Energy Dissipaters

DRAINAGE CONTROL TECHNIQUE

Low Gradient		Velocity Control	✓	Short Term	✓
Steep Gradient		Channel Lining		Medium-Long Term	✓
Outlet Control	✓	Soil Treatment		Permanent	[1]

[1] The design of permanent energy dissipaters may require consideration of issues not discussed within this fact sheet. Obtaining expert hydraulic advice is always recommended.

Symbol (not applicable)

Photo 1 – Rock mattress lined basin spillway and energy dissipater

Photo 2 – Rock lined basin spillway and energy dissipater

Key Principles

1. Energy dissipation must be contained within a suitably stabilised area, therefore it is essential for the designer to be able to control the **location** of the hydraulic jump.
2. The key performance objectives are to control soil erosion associated with the energy dissipater, and present structural damage to the chute, culvert or spillway.

Design Information

Energy dissipation is usually required to achieve one or more of the following:

- prevent the undermining of the outlet, chute or spillway;
- control of bed scour immediately downstream of the energy dissipater;
- control of bank erosion well downstream of the structure caused by an 'outlet jet', if such jetting is possible at the structure.

Bank erosion downstream of pipe outlet is likely to result from the effects of an outlet jet if:

- tailwater levels are above the centre of a pipe outlet (which causes the jet to float); and
- the flow velocity at the outlet exceeds the scour velocity of the bank material; and
- the distance between the outlet and the opposing bank is less than approximately 10 times the equivalent pipe diameter for a single outlet, or 13 times the equivalent pipe diameter for a multi-cell outlet.

The control of *bed scour* is usually achieved by the development of a thick, low velocity, boundary layer usually through the introduction of erosion resistant bed roughness (e.g. rock).

Downstream bank erosion is usually controlled by breaking-up the outlet jet through the energy dissipating effects of a hydraulic jump, plunge pool, or impact structure.

Bed friction outlets

These energy dissipaters use coarse riprap or rows of small concrete impact blocks as a form of bed roughness to retard the outlet flow. This bed roughness can help spread the flow and develop an effective boundary layer thus reducing the potential for downstream bed scour. If favourable tailwater conditions exist, these outlets can also induce a hydraulic jump to aid in energy dissipation.

Bed friction outlet structures exhibit only minimal control over 'floating' outlet jets. They are therefore most effective when operating under low tailwater conditions.

For design guidelines, refer to the separate fact sheet on *Outlet Structures*.

Photo 3 – Rock pad outlet structure

Photo 4 – Rock pad outlet structure

Hydraulic jump energy dissipaters

These energy dissipaters that rely of the formation of a hydraulic jump and are usually best used to control high velocity flows confined within rectangular or near-rectangular channels. These structures usually require well-regulated tailwater conditions to prevent the hydraulic jump from being swept downstream of the stabilised energy dissipation zone.

To control the location of the hydraulic jump, the outlet pond can be recessed into the bed of the channel forming a recessed energy dissipation pool. Generally these dissipation pools need to be designed to be free draining to avoid permanent ponding and prevent mosquito breeding.

If a hydraulic jump is required to be formed downstream of a chute, then the crest of the chute must be flat, and the chute's cross-section must be as close to *rectangular* as is possible to produce near-uniform, 1-dimentsional flow conditions. Trapezoidal chutes with flat side slopes can cause highly 3D flow conditions resulting in the formation of an ineffective hydraulic jump.

Hydraulic jump energy dissipaters are usually **not** effective downstream of piped outlets because jetting from the pipe can prevent an effective hydraulic jump from forming.

Photo 5 – Hydraulic jump type energy dissipater on sediment basin spillway

Photo 6 – Hydraulic jump dissipater downstream of detention basin outlet

Plunge pool energy dissipaters

Plunge pools can be an effective way of dissipating energy and controlling bed scour. However, in order to be effective the outlet jet **must** be allowed to free fall into the pool. Therefore, low tailwater conditions are required. Under high tailwater conditions (i.e. when a floating outlet jet is formed) plunge pool designs are relatively ineffective. Though distinguished from hydraulic jump dissipaters, most plunge pool dissipaters effectively act as 'confined' hydraulic jumps.

Concrete or other hard-lined plunge pool dissipaters should be free draining to avoid the formation of stagnant water. Many standardised plunge pool dissipater designs can be successfully modified to avoid long-term ponding by introducing a narrow, open notch within the end sill.

Plunge pool dissipaters can be highly dangerous hydraulic structures resulting in severe head injuries to persons being swept through the structure.

Photo 7 – Rock-lined plunge pool energy dissipater

Photo 8 – Note use of impact blocks to stabilise the location of the hydraulic jump

Stepped spillways

Stepped spillways dissipate energy as the flow passes down the face of the spillway (chute), as well as allowing the formation of a hydraulic jump at the base of the spillway. Each step can operate under conditions of either a plunging jet (nappe flow regime), or as a fully or partially formed hydraulic jump.

Under high flow conditions, the water can begin to skim over the individual steps (skimming flow regime) greatly reducing energy dissipation down the face of the spillway. Once skimming flow conditions are fully developed, the spillway begins to behave like an unstepped spillway.

For design guidelines, refer to *Hydraulic design of stepped channels and spillways*, H. Chanson, Report CH43/94, February 1994, Department of Civil Engineering, The University of Queensland, Brisbane.

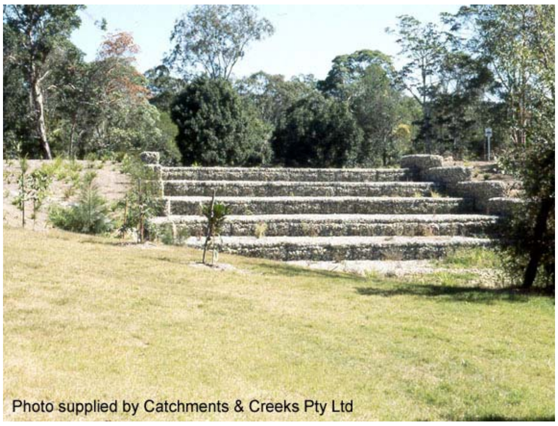

Photo 9 – Gabion lined stepped spillway on a stormwater detention basin

Photo 10 – Stepped chute acting as an outlet structure for a table drain

Impact structures

These structures contain impact walls, blocks or columns to break-up the jet and induce highly turbulent flow. They are generally very effective at dissipating flow energy from medium to high velocity outlets where control of the outlet jet is required. The control of bed scour immediately downstream of the outlet structure usually requires the use of additional riprap protection.

The height of impact blocks is usually set equal to the height of the incoming jet. In the case of culverts and stormwater outlets, this means a height equal to the height of the culvert or pipe.

These are some of the most dangerous of all the hydraulic structures. Their design and use must only be managed under the supervision of suitably trained experts.

Photo 11 – Baffled spillway

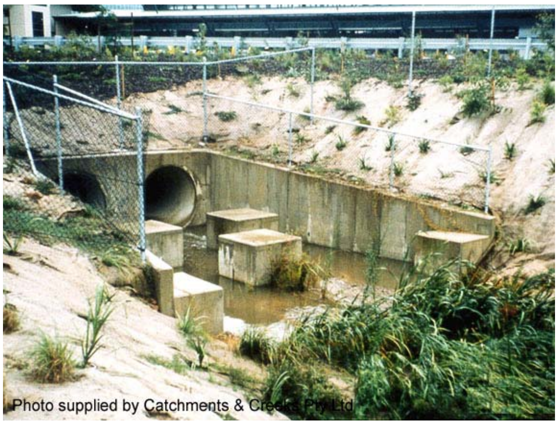

Photo 12 – Impact block energy dissipater

Design Information

Warning, energy dissipater can represent a significant safety risk to persons swept into the flow. In circumstance where a person could be swept into such danger, safety issues <u>must</u> be given appropriate consideration.

Energy dissipaters are usually major hydraulic structures requiring design input from experienced hydraulics specialists. This fact sheet does not provide sufficient information to allow energy dissipaters to be designed by inexperienced persons.

Photo 13 – Spillways <u>must</u> have a well-defined profile to fully contain the flow

Photo 14 – A suitable energy dissipater <u>must</u> be constructed at the base of the spillway

Design of rock mattress or concrete-lined energy dissipation pools:

The following design procedure and tables are provided as a guide only. This design information requires interpretation and application by experienced hydraulic design professionals.

Hydraulic design requires the estimation of flow depth, velocity, and Froude number at the base of the chute or spillway.

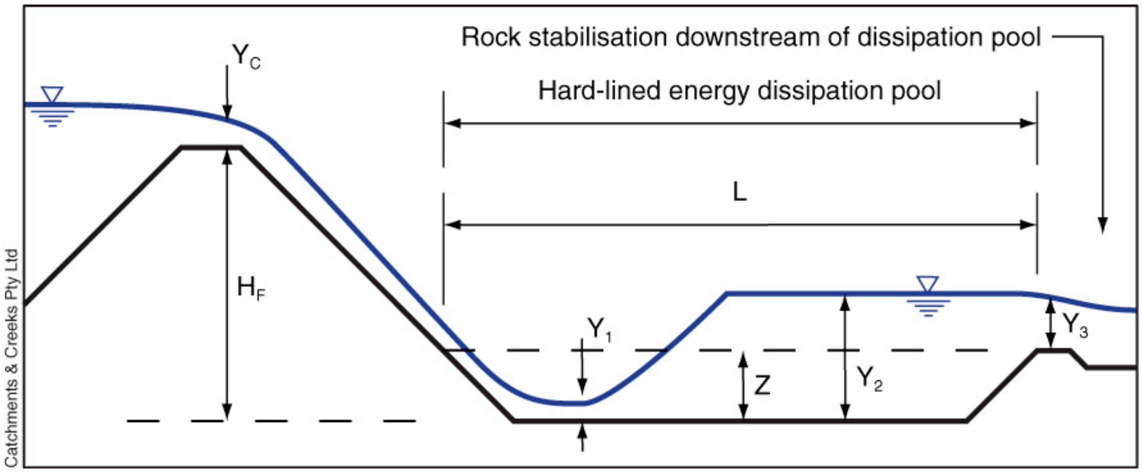

Figure 1 – typical profile of recessed, hard-lined energy dissipation pool located at the base of chute or spillway

Design steps:

1. Determine the flow depth (y_1), velocity (V_1) and Froude number (F_1) at the base of the chute for the design discharge.

$$F_1 = \frac{V_1}{\sqrt{g.y_1}} \quad \text{(Eqn 1)}$$

2. For flow conditions where $F_1 > 1$ (i.e. supercritical flow) and where the resulting hydraulic jump can be represented by 1-dimensional hydraulic analysis (i.e. a regular hydraulic jump contained within a rectangular channel), calculate the sequent depth (y_2) associated with the hydraulic jump.

$$y_2 = \frac{y_1}{2}\left(\sqrt{(1 + 8F_1^2)} - 1\right) \quad \text{(Eqn 2)}$$

3. Determine the probable tailwater conditions including water level and flow depth (y_3) downstream of the recessed energy dissipation pool. This downstream flow depth should not be less than the critical flow depth (y_c).

4. Determine the recess depth of the energy dissipation pool.

$$Z = y_2 - y_3 \quad \text{(Eqn 3)}$$

5. Calculate the desired length of the energy dissipation pool (L). Two equations can be used to determine this pool length, these equations are presented below as Equations 4 and 5.

$$L = 6y_2 \quad \text{(Eqn 4)}$$

$$L = 6.9(y_2 - y_1) \quad \text{(Eqn 5)}$$

An **approximate** length of the dissipation pool can be determined from Table 1 for an energy dissipation pool containing a standard, rectangular hydraulic jump. It is noted that hydraulic jumps formed within trapezoidal channels can be unpredictable in their shape and stability, potentially resulting in an increased length of the required energy dissipation basin.

Table 2 provides an **estimate** of the recess depth (Z) based on a downstream flow depth (y_3) equal to the critical flow depth (y_c). **Tables 1 and 2 should be used for preliminary design purposes only.**

Table 1 – Approximate length, L (m) of an energy dissipation pool containing a standard, rectangular hydraulic jump [1]

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	**0.3**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**	**5.0**
0.01	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.8	0.9	0.9
0.02	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.1	1.2	1.3
0.05	0.8	1.0	1.1	1.3	1.5	1.6	1.7	1.8	1.9	2.0
0.10	1.2	1.3	1.5	1.9	2.1	2.2	2.4	2.5	2.7	2.9
0.15	1.4	1.6	1.9	2.3	2.5	2.7	2.9	3.0	3.3	3.5
0.20	1.6	1.8	2.1	2.6	2.9	3.1	3.3	3.5	3.8	4.0
0.25	1.8	2.1	2.4	2.9	3.2	3.5	3.7	3.9	4.2	4.5
0.30	2.0	2.2	2.6	3.2	3.5	3.8	4.1	4.3	4.6	4.9
0.35	2.2	2.4	2.8	3.4	3.8	4.1	4.4	4.6	5.0	5.3
0.40	2.3	2.6	3.0	3.6	4.1	4.4	4.7	4.9	5.3	5.6
0.45	2.4	2.7	3.1	3.8	4.3	4.7	4.9	5.2	5.6	6.0
0.50	2.6	2.9	3.3	4.0	4.5	4.9	5.2	5.5	5.9	6.3
1.00	3.6	4.0	4.6	5.6	6.3	6.8	7.3	7.6	8.3	8.8
1.50	4.4	4.9	5.6	6.8	7.6	8.3	8.8	9.3	10.0	11.0

[1] Length of energy dissipation pool is based on an average of $6y_2$ and $6.9(y_2 - y_1)$, with y_1 based on a smooth chute (i.e. minimal friction loss), and y_2 determined from Table 5. Data is presented for preliminary design purposes only.

Table 2 – Approximate recess depth, Z (m) for an energy dissipation pool containing a standard, rectangular hydraulic jump [1]

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	**0.3**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**	**5.0**
0.01	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.12
0.02	0.06	0.06	0.08	0.10	0.11	0.12	0.13	0.14	0.16	0.17
0.05	0.08	0.09	0.11	0.15	0.17	0.19	0.20	0.22	0.24	0.25
0.10	0.10	0.12	0.15	0.20	0.23	0.26	0.28	0.29	0.32	0.35
0.15	0.12	0.14	0.18	0.24	0.27	0.30	0.33	0.35	0.39	0.42
0.20	0.14	0.16	0.20	0.26	0.31	0.34	0.37	0.40	0.44	0.47
0.25	0.15	0.18	0.22	0.29	0.34	0.38	0.41	0.44	0.48	0.52
0.30	0.16	0.19	0.23	0.31	0.37	0.41	0.44	0.47	0.52	0.57
0.35	0.17	0.20	0.25	0.33	0.39	0.43	0.47	0.50	0.56	0.60
0.40	0.17	0.21	0.26	0.35	0.41	0.46	0.50	0.53	0.59	0.64
0.45	0.18	0.22	0.27	0.37	0.43	0.48	0.52	0.56	0.62	0.67
0.50	0.19	0.23	0.29	0.38	0.45	0.50	0.55	0.59	0.65	0.71
1.00	0.24	0.29	0.37	0.50	0.59	0.67	0.73	0.78	0.87	0.95
1.50	0.28	0.34	0.43	0.58	0.69	0.78	0.86	0.92	1.03	1.12

[1] Recess depth is based on a downstream flow depth (y_3) equal to the critical flow depth, and y_1 based on a smooth chute (i.e. minimal friction loss). Data is presented for preliminary design purposes only.

Design of rock protection downstream of hydraulic jump energy dissipaters:

Equation 6 is the recommended equation for sizing rock placed within the zone of highly turbulent water immediately **downstream** of the end sill of an **energy dissipater** (i.e. not within the main energy dissipation zone).

$$d_{50} = \frac{(0.081).V^{2.23}}{(s_r - 1)} \qquad \text{(Eqn 6)}$$

where: d_{50} = nominal rock size (diameter) of which 10% of the rocks are smaller (m)

V = local, depth-average flow velocity immediately downstream of the end sill (m/s)

Design of rock-lined energy dissipation pools:

The following design procedure and tables are provided as a guide only. This design information requires interpretation and application by experienced hydraulic design professionals.

An **estimation** of the recess depth (relative to the downstream water level) of a rock-lined energy dissipation pool can be determined from Equation 7.

$$Z + y_3 = 4.75\frac{(H_F)^{0.2}\,q^{0.57}}{(d_{90})^{0.32}} \qquad \text{(Eqn 7)}$$

where: Z = Recess of energy dissipation pool relative to downstream ground level (m)

y_3 = depth of flow downstream of the energy dissipation pool at design flow (m)

H_F = fall in chute or spillway upstream of the energy dissipater (m)

q = design unit flow rate (m^2/s)

d_{90} = rock size, lining the dissipation pool, of which 90% of rocks are smaller (m)

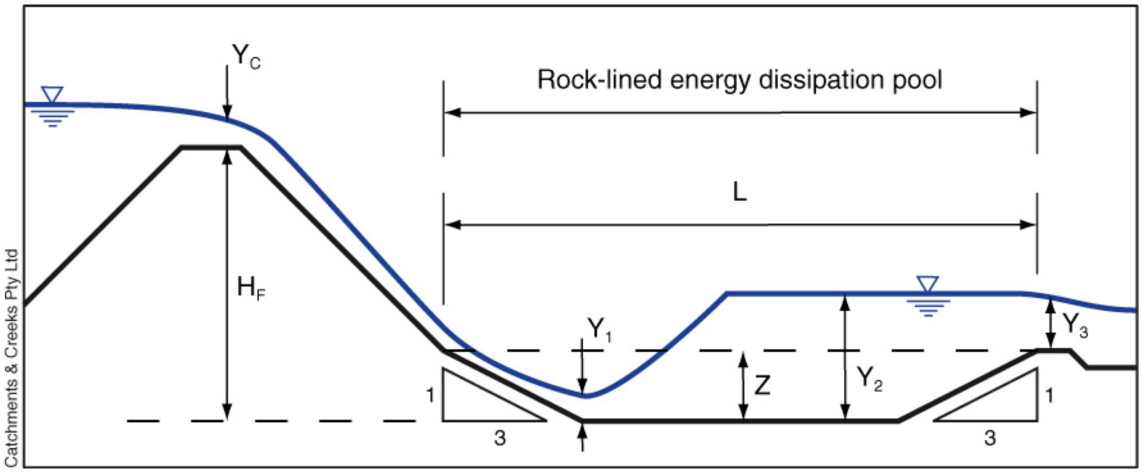

Figure 2 – Typical profile of rock-lined energy dissipation pool

The length of the dissipation pool (L) may be based on the same design procedures presented for a rock mattress or concrete-lined dissipation pool presented in the previous section.

Tables 3 to 5 provide an estimation of the recess depth (Z) for a mean rock size (d_{50}) of 200, 300 and 500mm, based on a rock size distribution, d_{50}/d_{90} = 0.5.

In circumstances where the energy dissipater is located downstream of a smooth channel surface (e.g. a concrete-lined chute or spillway), then the rocks located within the first quarter (minimum) of the dissipater basin should be grouted in place to avoid displacement. The displacement of loose rocks located immediately downstream of a smooth channel surface is partially caused by the changing boundary layer conditions from the smooth upstream channel to the rough, rock-lined basin.

Caution: trapezoidal chutes can result in the formation unstable, three-dimensional hydraulic jumps that may not dissipate energy as efficiently as rectangular chutes.

Table 3 – Approximate operating water depth within an energy dissipation pool ($Z + y_3$) lined with mean (d_{50}) 200mm rock, with rock size distribution, d_{50}/d_{90} = 0.5

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	**0.3**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**	**5.0**
0.005	0.23	0.24	0.27	0.31	0.34	0.36	0.37	0.39	0.41	0.43
0.01	0.33	0.36	0.40	0.46	0.50	0.53	0.55	0.57	0.61	0.64
0.02	0.50	0.54	0.60	0.68	0.74	0.79	0.82	0.85	0.90	0.94
0.04	0.74	0.80	0.89	1.02	1.10	1.17	1.22	1.27	1.34	1.40
0.06	0.93	1.01	1.12	1.28	1.39	1.47	1.54			
0.08	1.09	1.19	1.31	1.51						
0.10	1.24	1.35	1.49							
0.15	1.57									

Table 4 – Approximate operating water depth within an energy dissipation pool ($Z + y_3$) lined with mean (d_{50}) 300mm rock, with rock size distribution, d_{50}/d_{90} = 0.5

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	**0.3**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**	**5.0**
0.005	0.20	0.21	0.24	0.27	0.30	0.31	0.33	0.34	0.36	0.38
0.01	0.29	0.32	0.35	0.41	0.44	0.47	0.49	0.50	0.53	0.56
0.02	0.44	0.47	0.52	0.60	0.65	0.69	0.72	0.75	0.79	0.83
0.04	0.65	0.70	0.78	0.89	0.97	1.03	1.07	1.11	1.18	1.23
0.06	0.82	0.88	0.98	1.13	1.22	1.29	1.35	1.40	1.48	1.55
0.08	0.96	1.04	1.15	1.33	1.44	1.52				
0.10	1.09	1.18	1.31	1.51						
0.15	1.37	1.49								

Table 5 – Approximate operating water depth within an energy dissipation pool ($Z + y_3$) lined with mean (d_{50}) 500mm rock, with rock size distribution, d_{50}/d_{90} = 0.5

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	**0.3**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**	**5.0**
0.005	0.17	0.18	0.20	0.23	0.25	0.27	0.28	0.29	0.31	0.32
0.01	0.25	0.27	0.30	0.34	0.37	0.40	0.41	0.43	0.45	0.47
0.02	0.37	0.40	0.44	0.51	0.55	0.59	0.61	0.64	0.67	0.70
0.04	0.55	0.60	0.66	0.76	0.82	0.87	0.91	0.94	1.00	1.05
0.06	0.69	0.75	0.83	0.96	1.04	1.10	1.15	1.19	1.26	1.32
0.08	0.82	0.88	0.98	1.13	1.22	1.29	1.35	1.40	1.49	1.55
0.10	0.93	1.00	1.11	1.28	1.39	1.47	1.54			
0.15	1.17	1.27	1.40	1.61						
0.20	1.38	1.49								
0.25	1.56									