 \times T_c) \times (Q_p)$ (Area below hydrograph) $= 0.5 \times (2 \times 20 \times 60) \times (0.128)$ $= 153.6 m^3$	*Zone 3:* $V = 153.6 m^3$
Section 2.3.2	*Zone 4:* Rational Method Hydrograph Method (Type 2) Time of Concentration, t_c = 25 min Peak Discharge, Q_p = $0.088 m^3/s$	
	Therefore, $V = 0.5 \times (2 \times t_c) \times (Q_p)$ (Area below hydrograph) $= 0.5 \times (2 \times 25 \times 60) \times (0.088)$ $= 132.0 m^3$	*Zone 4:* $V = 132.0 m^3$
	2. <u>Calculation of Sediment Yield</u> In this case, the value of *K*, *LS*, *C*, and *P* factors are assumed the same as those used for soil loss estimation for disturbed (uncontrolled) condition. Using (MUSLE), the sediment yield can be calculated as shown below:	
Equation 12.4	(see table below)	

Zone	Runoff Volume, *V* (m^3)	Peak Discharge, Q_p (m^3/s)	*K* Factor	*LS* Factor	*C* Factor	*P* Factor	Sediment Yield, *Y* (tonne)
3	153.6	0.128	0.0266	5.3709	1.00	1.00	67.87
4	132.0	0.088	0.0266	0.1267	1.00	1.00	1.19
Total sediment yield to sediment basin							69.06

Note: LS for Zone 3 is taken as weighted average of LS factor for Zone 3 and Zone 1 shown previously,
where $LS = (LS_{zone3}(\lambda_{zone3}) + LS_{zone3}(\lambda_{zone3})) / (\lambda_{zone3} + \lambda_{zone3})$

Thus, the total sediment yield to sediment basin is: *Y* = 69.06 tonne (for the design storm)

Output: *Y* = 69.06 tonne

APPENDIX 12.E EXAMPLE – WET SEDIMENT BASIN

Problem:

Right after the final selection of BMPs is identified through soil loss assessment, the detailed design of the BMPs is to be carried out. The dimension and outlet sizing of the proposed sediment basin should be determined. Frequency of maintenance should also be estimated using available information.

Solution:

Reference	Calculation	Output
	The detailed design of the sediment basin is presented in this section. Detailed design of temporary crossing and diversion drains are similar to those of their permanent counter parts, as presented in other chapters of this manual and therefore are not shown here.	
	(1) Determination Type of soil:	
Table 12.16	According to Table 12.A1, the soil in the Plot 1 is loam. Hence, a wet sediment basin is chosen.	
	(2) Determination of Basin Dimension:	
Table 12.19	The required surface area is 340m²/ha and the required total volume is 510m³/ha (high runoff is selected due to bare soil condition). Figure 12.E1 illustrates the final dimensions of the sediment basin.	
	The surface area required for the site = 340 x 3.11 = 1,057.4m² (Note: this is the average surface area for the settling zone volume, i.e. at mid-depth)	Required Surface Area = 1057.4m²
	The total basin volume required for the site = 510 x 3.11 = 1,586.1m³	Required Volume = 1,586.1m³
	(a) Settling Zone:	
Table 12.17	The required settling zone, V_1 = 793.05m³ (half the total volume) and the selected settling zone depth, y_1 = 0.75m.	
	Try a settling zone average width, W_1 = 16m Required settling zone average length	
	$L_1 = \frac{V_1}{W_1 \times y_1} = \frac{793.05}{16 \times 0.75}$ = 66.09m , say 67m	
	Average surface area = 16 x 67 =	1,072m² > 1,057.4m² ; OK
	Check settling zone dimensions (Table 12.17: Basin Dimension):	
	$\frac{L_1}{y_1}$ ratio = $\frac{67}{0.75}$ =	89.33 < 200; OK
	$\frac{L_1}{W_1}$ ratio = $\frac{67}{16}$ =	4.19 > 2; OK

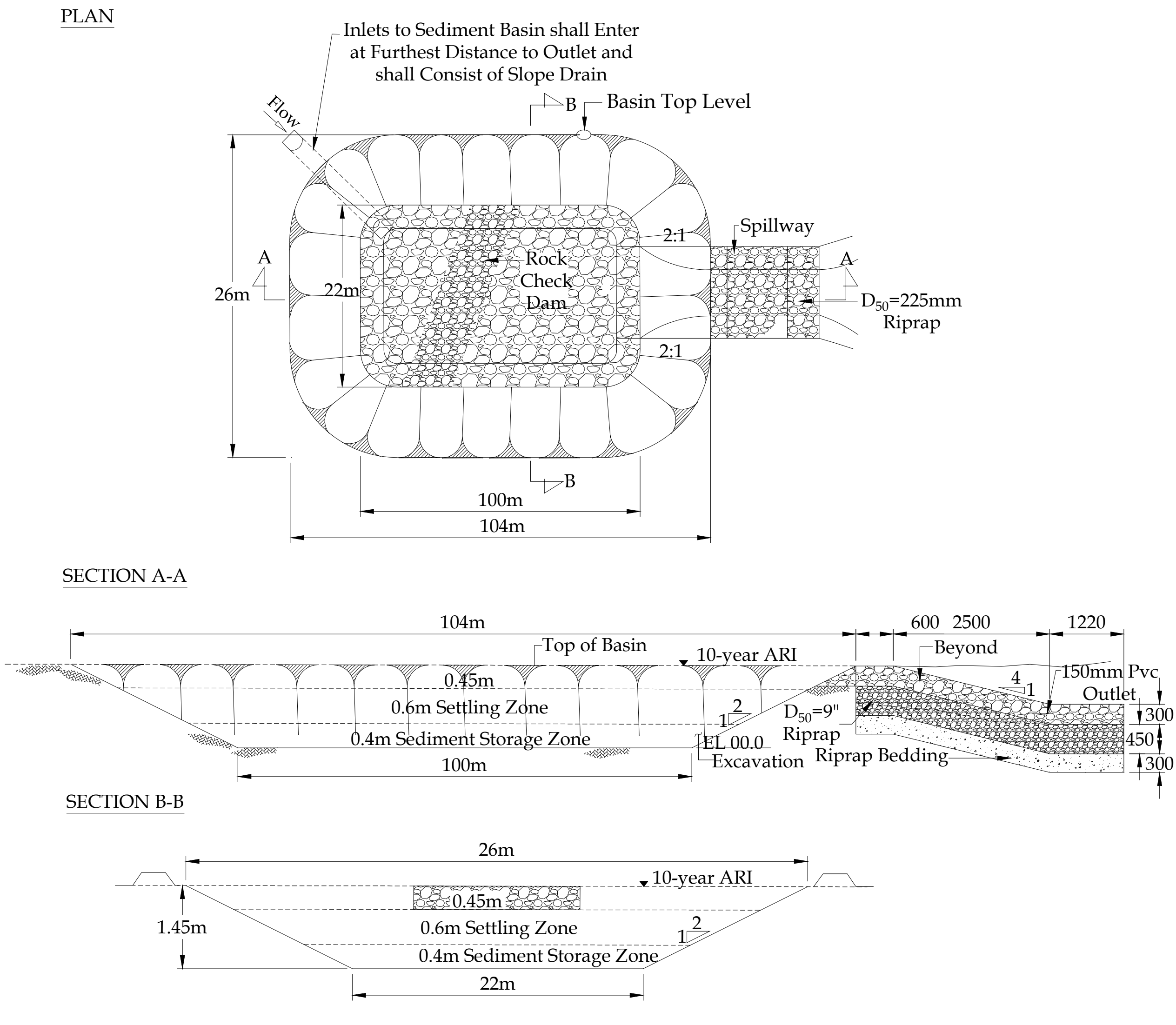
Reference	Calculation	Output
	(b) Sediment Storage Zone: The required sediment storage zone volume is half the total volume, V_2 = 793.05m^3 For a side slope Z = 2(H):1(V), the dimensions at the top of the sediment storage zone are, $W_2 = W_1 - 2 \times \frac{d_1}{2} \times Z = 16 - 2 \times 0.375 \times 2 = 15\text{m}$ $L_2 = L_1 - 2 \times \frac{d_1}{2} \times Z = 67 - 2 \times 0.375 \times 2 = 66\text{m}$ The required depth for the sediment storage zone, which must be at least 0.3 m, can be calculated from the following relationship, $V_2 = Z^2 y_2^3 - Z y_2^2 (W_2 + L_2) + y_2 (W_2 L_2)$ which gives, $793.05 = 4y_2^3 - 162y_2^2 + 990y_2$ Use trial and error to find y_2, For y_2 = 0.8m, V_2 = 690m^3 For y_2 = 0.9m, V_2 = 762m^3 For y_2 = 1m, V_2 = 832m^3	$y_2 >$ 0.3m; $V_2 >$ 793.05m^3; OK
	(c) Overall Basin Dimensions: Base: $W_B = W_1 - 2 \times Z \times \left(\frac{y_1}{2} + y_2\right) = 11\text{m}$ $L_B = L_1 - 2 \times Z \times \left(\frac{y_1}{2} + y_2\right) = 62\text{m}$ Depth: Settling Zone, y_1 = 0.75m Sediment Storage Zone, y_2 = 1.00m Side Slope Z = 2(H):1(V)	Total Basin Dimension: W_B= 11m L_B= 62m y_1=0.75m y_2=1.00m Z = 2(H):1(V)
Table 12.17	(3) <u>Sizing of Basin Outlet:</u> The spillway for this sediment basin must be design for 10-years ARI. The proposed spillway dimension is 1.5m wide x 0.3m high. The sill level must be set a minimum 300 mm above the basin top water level. To simplify the calculations, the following assumptions are made: • assume riser pipe flow is orifice flow through the top of the pipe only • riser pipe head is 300 mm, i.e. the height between the top of the pipe and the spillway crest level $Q_{required} = Q_{10} - Q_{riser}$	

Reference	Calculation	Output
	(a) Determination of Q_{10}	
Equation 2.2	$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}}$ where: i = the average rainfall intensity (mm/hr) for selected ARI (T) and storm duration (d); T = average recurrence interval, ARI (years); d = storm duration (hours); $0.20 \le d \le 72$and λ, κ, θ and η = fitting constants dependent on the raingauge location	
Appendix 2.B Table 2.B2	(see table below)	

Location & Station ID	ARI, T (years)	Storm duration d	Derived Parameters			
			λ	κ	θ	η
Gunung Brinchang (4513033)	10	25	42.004	0.164	0.046	0.802

Reference	Calculation	Output
	$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} = \frac{42.004(10)^{0.164}}{\left(\left(\frac{25}{60}\right)+0.164\right)^{0.802}} = 133.32\text{mm/hr}$	$^{10}I_{20}$ = 133.32 mm/hr
Section 2.3.1 Table 2.6	Rational Method, Coefficient of Runoff, C = 0.5 Catchment Area, A = 3.11ha (Zone 3 and Zone 4)	C = 0.5 A = 3.11ha
Equation 2.3	$Q_{10} = \frac{C.I.A}{360} = \frac{0.5 \times 133.32 \times 3.11}{360} = 0.576\text{m}^3/\text{s}$	Q_{10} = 0.58m^3/s
	Try with 1 orifice with diameter 0.45 m at same level. Allow head of 0.3m from centroid of orifice.	
	(b) Determination of Q_{riser} $Q_{riser} = C_o A_o \sqrt{2gH_o} = 0.6 \times \left(\frac{\pi(0.45)^2}{4}\right) \times \sqrt{2 \times 9.81 \times 0.3}$ = 0.23m^3/s	Q_{riser} = 0.23m^3/s
Equation 2.6	Therefore, allowing for the riser pipe flow the required spillway capacity is:	
	(c) Sizing Spillway $Q_{required}$ = 0.58 – 0.23 = 0.35m^3/s	$Q_{required}$ = 0.25m^3/s
Equation 2.10	$Q_{spillway} = C_{sp}\ B\ H_p^{1.5}$. Trial dimensions: B = 1.5m , H_p = 0.3m and C_{sp} = 1.48 from Table 2.7, $Q_{spillway}$ = 1.48 x 1.5 x 0.3$^{1.5}$ =	0.36m^3/s > 0.35m^3/s; OK

Reference	Calculation	Output
	Therefore, the total basin depth including the spillway is, 0.75 + 1.0 + 0.3 + 0.3 = **2.35m** (4) <u>Trapping Efficiency:</u> From previous calculation in Appendix 12.D, the sediment yield is estimated at 69.06 tonnes for the design storm. With the design sediment trapping efficiency of 90%, the total sediment trapped for the design event is 62.154 tonne or 38.84 m^3 (converted from soil bulk density 1600kg/m^3). The sediment storage zone for the basin is 793.05m^3. Hence, the provided sediment basin can contain the settled sediment from Plot 1. It would require 793.05/38.84 = 20 events of same magnitude to fill up the sediment storage zone. Assuming the design storm is equivalent to 3-month ARI, the storage zone is likely to be filled up in 20/4 = 5 years.	



Engineering Drawing for Wet Sediment Basin for Development Site

APPENDIX 12.F EXAMPLE – DRY SEDIMENT BASIN

Problem:

Using information for the same sediment basin designed in Appendix 12.E, assume that the area is covered by sandy soil, re-design the basin into a dry sediment basin.

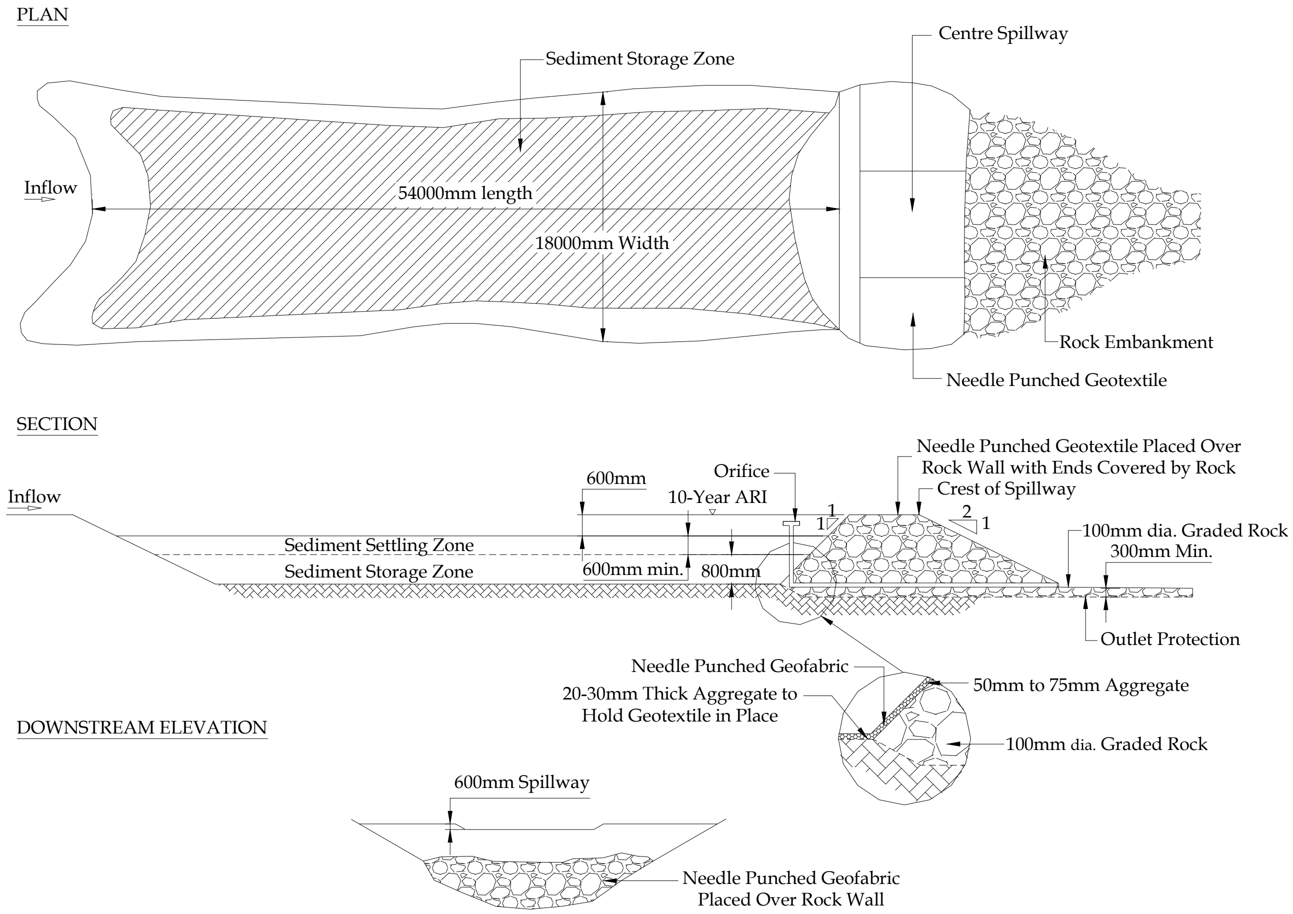
Solution:

Reference	Calculation	Output
	Design procedure of dry sediment basin is the same with wet sediment basin, except for the requirement of surface area and total basin volume. Calculations below show the design procedure of a dry sediment basin.	
	(1) Determination Type of soil:	
Table 12.16	Dry Sediment Basin is selected.	
	(2) Determination of Basin Dimension:	
Table 12.18	The required surface area is 250 m^2/ha and the required total volume is 300 m^3/ha (high runoff is selected due to bare soil condition). Figure 12.F1 illustrates the final dimensions of the sediment basin.	
	The surface area required for the site = 250 x 3.11 = 777.5m^2 (Note: this is the average surface area for the settling zone volume, i.e. at mid-depth)	Required Surface Area = 777.5m^2
	The total basin volume required for the site = 300 x 3.11 = 933m^3	Required Volume = 933m^3
	(a) Settling Zone:	
Table 12.17	The required settling zone, V_1 = 466.5m^3 (half the total volume) and the selected settling zone depth, y_1 = 0.60m.	
	Try a settling zone average width, W_1 = 15m Required settling zone average length	
	$L_1 = \frac{V_1}{W_1 \times y_1} = \frac{466.5}{15 \times 0.60}$ = 51.83m , say 52m	
	Average surface area = 15 x 52 =	780m^2 > 777.5m^2 ; OK
	Check settling zone dimensions (Table 12.17: Basin Dimension):	
	$\frac{L_1}{y_1}$ ratio = $\frac{52}{0.60}$ =	86.67 < 200; OK
	$\frac{L_1}{W_1}$ ratio = $\frac{52}{15}$ =	3.47 > 2; OK

Reference	Calculation	Output
	(b) Sediment Storage Zone:	
	The required sediment storage zone volume is half the total volume, V_2 = 466.5m^3	
	For a side slope Z = 2(H):1(V), the dimensions at the top of the sediment storage zone are, $W_2 = W_1 - 2 \times \frac{d_1}{2} \times Z = 15 - 2 \times 0.30 \times 2 = 13.8m$ say, 14m $L_2 = L_1 - 2 \times \frac{d_1}{2} \times Z = 52 - 2 \times 0.30 \times 2 = 50.8m$ say, 51m	
	The required depth for the sediment storage zone, which must be at least 0.3m, can be calculated from the following relationship, $V_2 = Z^2 y_2^3 - Z y_2^2 (W_2 + L_2) + y_2 (W_2 L_2)$	
	which gives, $466.5 = 4 y_2^3 - 130 y_2^2 + 714 y_2$	
	Use trial and error to find y_2,	
	For y_2 = 0.6 m, V_2 = 382 m^3 For y_2 = 0.7 m, V_2 = 437 m^3 **For y_2 = 0.8 m,** V_2 = 490 m^3	$y_2 >$ 0.3m; $V_2 >$ 466.5m^3; OK
	(c) Overall Basin Dimensions:	
	Base: $W_B = W_1 - 2 \times Z \times \left(\frac{y_1}{2} + y_2\right) = 10.8m$ say, 11m	W_B= 11m
	$L_B = L_1 - 2 \times Z \times \left(\frac{y_1}{2} + y_2\right) = 47.8m$ say, 48m	L_B= 48m
	Depth: Settling Zone, y_1 = 0.75m Sediment Storage Zone, y_2 = 1.00m Side Slope Z = 2(H):1(V)	y_1=0.60m y_2=0.80m Z = 2(H):1(V)
	(3) Sizing of Basin Outlet:	
Table 12.17	The spillway for this sediment basin must be design for 10-years ARI. The proposed spillway dimension is 1.5m wide x 0.3m high.	
	The sill level must be set a minimum 300mm above the basin top water level. To simplify the calculations, the following assumptions are made: • assume riser pipe flow is orifice flow through the top of the pipe only • riser pipe head is 300mm, i.e. the height between the top of the pipe and the spillway crest level	
	$Q_{required} = Q_{10} - Q_{riser}$	

Reference	Calculation	Output
	(a) Determination of Q_{10}	
Equation 2.2	Using IDF Coefficient of Cameron Highlands and Duration of 20 minutes (see APPENDIX 12.E), $^{10}I_{20}$ = 133.32mm/h	$^{10}I_{20}$ = 133.32 mm/h
Section 2.3.1 Table 2.6	Rational Method, Coefficient of Runoff, C = 0.5 Catchment Area, A = 3.11ha (Zone 3 and Zone 4)	C = 0.5 A = 3.11ha
Equation 2.3	$Q_{10} = \frac{C.^{10}I_{20}.A}{360} = \frac{0.5 x 133.32 x 3.11}{360} = 0.576 m^3/s$	Q_{10} = 0.58m³/s
	Try with 1 orifice with diameter 0.45 m at same level. Allow head of 0.3m from centroid of orifice.	
	(b) Determination of Q_{riser}	
Equation 2.6	$Q_{riser} = C_o A_o \sqrt{2gH_o} = 0.6 \times \left(\frac{\pi (0.45)^2}{4}\right) \times \sqrt{2 \times 9.81 \times 0.3}$ = 0.23m³/s	Q_{riser} = 0.23m³/s
	Therefore, allowing for the riser pipe flow the required spillway capacity is:	
	(c) Sizing Spillway	
	$Q_{required}$ = 0.48 – 0.23 = 0.25m³/s	$Q_{required}$ = 0.25m³/s
Equation 2.10	$Q_{spillway} = C_{sp}\ B\ H_p^{1.5}$.	
	Trial dimensions: B = 1.5m , H_p = 0.3m and C_{sp} = 1.48 ,	
Table 2.7	$Q_{spillway}$ = 1.48 x 1.5 x 0.3 $^{1.5}$	$Q_{spillway}$ = 0.36m³/s > 0.25m³/s; OK
	Therefore, the total basin depth including the spillway is, 0.60 + 0.80 + 0.30 + 0.30 = 2.00m	

Reference	Calculation	Output
	(4) <u>Trapping Efficiency:</u> From previous calculation in Appendix 12.D, the sediment yield is estimated at 69.06 tonnes for the design storm. With the design sediment trapping efficiency of 90%, the total sediment trapped for the design event is 62.154 tonne or 38.84m^3 (converted from soil bulk density 1600kg/m^3). The sediment storage zone for the basin is 466.5 m^3. Hence, the provided sediment basin can contain the settled sediment from Plot 1. It would require 466.5/38.84 = 12 events of same magnitude to fill up the sediment storage zone. Assuming the design storm is equivalent to 3-month ARI, the storage zone is likely to be filled up in 12/4 = 3 years.	



Engineering Drawing for Dry Sediment Basin for Development Site

Back To Top