Chapter 13
Outlet protection

13.1 Introduction

Erosion at pipe or channel outlets is common. Determination of the flow condition, scour potential and channel erodibility should be a standard component of stormwater management design. The only safe procedure is to design the outfall on the basis that erosion at the outlet and downstream channel is to be expected. A reasonable procedure is to provide at least minimum protection, and then inspect the outlet channel after major storms to determine if the protection must be increased or extended. Under this approach, the initial protection against channel erosion should be sufficient to provide some assurance that extensive damage would not result from one runoff event.

Two types of erosion result from stormwater discharges:

> Local scour in the vicinity of pipe or channel outfall
> General channel degradation further downstream

Local scour is the result of high velocity flow at the pipe outlet. It tends to have an effect for a limited distance downstream. Natural channel velocities are almost universally less than pipe outlet velocities, because the channel cross section, including the floodplain, is generally larger than the pipe flow area while the frictional resistance of a natural channel is less than the frictional resistance of a concrete pipe. Thus, flow eventally adjusts to a pattern controlled by the channel characteristics.

Channel degradation represents a long term lowering of the stream channel which may proceed in a fairly uniform manner over a long length or may be evident in one or more abrupt drops. Most stream channels in the Region are degrading as a result of increased stormwater runoff volumes from changed land use, initially from forest to rural use and further from rural to urban use. Consideration of instability issues of the waterway into which stormwater systems discharge is an essential part of overall stormwater management design.

Outlet protection for culverts, stormwater outfalls or ditches is essential to prevent erosion from damaging downstream channels and receiving environments. Outlet protection can be a channel lining, structure or flow barrier designed to lower excessive flow velocities from pipes and culverts, prevent scour, and dissipate energy. Good outlet protection will significantly reduce erosion and sedimention by reducing flow velocities.

Plate 13-1: Example of riprap at a stormwater outfall

13.2 Objective

Outlet protection aims to protect outfall areas from local scour. It is necessary whenever discharge velocities and energies at the outlets of pipes or ditches are sufficient to erode the downstream reach.

When an outfall is sited in a coastal environment, it is essential to also consider wave energy in determining appropriate rock sizing.

13.3 Design approach

Key design elements include:

- pipe grade
- outlet velocity
- riprap aprons
- engineered energy dissipators
- flow alignment and outfall setback in freshwater receiving environments
- erosion control in coastal environments

These are summarised below.

13.3.1 Pipe grade

To minimise the complexity of analysis and design of outlet protection structures, the first step to look for was to reduce the need for outlet protection by laying the pipe at as low a grade as possible, for example by using a drop structure in the pipe a short distance above the outfall.

13.3.2 Outlet velocity

In order to identify the need for further outlet protection, it is useful to compare outfall velocities with the velocities that natural channels can tolerate without accelerated erosion, as shown in Table 13-1.

The design and analysis of riprap protection, stilling basins, and other types of outlet structures can be a complex task to accomplish. The first step is to look for ways to reduce the need for outlet protection by laying the pipe at a grade no steeper than possible (possibly using a drop structure in pipe). When considering outfall velocities, there is value in considering what velocities that natural channels can tolerate prior to eroding. Table 12-1 provides those values.

The primary consideration in selecting the type of outlet protection is the outlet velocity for pipes or channels, which is dependent on the flow profile associated with the design storm.

Pipe flow may be controlled by:

- the type of inlet
- the throat section
- the pipe capacity or
- the type of outlet.

The type of control may change from outlet control to inlet control depending on the flow value.

For inlet control, the outlet velocity is assumed to be normal depth as calculated by Manning's equation.

For outlet control, the outelt velocity is found by calculating the channel flow from Manning's equation with the calculated tailwater depth or the critical flow depth of pipe, whichever is greater.

Table 13-1
Maximum permissible velocities for unlined channels

Fine Sand, colloidal	0.4
Sandy loam, noncolloidal	0.5
Silt loam, noncolloidal	0.6
Alluvial silts, noncolloidal	0.6
Ordinary firm loam	0.8
Volcanic ash	0.8
Stiff clay, very colloidal	1.1
Alluvial silts, colloidal	1.1
Shales and hardpans	1.8
Fine gravel	0.8
Graded loam to cobbles, noncolloidal	1.1
Graded silts to cobbles, colloidal	1.2
Coarse gravel, noncolloidal	1.2
Cobbles and shingles	1.5

13.3.3 Riprap aprons

Outlet protection can take the form of riprap placement with the stone sizing being done as part of the storm drainage design, and using these guidelines. Riprap outlet protection is usually less expensive and easier to install than concrete aprons or energy dissipators. A riprap channel lining is flexible and adjusts to settlement; it also serves to trap sediment and reduce flow velocities.

Riprap aprons should not be used to change the direction of outlet flow: an impact energy dissipator is more appropriate for this. Riprap aprons aim to manage the transition of piped stormwater into a stream channel primarily by their higher Manning's roughness coefficient, which slows the water velocityl.

Riprap aprons should be constructed, where possible, at zero percent grade for the specified length.

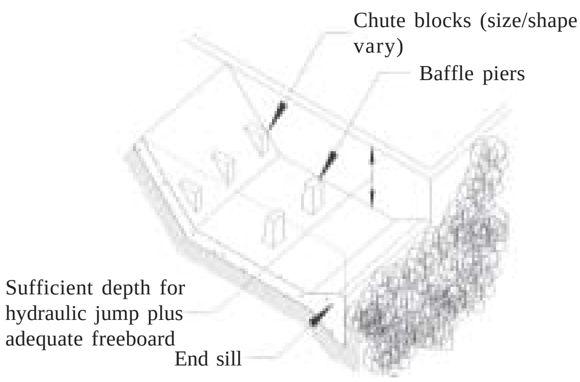
Grouted riprap may be subject to upheaval from periodic saturation of clay subgrades and is therefore not generally recommended for outlet velocity protection. Upheaval can crack the grout resulting in undersized riprap size for the velocities of flow. In general ungrouted, properly sized riprap provides better assurance of long term performance.

Laying riprap directly on soils can allow the water to hit soil particles, dislodging them and causing erosion. Filter cloth laid between the soil and riprap will assist this. Filter cloth is graded on the thickness and permeability characteristics. A qualitative judgement is usually made on the appropriate grade to prevent erosion and prevent puncture by riprap.

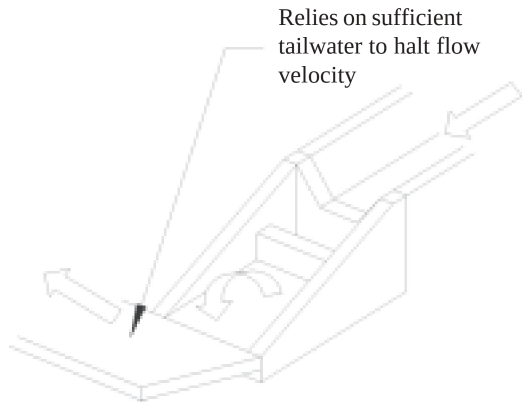
13.3.4 Engineered energy dissipators

There are many other types of energy dissipators. Auckland City has a design detail for a concrete energy dissipation structure in its Development and Connection Standards. An older document is the Culvert Manual, Volume 1 done by the Ministry of Works and Development in August, 1978. There have been many types developed over the years. Commonly used varieties include stilling basins, baffle blocks within a headwall and impact energy dissipators.

Engineered energy dissipaters including stilling basins, drop pools, hydraulic jump basins or baffled aprons are required for outfalls with design velocities more than 6 metres per second. These should be designed using published or commonly known techniques found in such references as *Hydraulic Design of Energy Dissipators for Culverts and Channels, HEC 14, September 1983, Metric Version*. This design approach can be downloaded from the internet at www.fhwa.dot.gov/bridge/hydpub.htm.



Typical Stilling Basin



Typical Impact Energy Dissipater

13.3.5 Flow alignment and outfall setback in freshwater receiving environments

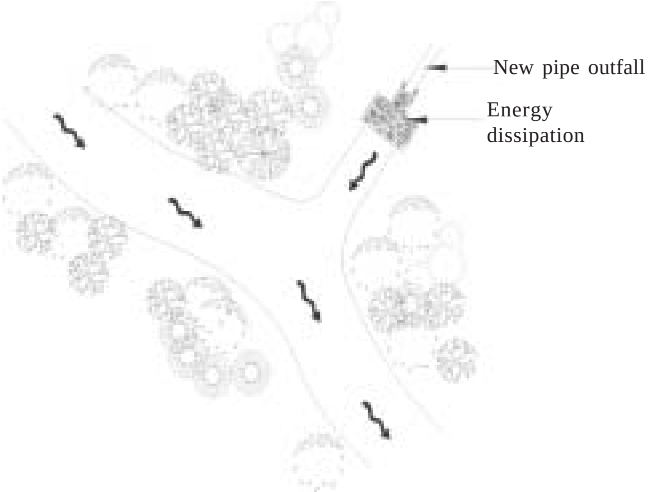
Depending on the location and alignment of the pipe outfall and the receiving stream, outfall structures can have a significant effect on receiving channels. Alignment at a right angle to the stream will force the flow to make a 90^o angle to the direction of flow. This can cause scour of the opposite stream bank in as well as causing significant turbulence at the point of entry.

The preferred approach is to align the pipe flow at no more than a 45^o angle to the stream.

If the pipe outfall must be directly into the stream channel, riprap must be placed on the opposite stream channel boundary to a depth of 300 mm above the elevation of the pipe crown. This is in addition to a riprap apron at the pipe outfall.

The impact of new pipe outfalls can be significantly reduced on receiving streams by locating them further back from the stream edge and digging a channel from the outfall to the stream. This would allow for energy dissipation before flows enter the stream, as shown in Figure 13-1. At a minimum, the pipe outfall should be located far enough back from the stream edge to prevent the energy dissipater intruding on the channel.

Figure 13-1
Energy dissipation prior to stream entry



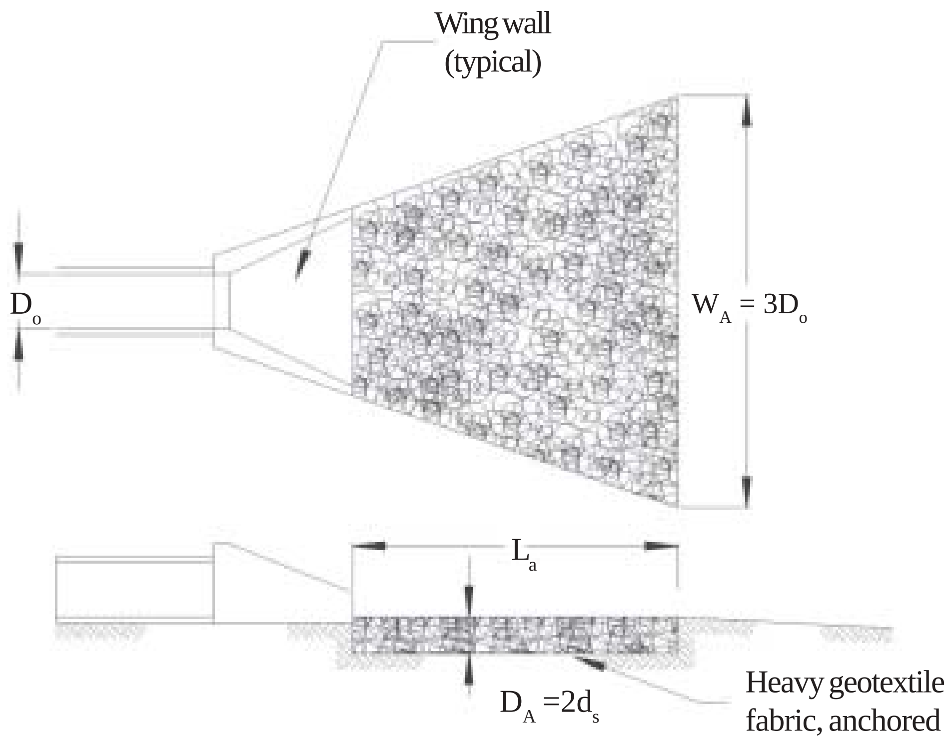
13.3.6 Erosion control in coastal receiving environments

Discharges and outlet structures may give rise to a number of adverse effects on the coastal environment if they are constructed of inappropriate materials and/or are poorly sited. For example, a discharge may cause or exacerbate erosion of a beach or an outlet may detract from the natural character or amenity value of the coastal environment or impede public access to, from and along the coast.

Before locating a discharge in the coastal marine area particular consideration should be given to the following matters to avoid/minimise any adverse effect on the natural character, amenity or public access values of the coastal environment:

1. Discharging in such a location that will not unnecessarily cause or exacerbate erosion, particularly of

Figure 13-2
Schematic of outfall protection



beach materials. For a discharge to a beach, this may involve locating the point of discharge away from the active beach system, e.g. at or near an adjacent headland.
2. Where there are more than one points of discharge to a beach system, consideration should be given to combining discharges to a common point of discharge, including via a common structure.
3. Ensuring the visual form and appearance of the outlet does not detract from its immediate surrounds and the natural character of the coastal environment, e.g. ensuring the structure is assumed into its locality rather than contrasts with that environment. The use of locally sourced rock and/or coloured and sculpted concrete forms may be appropriate.
4. Keeping the "footprint" of the structure to a minimum.
5. Incorporating the discharge pipe into another structure, e.g. a boat ramp, to minimise the number of structures in the coastal environment.
6. Locating the outlet and discharge in such a position as to not create an abstacle to public access to, from or along the coastal marine area.

13.4 Detailed design

The design of outlet protection can be done in two ways. The most accurate approach is that in *Hydraulic Design of Energy Dissipators for Culverts and Channels, HEC 14, September 1983, Metric Version*. This is widely used by design professionals and is recommended by the ARC.

The second approach is a simplified approach, which is conservative in order to ensure that adequate channel protection is provided. The approach still requires that velocities for the design discharge to be calculated and inputted into the equations. The design approach based on Figure 13-2 is:

1. Determine the discharge velocity for the design storm. For stormwater management structures the design storm is the maximum flow that can be carried by the pipe. This will normally be the 10 year design flow.

2. Enter that value into the following equation to determine the equivalent diameter of the stone.

$$d_s = 0.25 \times D_o \times F_o$$

where

d_s = riprap diameter (m)
D_o = pipe diameter (m)
F_o = Froude number = $V/(g \times d_p)^{0.5}$
d_p = depth of flow in pipe (m)
V = velocity of flow in pipe (m/s)

3. The thickness of the stone layer is 2 times the stone dimension. $D_A = 2d_s$
4. The width of the area protected is 3 times the diameter of the pipe. $W_A = 3D_o$
5. The height of the stone is the crown of the pipe + 300 mm.
6. The length of the outfall protection is determined by the following formula.

$$L_a = D_o(8 + 17 \times \text{Log } F_o)$$

Where

L_a = Apron length (m)
g = 9.8 m/sec^2

As can be seen from the equations, any reduction in the discharge velocity will reduce the stone size and apron length. Mechanisms to reduce velocity prior to discharge from the outfall are encouraged, such as drop manholes, rapid expansion into pipes of much larger size, or well up discharge designs.

13.5 Construction

Construction of the outfall protection must be done at the same time as construction of the pipe outfall itself. In terms of environmental protection and timing of construction, it is best to construct the outfall unit from the bottom up, to prevent concentrated flows from being discharged into an unstabilised location. If construction of the outfall system is done from the top end first, the entrance to the system should be blocked off to prevent flow from travelling through the pipe until the outfall protection is completed.

Outfall structures associated with stormwater management ponds shall be done in a similar fashion. Once the embankment has been completed and the pipe outfall structure installed, the outfall erosion protection must be constructed.

It is important that a sequence of construction be established and followed, such as, for example:

1. Clear the foundation area of trees, stumps, roots, grass, loose rock, or other unsuitable material.
2. Excavate the cross-section to the lines and grades as shown on the design plans. Backfill over-excavated areas with moist soil compacted to the density of the surrounding material.
3. Ensure there are no abrupt deviations from the design grade or horizontal alignment.
4. Place filter cloth and riprap to line and grade and in the manner specified. Sections of fabric should overlap at least 300 mm and extend 300 mm beyond the rock. Secure the filter cloth at the edges via secure pins or a key trench.
5. Ensure the construction operations are done so as to minimuse erosion or water contamination, with all disturbed areas vegetated or otherwise protected against soil erosion.
6. For coastal sites, undertake construction at periods of low tide.

13.6 Operation and maintenance

Key tasks are:

- inspect outlet protection on a regular basis for erosion, sedimentation, scour or undercutting
- repair or replace riprap, geotextile or concrete structures as necessary to handle design flows
- remove trash, debris, grass, or sediment

Maintenance may be more extensive as smaller riprap sizes are used, as children may be tempted to throw or otherwise displace stones or rocks.

13.7 Bibliography

City of Portland, Stormwater Management Manual, Adopted 1 July, 1999; revised 1 September, 2000.

Department of Natural Resources and Environmental Control, Delaware erosion and Sediment Control Handbook for Development, undated.

Ministry of Works and Development, Culvert Manual, Volume 1, Civil Division Publication CDP 706/A, August 1978.

North Shore City Council Coastal Outfalls, report prepared by Beca Carter Hollings and Ferner, October 2001

U.S. Army Corps of Engineers, Hydraulic Design of Energy Dissipators for Culverts and Channels, HEC 14, September, 1983, *Metric Version*.

Washington State Department of Ecology, Stormwater Management Manual for Western Washington, Volume 5, Runoff Treatment BMP's, Publications No. 99-15, August, 2000.