Outlet Structures

DRAINAGE CONTROL TECHNIQUE

Low Gradient		Velocity Control	✓	Short Term	✓
Steep Gradient		Channel Lining		Medium-Long Term	
Outlet Control	✓	Soil Treatment		Permanent	

Symbol

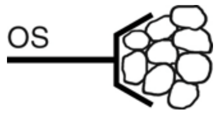

Photo 1 – Temporary *Slope Drain* with rock stabilisation at inlet and outlet

Photo 2 – Temporary rock mattress outlet structure at end of a *Chute*

Key Principles

1. The primary performance objectives generally relate to minimising the risk of soil erosion at the outlet, and preventing excessive undermining of the pipe and/or headwall.
2. Critical design parameters are the mean rock size (d_{50}) and length of rock protection (L).
3. The recommended rock sizing design charts/tables are based on the acceptance of some degree of rock movement (rearrangement) following initial storm events.
4. Critical construction issues relate to the provision of suitable rock (size and density), suitable pad dimensions (width, length and depth), and suitably recessing/integrating the rocks into the outlet channel to allow outflows to pass evenly over the rocks.

Design Information – General:

The design procedures presented in this fact sheet are <u>not</u> appropriate for the design of energy dissipaters for Sediment Basin spillways. Designers are advised to always seek expert hydraulic advice regarding the appropriate use of the material supplied within this fact sheet.

The following information is appropriate for the design of loose rock outlet structures for small Slope Drains (300/375mm diameter) and minor batter Chutes (<300mm flow depth).

Recommended mean (d_{50}) rock sizes and length (L) of rock protection for ***Slope Drain*** outlets are presented in Tables 2 and 3 for smooth and rough internal sidewall pipes respectively.

Recommended mean (d_{50}) rock sizes and length (L) of rock protection for minor batter ***Chute*** outlets are presented in Tables 4 and 5. These rock sizes are based on information presented within ASCE (1992) rounded up to the next 100mm increment, with a minimum rock size set as 100mm.

The thickness of the rock pad should be based on at least two layers of rock. This typically results in a minimum thickness as presented in Table 1.

Table 1 – Minimum thickness (T) of rock pad

Min. Thickness (T)	Size distribution (d_{50}/d_{90})	Description
1.4 d_{50}	1.0	Highly uniform rock size
1.6 d_{50}	0.8	Typical upper limit of quarry rock
1.8 d_{50}	0.67	Recommended lower limit of distribution
2.1 d_{50}	0.5	Typical lower limit of quarry rock

[1] d_{50} = nominal rock size (diameter) of which 50% of the rocks are smaller (i.e. the mean rock size).

Design Information – Outlet structures for Slope Drains:

Table 2 – Mean rock size (mm) and length (m) of rock pad outlet structure for <u>smooth</u> internal sidewall slope drain

Pipe diameter: 300 and 375mm							Smooth internal sidewall: n = 0.01						
Pipe slope (X:1)	Pipe discharge (L/s)												
	30	40	50	60	70	80	100	120	140	160	180	200	220
10	150	150	150	150	150	150	200	200	200	200	200	300	300
8	150	150	150	150	150	150	200	200	200	200	300	300	300
7	150	150	150	150	150	150	200	200	200	300	300	300	300
6	150	150	150	150	150	200	200	200	300	300	300	300	300
5	150	150	150	150	200	200	200	200	300	300	300	300	300
4	150	150	150	200	200	200	200	300	300	300	300	300	300
3	150	150	200	200	200	200	300	300	300	300	300	300	300
2	150	200	200	200	200	300	300	300	300	300	400	400	400
1	200	200	300	300	300	300	300	400	400	400	400	400	400
L [1]	**1.1**	**1.2**	**1.5**	**1.5**	**1.5**	**1.5**	**1.7**	**2.0**	**2.0**	**2.0**	**2.1**	**2.1**	**2.5**

[1] Recommended minimum length (m) of rock pad outlet structure.

Table 3 – Mean rock size (mm) and length (m) of rock pad outlet structure for <u>rough</u> internal sidewall slope drain

Pipe diameter: 300 and 375mm							Rough internal sidewall: n = 0.03						
Pipe slope (X:1)	Pipe discharge (L/s)												
	30	40	50	60	70	80	100	120	140	160	180	200	220
10	150	150	150	150	150	150	150	150	150	150	150	150	150
8	150	150	150	150	150	150	150	150	150	150	150	150	150
7	150	150	150	150	150	150	150	150	150	150	150	150	150
6	150	150	150	150	150	150	150	150	150	150	150	150	150
5	150	150	150	150	150	150	150	150	150	150	150	150	150
4	150	150	150	150	150	150	150	150	150	150	150	150	200
3	150	150	150	150	150	150	150	150	150	150	200	200	200
2	150	150	150	150	150	150	150	150	200	200	200	200	200
1	150	150	150	150	150	150	200	200	200	200	300	300	300
L [1]	**1.6**	**1.8**	**1.9**	**2.1**	**2.2**	**2.3**	**2.5**	**2.6**	**2.8**	**2.9**	**3.1**	**3.2**	**3.3**

[1] Recommended minimum length (m) of rock pad outlet structure.

Technical Note – Development of Tables 2 and 3

Many of the rock sizing charts traditionally presented for the design outlet structures can attribute their origins to the published work of Bohan (1970). This research work was based on low gradient flow conditions where the pipe is flowing full just upstream of the outlet, and during low tailwater conditions, the flow passed through critical depth at or near the outlet of the pipe. Such flow conditions are not consistent with the high-velocity, partial-full flow expected at the base of a slope drain.

The rock sizes and pad lengths presented in Tables 2 and 3 have been determined by firstly determining the partial-full, supercritical flow velocity expected at the base of a slope drain for a given discharge, internal pipe roughness, and slope gradient. Secondly an equivalent pipe diameter was determined that would have a full-pipe discharge and velocity equivalent to that determined above. Using this equivalent pipe diameter and actual discharge velocity, the design charts presented by Bohan for low tailwater conditions were used to determine the required mean rock size and length of rock protection. The rock sizes where then rounded up to the nearest 100mm rock size, with a minimum rock size set as 150mm.

The typical layouts of a rock pad for a *Slope Drain* is shown in Figure 1. The rock pad should straight and align with the direction of the pipe outlet.

If the width of the rock pad is governed by the width of the receiving channel, then the rock protection should ideally extend up the banks of the channel to a height no less than the central elevation of the pipe outlet, but no more than the expected depth of flow.

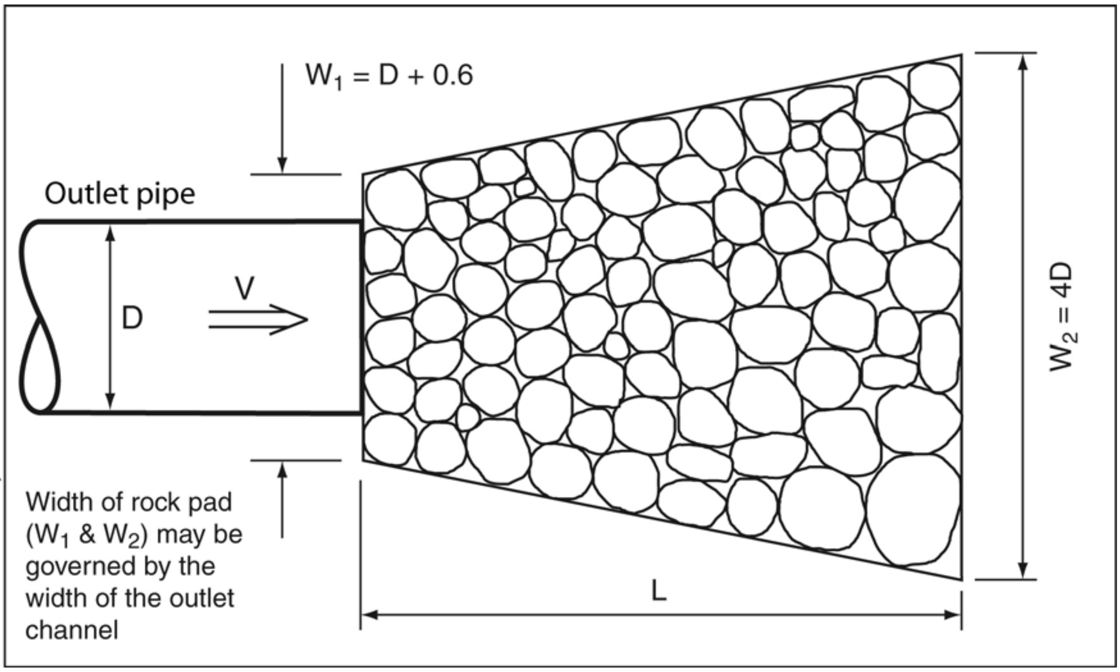

Figure 1 – Typical layout of a rock pad for a single pipe outlet (plan view)

The outlet structure for *Slope Drains* should be constructed at a level grade, or a gradient equal to that of the receiving channel.

The surface level of the downstream end of the rock pad should be level with the invert of the receiving channel, i.e. the rocks should be recessed into the outlet channel to minimise the risk of erosion around the outer edges of the rock pad.

The placement of filter cloth under the rock pad is generally considered optional for temporary outlet structures placed at the end of *Slope Drains*.

Design Information – Outlet structures for temporary drainage Chutes:

Table 4 – Mean rock size, d_{50} (mm) for batter *Chute* outlet protection [1]

Depth of approach flow (mm) [2]	Flow velocity at base of *Chute* (m/s)						
	2.0	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**
50	100	100	100	200	200	200	300
100	100	100	200	200	300	300	400
200	100	200	300	300	400	[3]	[3]
300	200	200	300	400	[3]	[3]	[3]

[1] For exit flow velocities not exceeding 1.5m/s, and where growing conditions allow, loose 100mm rock may be replaced with 75mm rock stabilised with a good cover of grass.

[2] Flow depth is based on the maximum depth, not the average flow depth.

[3] Consider using 400mm grouted rock pad, or a rock-filled mattress outlet.

The outlet pad lengths provided in Table 5 are suitable for temporary, rock-lined outlet structures only. These rock pad length will not necessarily fully contain all energy dissipation and flow turbulence; therefore, some degree of scour may still occur downstream of the outlet structure.

For permanent structures, or concrete-lined energy dissipaters, the length of the dissipater should be based on the estimated length of the resulting hydraulic jump. Also, in circumstances where the outlet structure is located downstream of a smooth surface chute, e.g. concrete-lined chutes, then the rocks should be grouted in place to avoid displacement.

Table 5 – Recommended length, L (m) of rock pad for batter *Chute* outlet protection [1]

Depth of approach flow (mm)	Flow velocity at base of *Chute* (m/s)						
	2.0	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**
50	1.0	1.5	2.1	2.6	3.1	3.6	4.2
100	1.3	2.0	2.7	3.4	4.1	4.8	5.5
200	2.1	2.7	3.4	4.3	5.2	6.1	7.0
300	2.7	3.6	4.3	4.8	5.8	6.8	7.9

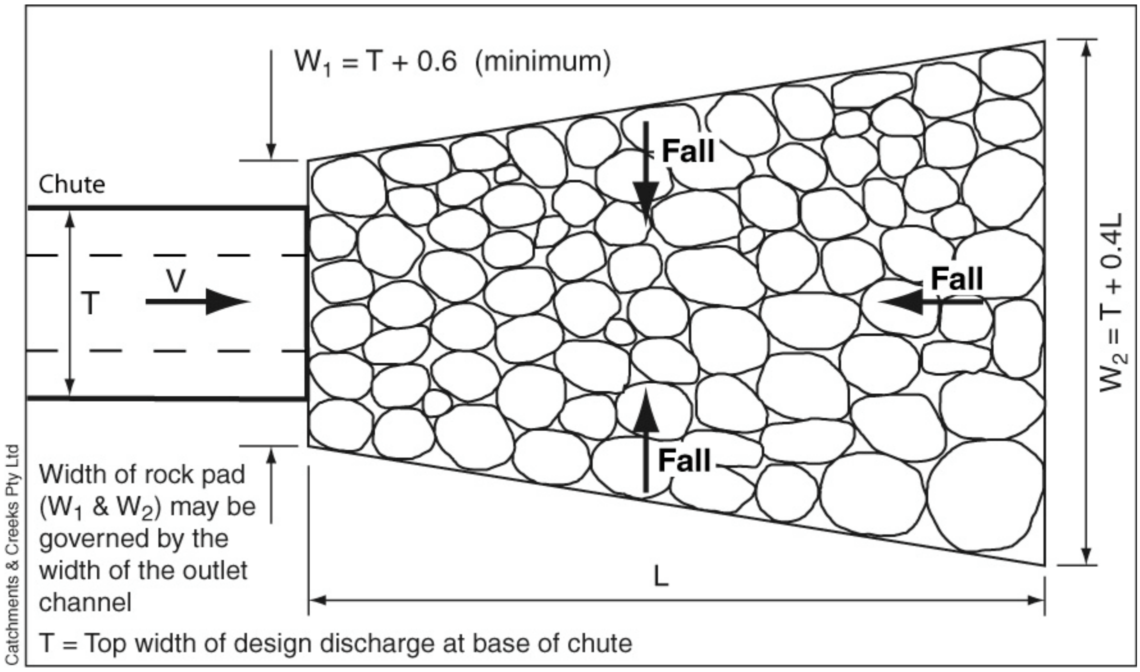

Figure 2 – Typical layout of a recessed rock pad for a *Chute* (plan view)

As indicated in Figures 2, 3 and 4, outlet structures for minor batter *Chutes* should be recessed below the surrounding ground level to promote effective energy dissipation. The recommended recess depth (Z) can be determined from Table 6.

Table 6 – Recommended recess depth, Z (m) for batter *Chute* outlet protection

Depth of approach flow (mm)	Flow velocity at base of *Chute* (m/s)						
	2.0	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**
50	0.13	0.20	0.28	0.36	0.43	0.50	0.60
100	0.14	0.23	0.32	0.42	0.50	0.60	0.70
200	0.12	0.21	0.31	0.42	0.50	0.60	0.70
300	0.07	0.16	0.25	0.35	0.44	0.55	0.65

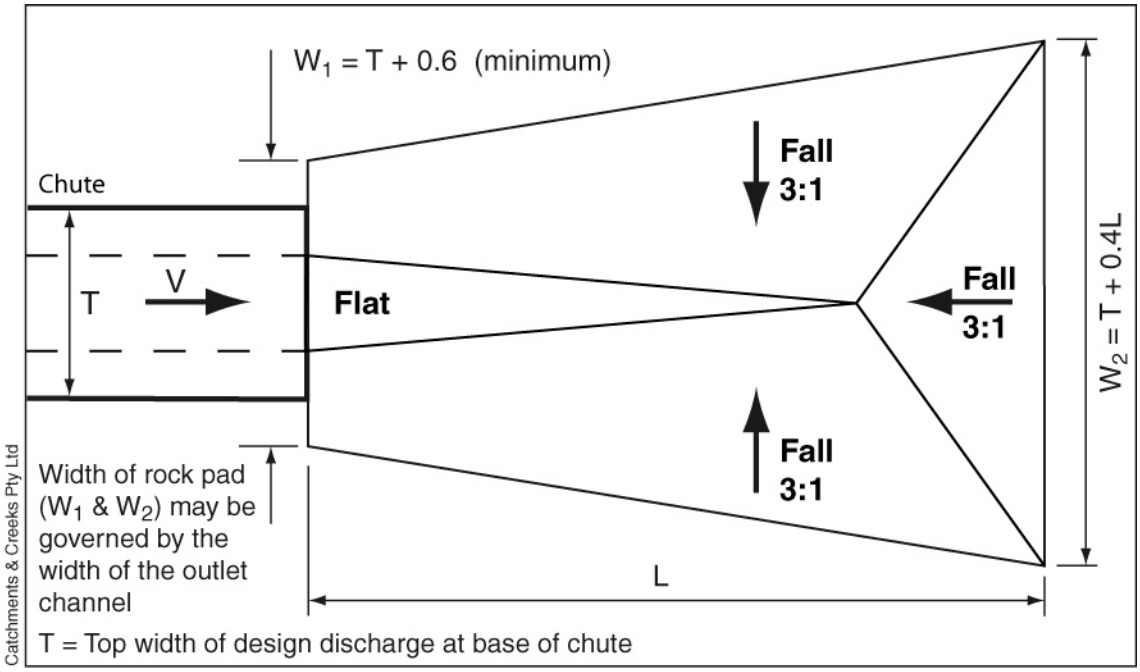

Figure 3 – Typical arrangement of recessed outlet structure for minor *Chutes*

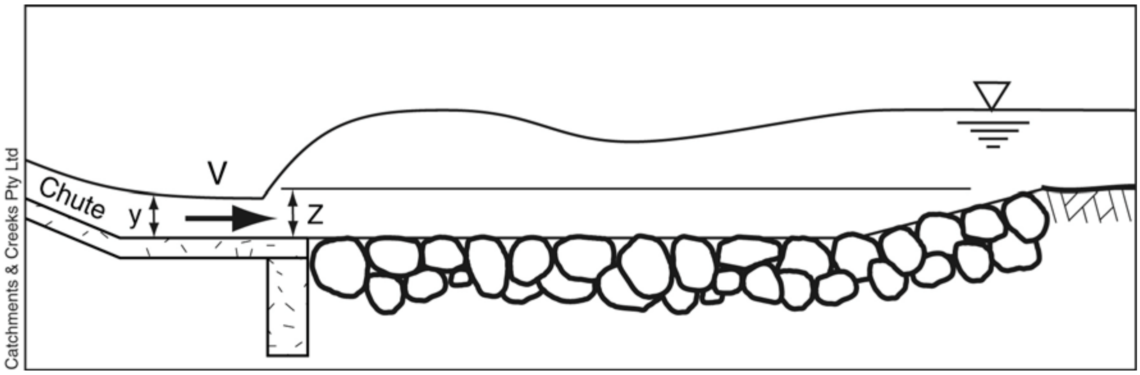

Figure 4 – Typical profile of recessed outlet structure for minor *Chutes*

References:

ASCE 1992, *Design and construction of urban stormwater management systems*. ASCE Manuals and Reports of Engineering Practice No. 77, and Water Environment Federation Manual of Practice FD-20, American Society of Civil Engineers, New York.

Bohan, J.P. 1970, *Erosion and riprap requirements at culvert and storm-drain outlets*. Research Report H-70-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Design example 1 – Slope drain outlet structure:

Design the outlet protection for a temporary slope drain with a diameter (D) of 300mm, smooth internal sidewall, and design discharge of 100L/s.

Solution

Given D = 300mm and Q = 100L/s, the recommended mean rock size as obtained from Table 2 is d_{50} = 300mm and L = 1.7m.

Upstream width of the rock pad, W1 = D + 0.6 = 0.9m (see Figure 1).

Downstream width of the rock pad, W2 = 4D = 1.2m

If it is assumed that the largest rock is likely to be around 1.5 times the size of the average rock size, i.e. d_{50}/d_{90} approximately equals 0.67, then from Table 1 we can obtain the required depth of rock protection as, T = 1.8(d_{50}) = 0.54m. In any case, a minimum of two layers of rock should be specified on the construction plans.

Design example 2 – Chute outlet structure:

Design the outlet protection for a temporary, trapezoidal chute lined with filter cloth on a 3:1 batter slope with a base width of 1.0m, side slopes of 2:1, and design discharge of 600L/s.

Solution

Adopting a Manning's roughness of, n = 0.022 for the filter cloth, the flow conditions at the base of the chute can be determined from Manning's equation as:

Discharge, Q = 0.6m^3/s

Manning's roughness, n = 0.022 (based on an expected flow depth > 0.1m)

Channel slope, S = 0.333 (m/m)

Bed width, b = 1.0m

Channel side slope, m = 2:1

Flow depth, y = 0.1m

Flow top width, T = b + 2my = 1.4m

Hydraulic radius, R = 0.083m

Velocity, $$V = \frac{1}{n} R^{2/3} S^{1/2} = \frac{1}{0.022}(0.083)^{2/3}(0.333)^{1/2} = 5.0\,\text{m/s}$$

From Table 4 the mean rock size, d_{50} = 200mm

From Table 5 the length of the rock pad, L = 3.4m

From Table 6 the recommended recess depth, Z = 0.42m

From Figure 3 the upstream width of the rock pad, W1 = T + 0.6 = 2.0m

From Figure 3 the downstream width of the rock pad, W2 = T + 0.4L = 2.8m

If it is assumed that the largest rock is likely to be around 1.5 times the size of the average rock size, i.e. d_{50}/d_{90} approximately equals 0.67, then from Table 1 we can obtain the required depth of rock protection as, T = 1.8(d_{50}) = 0.36m. In any case, a minimum of two layers of rock should be specified on the construction plans.

Note, the symbol 'T' has traditionally been used for both the depth of rock protection (as in Example 1), and the top width of flow (as in Example 2).

Description

The term *Outlet Structure* refers to a wide range of outlet control devices including rock pads, rock mattress aprons, and various impact-type energy dissipaters.

The standard outlet structure consists of a pad of medium sized rock placed at the outlet of *Slope Drain*, *Chute*, stormwater pipe or culvert.

Purpose

Used to control soil erosion adjacent to the outlet and to dissipate flow energy.

Limitations

These rock pads are generally ineffective in controlling erosion caused by high-velocity outlet ‘jetting’ occurring during high tailwater conditions.

Advantages

Quick to install.

The rock can often be retained as a permanent erosion control measure.

Disadvantages

If the rock is not appropriately recessed into the surrounding soil, erosion can occur around the edge of the rock pad.

Common Problems

Inadequate rock size.

Inadequate length, width or depth of rock protection.

Rock not recessed into the channel bed.

Erosion along the outer edge of the rock pad caused by lateral inflows (i.e. water flowing towards the outlet from a location other than the pipe).

Special Requirements

Important to recess the rock so that the top of the rock pad is level with the surrounding earth surface.

The rock should extend downstream until non-erosive flow conditions are achieved. In some cases this may require the rock protection to be extended beyond standards outlet dimensions determined from the attached design tables.

Location

Rock pad outlet structures are constructed downstream of temporary *Chutes* and *Slope Drains*, as well as permanent stormwater outlets and culverts.

Site Inspection

Check for erosion around the edge of the rock pad.

Ensure the rocks are adequately recessed into the earth.

Check for excessive displacement of rocks. Some degree of rock movement should be expected, especially immediately down-stream of the pipe or concrete apron.

Check for excessive sediment deposition.

Materials (Rock pads)

- Rock: hard, angular, durable, weather resistant and evenly graded with 50% by weight larger than the specified nominal rock size and sufficient small rock to fill the voids between the larger rock. The diameter of the largest rock size should be no larger than 1.5 times the nominal rock size. Specific gravity to be at least 2.5.
- Geotextile fabric: heavy-duty, needle-punched, non-woven filter cloth, minimum ‘bidim’ A24 or equivalent.

Installation (Rock pads)

1. Refer to approved plans for location and construction details. If there are questions or problems with the location, dimensions or method of installation contact the engineer or responsible on-site officer for assistance.
2. The dimensions of the outlet structure must align with the dominant flow direction.
3. Excavate the outlet pad footprint to the specified dimension such the when the rock is placed in the excavated pit the top of the rocks will be level with the surrounding ground, unless otherwise directed.
4. If the excavated soils are dispersive, over-excavated the rock pad by at least 300mm and backfill with stable, non-dispersive material.
5. Line the excavated pit with geotextile filter cloth, preferably using a single sheet. If joints are required, overlap the fabric at least 300mm.
6. Ensure the filter cloth is protected from punching or tearing during installation of the fabric and the rock. Repair any damage by removing the rock and placing with another piece of filter cloth over the damaged area overlapping the existing fabric a minimum of 300mm.
7. Ensure there are at least two layers of rocks. Where necessary, reposition the larger rocks to ensure two layers of rocks are achieved without elevating the upper surface above the pipe invert.
8. Ensure the rock is placed in a manner that will allow water to discharge freely from the pipe.
9. Ensure the upper surface of the rock pad does not cause water to be deflected around the edge of the rock pad.
10. Immediately after construction, appropriately stabilise all disturbed areas.

Maintenance

1. While construction works continue on the site, inspect the outlet structure prior to forecast rainfall, daily during extended periods of rainfall, after significant runoff producing rainfall, and on at least a weekly basis.
2. Replace any displaced rock with rock of a significantly (minimum 110%) larger size than the displaced rock.

Removal

1. Temporary outlet structures should be completely removed, or where appropriate, rehabilitated so as not to cause ongoing environmental nuisance or harm.
2. Following removal of the device, the disturbed area must be appropriately rehabilitated so as not to cause ongoing environmental nuisance or harm.
3. Remove materials and collected sediment and dispose of in a suitable manner that will not cause an erosion or pollution hazard.