

Hydraulic Energy Management: Inlet and Outlet Design for Treatment Devices

July 2013

Technical Report: 2013/018



**Auckland
Council**
Te Kaunihera o Tāmaki Makaurau





Hydraulic Energy Management: Inlet and Outlet Design for Treatment Devices

July 2013

Technical Report 2013/018

Auckland Council
Technical Report 2013/018
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-927216-49-1 (Print)
ISBN 978-1-927216-50-7 (PDF)

This report has been peer reviewed by the Peer Review Panel using the Panel's terms of reference.	
Reviewed for Auckland Council by	
Name: Sam Blackbourn Position: Stormwater Technical Specialist Date: 15/07/2013	
Approved for Auckland Council publication by	
Name: Judy-Ann Ansen Position: Manager of Stormwater Technical Services Date: 15/07/2013	

Recommended citation:

Buchanan K, Clarke C, Voyde E, (2013). Hydraulic energy management: inlet and outlet design for treatment devices. Prepared by Morphum Environmental Limited for Auckland Council. Auckland Council technical report, TR2013/018

© 2013 Auckland Council

This publication is provided strictly subject to Auckland Council's copyright and other intellectual property rights (if any) in the publication. Users of the publication may only access, reproduce and use the publication, in a secure digital medium or hard copy, for responsible genuine non-commercial purposes relating to personal, public service or educational purposes, provided that the publication is only ever accurately reproduced and proper attribution of its source, publication date and authorship is attached to any use or reproduction. This publication must not be used in any way for any commercial purpose without the prior written consent of Auckland Council. Auckland Council does not give any warranty whatsoever, including without limitation, as to the availability, accuracy, completeness, currency or reliability of the information or data (including third party data) made available via the publication and expressly disclaim (to the maximum extent permitted in law) all liability for any damage or loss resulting from your use of, or reliance on the publication or the information and data provided via the publication. The publication, information, and data contained within it are provided on an "as is" basis.

Hydraulic Energy Management: Inlet and Outlet Design for Treatment Devices

Kim Buchanan

Caleb Clarke

Emily Voyde

Prepared for Auckland Council by:

Morphum Environmental Ltd

PO Box 99642

Newmarket, Auckland 1149

Executive Summary

Inlets and outlets of stormwater assets are used to provide a transition between the reticulation network, treatment devices and the receiving waters.

They are an integral part of the stormwater system and can affect whether the network is safe, whether treatment devices operate effectively, and whether erosion or other environmental problems occur. They also offer the space and opportunity to provide energy dissipation and mitigation measures to address high velocity stormwater flows, safety, or operational issues.

Many inlets and outlets are in reserves or other public spaces. Poor attention to critical design details can result in the area being unattractive, unsafe, underutilised, and unappealing. Poor design (or lack of design) also misses an opportunity for providing landscape or recreational elements.

This report provides information to supersede Chapter 13 and other sections of the former Auckland Regional Council Technical Publication 10 (TP10), Stormwater management devices: Design guidelines manual. Since TP10 was last revised there have been improvements in treatment technologies, a strong focus on low impact design, and more institutional and development community experience in designing appropriate treatment. This new report broadens the topic to include developing smooth inlet transitions and functional outlets for treatment devices and acknowledges that the stormwater network needs to integrate with the environment it sits in. It also acknowledges that a stormwater network is exactly that, a network of various reticulation, appurtenances, devices, and receiving streams that all need to work together optimally to achieve the goals of good stormwater management.

This report contains technical information regarding hydraulic energy management including fundamental energy and momentum relationships and equations. It discusses the concepts of hydraulic grade line design, provides information for outlet design, and includes methods for energy dissipation. It also discusses other design issues, such as providing for safety and addressing operational issues. Information is presented on materials that can be used for, and how to achieve, aesthetic and community outcomes. Finally a series of design checklists are provided to help identify key issues and promote robust design.

In addition to sections on hydraulics and inlet and outlet configurations, this report is organised around design considerations associated with the four well-beings: environmental, social, cultural, and economic. Environmental considerations include habitat, planting, and fish passage; social and cultural considerations include risk, safety, and amenity; while economic considerations include discussions regarding materials, long-term performance, and operation.

For extreme situations, those with very large flows or velocities over $5 \text{ m}^3 \text{ s}^{-1}$, for example, site specific design is encouraged and required. The bibliography provides a number of technical design guidelines that may be used in this instance.

Stormwater devices are intended to remove pollutants, reduce runoff volume and temporarily store runoff so that the impact on the receiving environment is minimised as far as practicable and there is no increase in downstream flooding. The degree to which inlets and outlets can contribute to the treatment effectiveness and ancillary benefits is large (and, for example, can make the difference between a device being an amenity or hazard). A key goal of inlet and outlet design is to minimise the energy and high velocities within a treatment device so it can operate effectively.

Typical approaches to energy dissipation include riprap, devices to induce hydraulic jump or generate turbulence, and flow transitions to reduce flows. Each of these methods requires some degree of space; this may dictate what approach should be used. If there is not enough room it will not be possible to use the method, or the method will not work as intended.

Maintenance is required of all devices. Inlets can be especially prone to blockage and outlets prone to erosion so proper design can result in lower long term maintenance costs.

The current desire of stormwater management practitioners to integrate with the environment presents challenges. However, if a designer perseveres they can complete a more integrated design accommodating aspirational notions and satisfying environmental, economic and even social and cultural objectives.

Table of Contents

1.0	Introduction.....	1
1.1	Background.....	2
1.2	Content and Organisation	2
1.3	Acronyms and Definitions	3
1.4	General Considerations	4
2.0	Technical Basis for Hydraulic Energy Management	5
2.1	Introduction.....	5
2.2	Energy and Continuity	5
2.3	Erosion and Sedimentation	6
2.4	Hydraulic Grade Design: Inlet and Outlet Control.....	8
3.0	Inlets: Reducing Erosion, Achieving Low Energy Flow	9
3.1	Inlet Flow Management	9
3.2	Level Spreaders	11
3.3	Flow Splitters and Diversions	16
3.4	Other Inflows.....	17
4.0	Outlets	18
4.1	Outlet Flow Management	18
4.2	Stage Discharge Outlets	20
4.3	Underdrains.....	23
4.4	Energy Dissipation	25
5.0	Design Considerations.....	38
5.1	Environmental Outcomes.....	38
5.2	Social and Cultural Outcomes	41
5.3	Economic Considerations	51
6.0	Approaches to Design.....	59
7.0	Conclusion	60
8.0	References and Further Reading.....	61
Appendix A	Riprap Sizing	A-1
Appendix B	Design Checklists	B-1

List of Figures

Figure 1: Poorly Designed, Poorly Constructed Rain Garden Inlet in a Public Reserve	1
Figure 2: Appropriate Fringe and Bund Planting of a Pond	9
Figure 3: Kerb Cuts	10
Figure 4: Boulders Distribute Inlet Flow	10
Figure 5: Vane Retrofitted Between Two Culverts.....	11
Figure 6: Simple PVC Level Spreader	12
Figure 7: Dispersal Bar with Suitable Supporting Structure and Outlet Holes.....	13
Figure 8: Poorly Designed and Constructed Level Spreader	14
Figure 9: Well Designed and Constructed Concrete Beam Level Spreader	14
Figure 10: Standard Level Spreader Design.....	15
Figure 11: Weir Splitter in Manhole	16
Figure 12: Outlet with Weir and High Level Intake	18
Figure 13: Riser Outlet.....	19
Figure 14: Perforated Riser Outlet	23
Figure 15: Riprap Channel Obscured by Riparian Planting.....	26
Figure 16: Riprap with Check Dam at Pond Spillway.....	27
Figure 17: Riprap Protection and Dissipation and Pipe Outfall.....	27
Figure 18: Simplified Riprap Sizing Chart	28
Figure 19: Hessian Bags filled with Weak Concrete	29
Figure 20: Standard Wing-wall Outlet with Apron, Fencing, Planting and Downstream Riprap	30
Figure 21: Riprap Apron Design Dimensions.....	31
Figure 22: Apron Length Sizing Based on Flow Velocity Exiting the Culvert	32
Figure 23: Concrete Aprons with Baffle Blocks Embedded for Energy Dissipation	33
Figure 24: Typical Baffle Block Arrangement and Spacing for Single or Double Outlet Jets.....	34
Figure 25: Bubble-up Pit Incorporating Drop Structure with Multiple Outlets (long-section)	36
Figure 26: Bubble-up Pit Incorporating Drop Structure with Multiple Outlets (profile).....	36
Figure 27: Bubble up Pit in Bush Gully Looking Downstream (left) and Upstream (right)	37
Figure 28: Outfall with Channel Rock Protection and Gabions to Protect Opposite Bank	38
Figure 29: Outfall Planting Plan	39
Figure 30: Example Stream Daylighting Concept	45
Figure 31: Cycleway Across Forebay Weir	46
Figure 32: Viewing Platform Hides Wetland Weir Detail	46
Figure 33: Pond Outlet Hidden Under Viewing Platform	47
Figure 34: Poor Finish on Concrete Weir	48
Figure 35: Culvert Apron with Cement, Sand and Shell Natural Finish	48
Figure 36: Outfall Energy Dissipation with Natural Finish.....	49
Figure 37: Grouted Rock Headwall.....	49
Figure 38: Outfall with Riprap and "Living Wall" Confined Earth Retaining Structure	50
Figure 39: Attractive and Unattractive Grilled Domes	50
Figure 40: Gabion Basket Outlet	52
Figure 41: Downturned Bend on Simple Outlet	54
Figure 42: Looking Inside Pond Service Outlet Chamber	54
Figure 43: Poorly Built Retrofitted Debris Grille.....	55
Figure 44: Debris Grille	55
Figure 45: Effective Debris Fencing Upstream of Critical Inlet.....	56

Figure 46: Large Inlet Structure with Maintenance Access and Numerous Grilles.....	56
--	----

List of Tables

Table 1: Maximum Velocities for Erosion Control.....	7
Table 2: Level Spreader Design Criteria.....	15
Table 3: Rock Check Dam Design	20
Table 4: Inlet and Outlet Hydraulic Energy Management Checklist	B-1
Table 5: Inlet and Outlet Design Considerations Checklist	B-3

1.0 Introduction

Inlets and outlets are used to provide a transition between the reticulation network, treatment devices, and the receiving waters.

They are an integral part of the stormwater system and can affect whether the network is safe, whether treatment devices operate effectively, and whether erosion or other environmental problems occur. They may also offer the opportunity to provide the energy dissipation and mitigation measures to address high velocity stormwater flows, safety, or operational issues.

Many inlets and outlets are in reserves or other public spaces. Poor attention to critical design details can result in the area being unattractive, unsafe, underutilised, and unappealing (Figure 1). Poor design (or lack of design) also misses an opportunity for providing landscape or recreational elements.



Figure 1: Poorly Designed, Poorly Constructed Rain Garden Inlet in a Public Reserve

Urban development has the potential to increase stormwater volumes and peak flows, alter the timing of runoff events, and reduce baseflow to streams. This often results in concentrated discharges and high water velocities. Scour and downcutting of stream beds and bank erosion occurs which leads to a reduction in aquatic habitat values, siltation, and reduced fish passage. Within the stormwater network itself, high stormwater volumes and velocities exacerbate flooding risk, can overwhelm treatment devices, and even cause components to fail.

The purpose of this report is to provide ideas and information for developing appropriate design for inlets and outlets that provide a smooth transition between network elements, dissipate energy, allow treatment devices to operate as they are intended, and ensure maintenance requirements are minimised.

1.1 Background

This report provides information to supersede Chapter 13 and other sections of the former Auckland Regional Council Technical Publication 10 (TP10), Stormwater management devices: Design guidelines manual. The most recent version of TP10 is the second edition, published in 2003 (ARC, 2003). Since that time there have been improvements in treatment technologies, a strong focus on low impact design, and more institutional and development community experience in designing appropriate treatment. This report presents an opportunity to incorporate the wealth of experience from stormwater operators and designers developed over the past 10 years.

The original Chapter 13 in TP10 addressed stormwater outlet protection and was focussed on outlets discharging to marine and freshwater receiving environments. This new report broadens the topic to include developing smooth inlet transitions and functional outlets for treatment devices and acknowledges that the stormwater network needs to integrate with the environment it sits in. It also acknowledges that a stormwater network is exactly that, a network of various reticulation, appurtenances, devices and receiving streams that all need to work together optimally to achieve the goals of good stormwater management.

This project has drawn from a literature review on outfall structures (Miselis and Goodfellow, 2010), draft revised TP10 chapters in review, and operational experience by a number of local area engineers. It also includes review and incorporation of information provided in earlier Technical Publications by the former Auckland Regional Council and other data sources which are included in Section 8.0.

1.2 Content and Organisation

This report contains technical information regarding hydraulic energy management including fundamental energy and momentum relationships and equations. It discusses the concepts of hydraulic grade line design; provides information for outlet design and includes methods for energy dissipation. It also discusses other design issues, such as providing for safety and addressing operational issues. Information is presented on materials and methods to achieve aesthetic and community outcomes. Finally a series of design checklists are provided to help identify key issues and promote robust design.

In addition to sections on hydraulics and inlet and outlet configurations, the report is organised around design considerations associated with the four well-beings: environmental, social, cultural and economic. Environmental considerations include habitat, planting, and fish passage considerations; social and cultural considerations include risk, safety, and amenity; while economic considerations include discussions regarding materials, long-term performance, and operation.

The guideline is not intended to be an exhaustive treatise on hydraulic design and energy dissipation. There are alternative design approaches to those included in this report and this work is not intended to preclude other appropriate and robust design methodologies. Rather it is intended to provide guidance on common issues associated with inlets and outlets, particularly associated with treatment devices and particularly within the Auckland Region. For extreme situations, those with very large flows or velocities over $5 \text{ m}^3 \text{ s}^{-1}$, for example, site specific design is encouraged and required. The bibliography in Section 8.0 provides a number of technical design guidelines that may be used in this instance.

This guideline is for engineers, developers, landscapers and designers to assist them in providing acceptable solutions. This report should be read in conjunction with other best practice design guides, including Engineering Standards for Design and Construction, and existing ARC technical publications.

1.3 Acronyms and Definitions

For the purposes of this report **inlet** refers to the inlet to a treatment device. The term **outlet** refers to the outlet of the device which may include a service outlet, outlet culvert, high or low flow weirs, underdrains, etc. or a combination of the above. The discharge part of a network, to a stream or coastal receiving environment is the **outfall** and would include pipes, culverts, headwalls, etc.

Apron – Energy dissipation structure provided at base of culvert outfall and could be formed from concrete or rock.

Critical flow – Critical flow conditions are those where the specific energy of the flow is minimised, $F_o = 1$.

Froude Number, $F_o = v/(g \times d_p)^{0.5}$ where $g = 9.8 \text{ m s}^{-2}$ and d_p = depth of flow in an open channel. Froude numbers are dimensionless numbers that represent the ratio between the bulk velocity (v) and the propagation velocity of a shallow wave. Froude numbers are used to characterise flow and can help determine whether or what type of energy dissipation may be needed.

GPT – Gross pollutant trap

Head – Broadly speaking, head represents potential energy and includes elevation differences, friction losses, and inlet/outlet losses.

Headwall – A formed surround on a culvert inlet or outlet intended to minimise erosion and to direct flow.

Headwater – The total flow depth in the upstream channel measured from the culvert invert.

Hydraulic jump – An abrupt change in the water surface level when a shallow high velocity flow transitions into a deeper, lower-velocity flow. During hydraulic jumps energy dissipates and head loss occurs so that the downstream flow (known as subcritical flow, $F_o < 1$) contains less energy than the upstream (supercritical flow, $F_o > 1$).

Inlet Control – Inlet control occurs on typically steeper culverts when the inlet configuration controls the hydraulic capacity of the culvert.

Outlet Control - Outlet control occurs when hydraulic capacity is governed by friction along the culvert and the tailwater depth.

PE - Polyethylene

Riprap - a layer of rock used to protect soil from erosion in areas of concentrated runoff, and to armour stream beds, banks and shorelines.

Specific energy – Specific energy of flow in an open channel is defined by the sum of its kinetic and potential energy per unit weight of flowing liquid relative to the channel bottom.

Subcritical flow – Characterised by slower velocity, deeper flow (more than critical flow depth) on a shallow channel slope, $F_o < 1$.

Supercritical flow – Characterised by high velocity, shallow flow (less than critical flow depth) on a steep channel slope, $F_o > 1$.

Tailwater – The total flow depth in the downstream channel measured from the invert of the culvert outlet.

Tomos – Holes formed by seepage through soil cracks which erodes fine grained clay soil leaving a void. This void can undermine culvert outlet aprons or other hydraulic structures. Geotextile fabrics or granular filter layers are installed under hydraulic structures to avoid tomos.

D₅₀, D₁₀₀ – Riprap diameter; D₅₀ is the median riprap diameter, while D₁₀₀ is the maximum diameter.

1.4 General Considerations

Stormwater treatment devices are intended to remove pollutants and temporarily store, infiltrate, and/or evapotranspire runoff so that the impact on the environment is minimised and downstream flooding is adequately managed. The degree to which inlets and outlets can contribute to treatment effectiveness and ancillary benefits is large (and, for example, can make the difference between a device being an amenity or hazard). A key goal of inlet and outlet design is to minimise the energy and high velocities within a treatment device so it can operate effectively.

Velocity control and energy dissipation should be considered as part of a larger system design that could include culverts, treatment devices, channel protection, and channel enhancement.

Typical approaches to energy dissipation include installing riprap, introducing flow transitions to reduce velocity, and devices to generate turbulence or induce hydraulic jumps. Each of these methods requires some degree of space; this may dictate what approach should be used, and if there is not enough room the method will not work.

Maintenance is required of all devices. Inlets can be especially prone to blockage and outlets prone to erosion so proper design consideration can result in lower long term maintenance costs.

The current desire of stormwater management practitioners to integrate with the environment presents challenges. However, if a designer perseveres they can complete a more integrated design accommodating aspirational notions and satisfying environmental, economic, and even social and cultural objectives.

2.0 Technical Basis for Hydraulic Energy Management

2.1 Introduction

Designing appropriate inlets and outlets is primarily about energy management. Low energy environments promote laminar flow and allow particles to settle while high energy can induce shear stresses and cause erosion and sediment resuspension.

Energy is in the form of kinetic energy (velocity) and potential energy (elevation head). Besides manipulating these energy parameters, inducing energy losses (e.g. dissipation) is the only other parameter that a designer can utilise. The key is to manage energy reduction in a controlled situation, like a manhole, riprap apron, or forebay, rather than within the treatment device or downstream receiving water.

This section discusses the basic hydraulic equations that describe energy and identifies how specific variables contribute to energy management.

2.2 Energy and Continuity

Two key equations that engineers apply in hydraulics are:

Continuity	$Q = A \times v$	Equation 1
------------	------------------	------------

Bernoulli	$H_E = \frac{p}{\gamma} + \frac{v^2}{2g} + h$	Equation 2
-----------	---	------------

Where;

Q	= flow discharge, m ³ s ⁻¹
A	= cross-sectional area, m ²
v	= velocity, m s ⁻¹
H _E	= total energy head (potential and kinetic), m
$\frac{p}{\gamma}$	= pressure head, m
$\frac{v^2}{2g}$	= velocity head, m
h	= elevation head, m
g	= 9.81 m s ⁻² gravitational acceleration

Usually, Equation 2 is used to equate upstream and downstream energy head so that:

$$\frac{v_1^2}{2g} + h_1 = \frac{v_2^2}{2g} + h_2 + h_L \quad \text{Equation 3}$$

Where;

h _L	= head losses (e.g. entrance, exit, friction), m
1 and 2	= upstream and downstream locations

Note that with open channel flow pressure is atmospheric and the same at locations 1 and 2, so pressure cancels out.

The key aspect of Equation 1 and Equation 2 is that the most direct way to reduce energy is to increase the cross sectional area for a given flow. Secondly, Equation 2 and Equation 3 show that total energy head is reduced if velocity head is reduced or friction (e.g. head losses) is increased.

Velocity derived through hydraulic modelling, or other formulae, can be compared to the maximum permissible velocities for natural channels in Table 1 to consider whether and how much energy dissipation is needed.

2.2.1 Summary of Useful Formulas

A variety of outlet design equations for weirs and orifice devices are given in Section 4.2.1.

2.3 Erosion and Sedimentation

In addition to hydraulic function relating to the frequency, duration and scale of velocity, inlets and outlets play a part in the physical functions of erosion and sedimentation which are governed by a number of physical factors.

2.3.1 Erosion

Erosion is the process of breaking down and wearing away soil and other materials of the earth's surface. Erosion occurs through natural weathering, abrasion, corrosion, and transportation, but these processes accelerate when urban runoff is concentrated. In addition to water velocity, the amount and degree of erosion is related to the soil type and whether it is colloidal, cohesive or granular, or whether the land is subject to tomos and other geologic phenomena. The slope of the banks and channel bed, and whether there is vegetation or other surface protection, also controls erosion.

Erosion from stormwater discharges typically takes the form of local scour in the vicinity of the pipe or channel outfall, or general channel degradation downstream. General channel degradation is due to increased stormwater runoff volumes from urbanisation within a catchment. In the context of inlet and outlet design, local scour resulting from high velocity flow at the outlet is the predominant erosion concern.

For discharges to natural streams or gullies the erosion potential can be evaluated by calculating the outfall exit velocity and comparing it to the velocities that cause erosion in different channel materials as listed in Table 1. Natural channel velocities are typically less than outlet velocities, because the channel cross section is larger than the pipe flow area and roughness (frictional resistance) of the natural channel is greater than that of a concrete pipe. However, over a short distance from the outlet, the channel characteristics adjust to a pattern controlled by the outlet velocity. Note that the Table 1 velocities are general guidelines and site specific factors such as channel grade, material compaction, or percentage and robustness of vegetation may affect erosion potential.

Outlet and outfall design can reduce erosion potential by:

- Avoiding drops from outfalls or aprons to the watercourse.
- Minimising pipe grade to the outlet.
- Aligning outfall discharge with stream flow so that jetting or high velocity flows against opposite stream banks are avoided.

- Undertaking modifications to the surface treatments including riprap and planting. Establishment of robust vegetation including strong root formations is preferable due to accompanying increases in friction, long term stability, and added environmental, amenity, and cultural benefits.
- Reducing flow velocities and dissipating energy.

Table 1: Maximum Velocities for Erosion Control

Material	Maximum velocities for erosion control in unlined channels ^a (m s ⁻¹)
Fine sand, colloidal	0.5
Sandy loam, noncolloidal	0.5
Silt loam and Alluvial silt, noncolloidal	0.6
Ordinary firm loam	0.8
Volcanic ash	0.8
Stiff clay and Alluvial silt, colloidal	1.1
Shales and hardpans	1.8
Fine gravel	0.8
Graded loam to cobbles, noncolloidal	1.1
Graded silt to cobbles, colloidal	1.2
Coarse gravel	1.2
Cobbles and Shingles	1.5
Tussock type grasses ^b	0.5–1.3
Couch, carpet and sward –forming grasses ^b	1.4–2.0
Kikuyu grass ^b	1.9–2.5

a) From Stormwater Treatment Standard for State Highway Infrastructure (NZTA, 2010) and Brisbane City Council (2003).

b) Range presented as values are dependent on vegetation health and cover, and soil erodibility (Brisbane City Council, 2003).

2.3.2 Sedimentation

Sedimentation is the process of particles being deposited at the bottom of a body of water. This usually occurs when velocity is low and when there is enough residence time for settlement to occur. As well as particle size and density, other physical/chemical processes, such as flocculation, may influence settlement rates.

Stormwater treatment devices may include pre-treatment or treatment trains to maximise sedimentation and provide treatment for a range of particle sizes. Inlet and outlet design can promote sedimentation in the following ways:

- Inlets should disperse flow across the treatment device at the lowest velocity possible

- Inlets and outlets should be positioned to maximise residence time and not allow short-circuiting through the device
- Inlets and outlets should be positioned high enough relative to permanent water levels within the device so that jetting or high velocity flows do not cause resuspension of already settled particles
- Inlets should be positioned at an elevation that avoids excessive submergence by permanent and temporary elevated water levels in the device, as this can lead to deposition and blockage of upstream networks. If a submerged outlet is required due to level or other constraints, the effects of upstream sedimentation should be taken account in the design or through maintenance planning.
- Outlets should be positioned, below elevated water temperatures near the surface of the ponding zone and above the base sediments to avoid sediment resuspension.

2.4 Hydraulic Grade Design: Inlet and Outlet Control

Typical design considerations for stormwater conveyance systems either side of treatment devices include whether a system operates under inlet or outlet control. This relates to a consideration of the hydraulic grade of the conveyance system. The Bernoulli Equation (Equation 2 above) provides a tool to assess the hydraulic grade through a system, and can lead to an understanding of the dynamic water and energy head levels through the system under varying flow conditions. For complex situations a hydraulic grade line assessment could be conducted using hydraulic modelling software or by conducting hydraulic grade line design through the device. Alternatively, as a minimum, consideration should be given to whether the elements above and below the treatment device would function under inlet or outlet control.

Inlet control occurs on typically steeper systems, such as culverts, when the inlet configuration controls the hydraulic capacity of the culvert and the outlet is relatively free-flowing. Typically inlet head losses are high and flow within the culvert is supercritical (Froude numbers, $F_o > 1.0$). Under inlet control, if the outlet is not submerged and the differences between the upstream and downstream head is large, the flow contracts to a supercritical jet, hydraulic jumps can form, and flow is turbulent with high velocities. This is unlikely to promote good downstream treatment efficiency.

Important design factors associated with inlet control are headwater depth and entrance conditions. Roughness, length and outlet conditions are relatively unimportant when calculating flow rates or resultant velocities. Inlet control is often utilised at treatment devices such as flow splitters (Section 3.3), or at outlets to govern storage functions within the device. In these situations, the subsequent dissipation of the velocity created by the inlet control can be important to ensure optimal conditions for treatment occur and to minimise sediment re-suspension and scour.

Outlet control occurs when hydraulic capacity is governed by friction through the hydraulic element and tailwater depth. Hydraulic performance is defined by the difference between headwater and tailwater depth, inlet condition, and pipe slope, roughness and length. Under outlet control, flow is typically subcritical ($F_o < 1.0$). Outlet control allows the designer to utilise friction losses and tailwater depth to help reduce velocity. An example of outlet control on a treatment device can be the design of inlets to be submerged during live detention engagement, allowing for energy dissipation during high flow, times that may otherwise be responsible for excessive velocities and re-suspension.

3.0 Inlets: Reducing Erosion, Achieving Low Energy Flow

There are a number of methods that can promote low energy inflow. These include manipulating inlet conditions, dispersing inflows, and introducing friction. In Figure 2 appropriate fringe and bund planting reduces edge erosion, promotes uniform flow and quiescent conditions.



Figure 2: Appropriate Fringe and Bund Planting of a Pond

3.1 Inlet Flow Management

If possible, the inlet to a pond or wetland should be submerged to dissipate the energy of the inflow. However, the inlet should be well above the base to minimise the resuspension of settled sediments.

There are other mechanisms for introducing stormwater into a treatment device aside from culverts. These include:

- Disperse low velocity flow across a landscaped area or through a grassed filter strip.
- Disperse flow through kerb cuts. Figure 3 shows kerb cuts that provide a distributed inlet to a roadside treatment device.
- Disperse flow across pavement and/or past wheel stops for parking areas. The boulders shown in Figure 4 serve to protect a rain garden from traffic and provide distributed inlet flow
- A flow spreading trench around the perimeter of a bioretention area. This could be filled with coarse rock, pea gravel or river stone, or formed as a vegetated swale.



Figure 3: Kerb Cuts



Figure 4: Boulders Distribute Inlet Flow

The design and location of inlets should consider pedestrian and vehicle traffic safety and comfort. A gutter inlet (e.g. catchpit) may be more efficient than a kerb inlet (Figure 3, Figure 4) in capturing gutter flow, but clogging by debris is a problem. However, there are a number of combination gutter inlets that provide some segregation of debris. Information on these types of inlets will be found in transport drainage specifications and through manufacturers.

3.1.1 Booms, Vanes, Baffles, and Anti-Vortex Devices

Other inlet design features that may be considered include various booms, vanes, or baffles. Generally booms and baffles promote uniform flow (reducing areas of high energy flow), while vanes and anti-vortex devices are used to reduce turbulence (which can cause scour).

Floating booms can be used to segregate floatables and oil for collection and/or to reduce blockage potential.

Although more common for wastewater applications, vanes and baffles can be used to help achieve uniform flow or deliberately separate an inlet from an outlet to prevent short-circuiting. There are two general types of baffles: solid baffles, perpendicular to flow to change flow direction; and perforated baffles, such as gabions or concrete baffles with perforations, which are used to break up a jet flow into a more uniform, lower velocity flow across a larger area.



Figure 5: Vane Retrofitted Between Two Culverts

Figure 5 shows a vane profile which was retrofitted to a culvert system that had extremely poor inlet conditions that caused turbulence, excessive spray, and reduced inflow. Although this vane has increased hydraulic efficiency and conserved energy in the flow (i.e. it has not reduced velocities), it did reduce gross turbulence that caused scour and erosion. Section 4.4.3.2 discusses baffles used for energy dissipation.

3.2 Level Spreaders

The purpose of level spreaders is to disperse concentrated flows and promote low velocity sheet flow. They are commonly installed:

- upstream of filter strips or riparian buffer areas to help prevent rill erosion or preferential flow paths
- as inlets to:
 - rain gardens
 - ponds and wetlands
 - sandfilters or cartridge filters (downstream of flow splitters)
- to provide dispersed flow from rain tank overflows.

Level spreaders can have several forms including wood or concrete beams, subsoil drain pipes and gravel filled trenches, perforated PVC pipes laid level and parallel with the ground contour (Figure 6), or dispersal bars laid level and parallel with the ground contour but elevated above the surface (Figure 7). These devices serve to spread discharges from a system over a sufficiently large area to avoid concentrated flow.

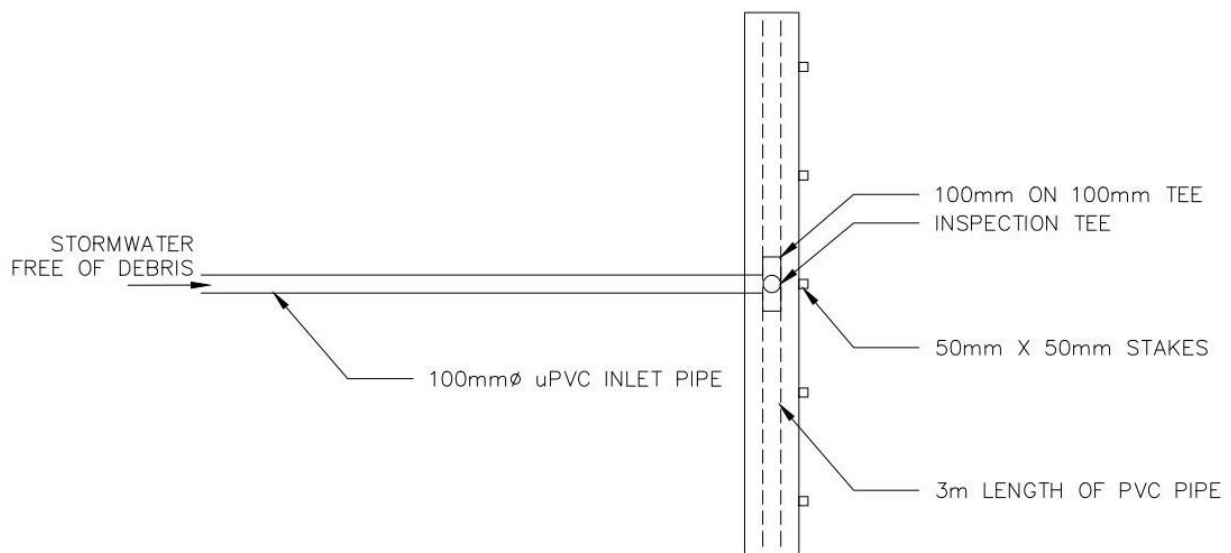


Figure 6: Simple PVC Level Spreader



Figure 7: Dispersal Bar with Suitable Supporting Structure and Outlet Holes

The key aspect of level spreaders is that they are absolutely level; some designs which rely on perforated PVC pipe pegged into the ground by drainlayers with no levelling equipment are notorious for not being truly level and then not performing as intended. While these may be adjustable, that often does not occur. A more robust method would be a cast in place concrete level beam where the forms can be properly levelled and a screed used to level the concrete (Figure 9 and Figure 10).

Figure 8 is an example of a poorly designed level spreader: it is not level, there is exposed reno mattress and formwork, and erosion has occurred around the sides of the level spreader bar. Therefore, it is important to ensure the terminations are elevated or otherwise stabilised against erosion and piping. For example, the ends of the level spreader could be extended and buried into the banks of the channel to prevent scouring in large events. Similar consideration should be taken to prevent the level spreader being undercut.

Even though level spreaders seek to distribute flow as low velocity sheet flow, downstream erosion protection may still be needed. Figure 9 demonstrates a well designed and constructed level spreader: elevated ends are buried into the banks, appropriate downstream erosion protection is provided and upstream erosion protection prevents undercutting.

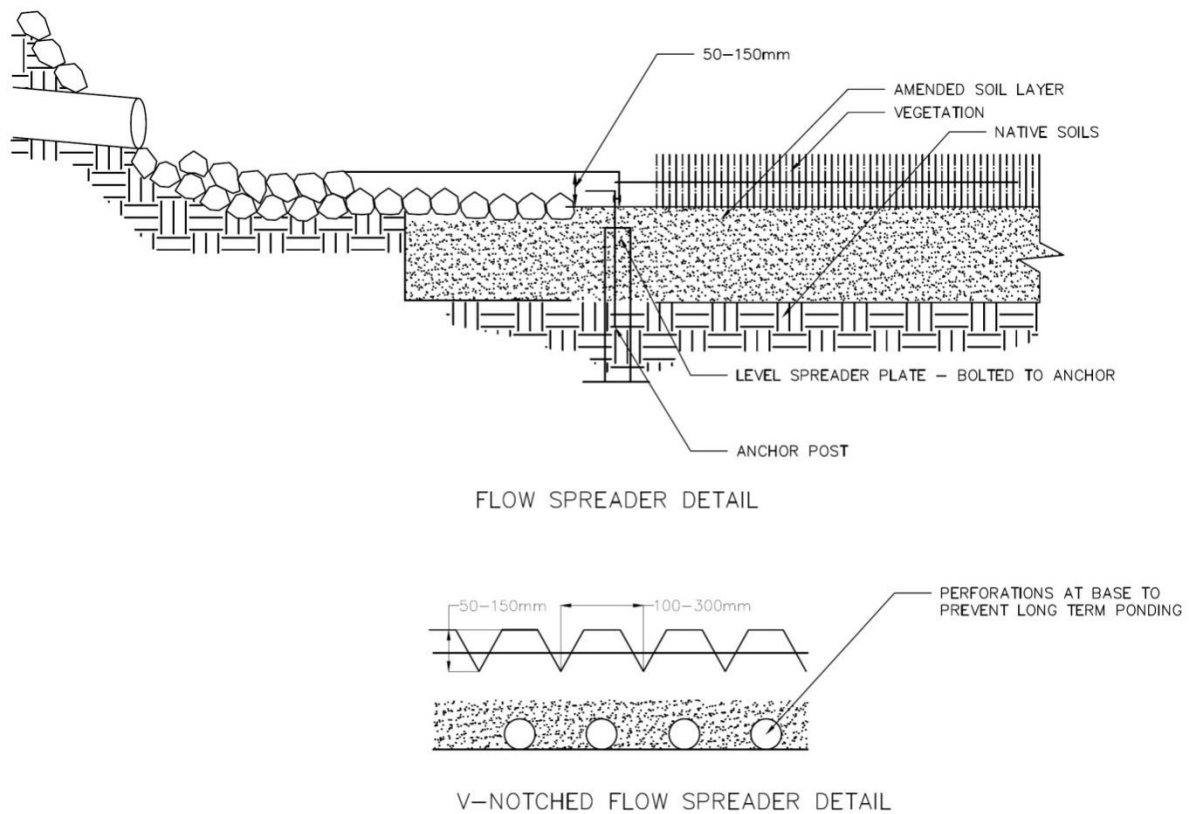
Another alternative is incorporating v-notched flow spreader plates, as shown in Figure 10, which are less sensitive to minor inconsistencies in level. Typically flow spreader plates, whether v-notched or not, are designed to be adjustable.



Figure 8: Poorly Designed and Constructed Level Spreader



Figure 9: Well Designed and Constructed Concrete Beam Level Spreader



NOTE:
1. ANCHOR POSTS SHALL BE CONCRETE, WOOD, STEEL OR OTHER MATERIAL RESISTANT TO DECAY.

Figure 10: Standard Level Spreader Design

Recommended minimum sizing parameters for a lateral overflow spreader are presented in Table 2. These values are taken from Table 1.10 in TP90 (ARC, 1999) and are also presented in international literature (SUDAS, 2013; USDA NRCS, 2012). Other literature recommends greater minimum lengths, of 3.9 m per $0.03 \text{ m}^3 \text{ s}^{-1}$ flow, to limit erosion in the vegetated buffer zone below the level spreader (VA DCR, 2011; Hathaway & Hunt, 2006). Otherwise, a level spreader could be sized using formulas for broad crested weirs.

Table 2: Level Spreader Design Criteria

Design flow ($\text{m}^3 \text{ s}^{-1}$)	Parallel Inlet Channel Width (m)	Depth (mm)	Length (m)
0 – 0.3	3	150	3
0.3 – 0.6	5	180	7
0.6 – 0.9	7	220	10

A proper entrance angle to the level spreader is important to prevent short circuiting. Ideally the direction of inlet flow should be parallel to the level spreader bar, to most effectively diffuse flow. Design flows should be relatively small and depth of flow across the spreader shallow (below

200 mm). The downstream reach should be stable, not steep, and protected from erosion (via riprap or planting).

3.3 Flow Splitters and Diversions

Flow splitters are incorporated into inlet configurations so that flow in excess of the design capacity of a treatment device can be diverted safely away in a controlled manner. They are commonly used for soakage devices and some gross pollutant traps (GPTs), such as centrifugal debris separators, and less commonly used with ponds, wetlands, and rain gardens. Flow splitters can improve treatment efficiency, reduce the likelihood for sediment resuspension (due to high flows), and in some cases reduce the size of the treatment device.

Flow diversions are specifically designed depending on the situation, but often are developed via a weir formed inside a manhole (Figure 11). Weirs can be formed with concrete or by a plate fixed to the concrete manhole. Runoff enters the manhole with the normal discharge to the treatment device on one side of the weir with high flows overtopping the weir and exiting through a secondary outlet. Smooth benching and concrete finishing is important so that turbulence is minimised. It is also important to consider maintenance access and whether the diversion will ‘trap’ debris or become blocked.

Flow splitters are often used to divert large event, high velocity flows away from a treatment device to avoid scour and sediment re-suspension. In this case, the water quality volume or 2-yr ARI flow (for example) is passed through the device with flows in excess being diverted. This is not allowable where the treatment device also provides attenuation.

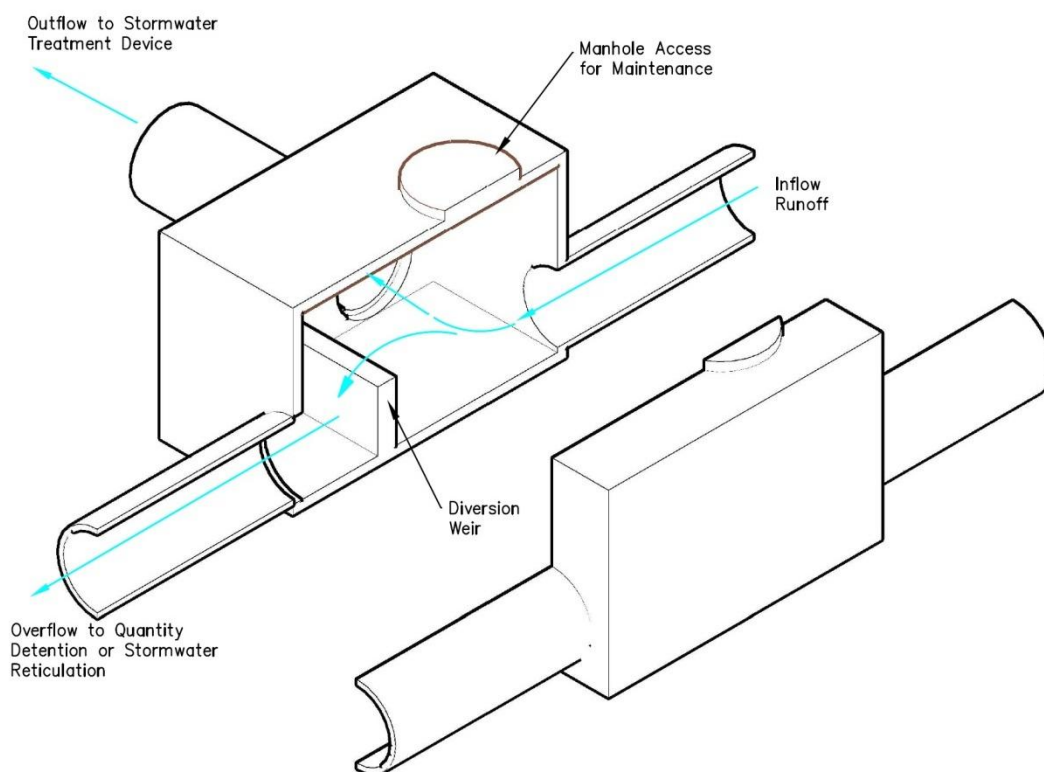


Figure 11: Weir Splitter in Manhole

3.4 Other Inflows

The inlet to a treatment device is also likely to be the location where other sources of water may concentrate and enter the device or network. As the low point for the upstream catchment, the inlet can concentrate and intercept groundwater flows, overland flows can discharge over the bank and across the headwall of an inlet, and soil drainage and private drainage outlets also often terminate at this location. All of these inflows should be considered in an inlet design.

3.4.1 Ground Water Infiltration

Groundwater can saturate the substrate and increase pore pressure, resulting in gradual mobilisation of material and soil regression or tomos. These discharges can increase the risk of erosion. The following treatments should be considered to mitigate this risk:

- Riprap and Planting - can provide erosion resistance for substrates vulnerable to frittering from groundwater discharge. This can be in addition to a primary outlet treatment.
- Perforated pipe – Installation of drainage media and a perforated pipe can be used to release groundwater that may collect in the vicinity of treatment device inlets (also known as sub-soil drains and underdrains).
- Geotextile fabric – There are specific geotextiles that have been developed to act as a drainage blanket to relieve pressure and facilitate drainage.

3.4.2 Overland Flow

Overland flowpaths descending to inlets can carry large volumes of high velocity water and rapidly erode and dislodge inlet structures. This flow must be allowed for in design, including any increase in the risk of erosion. The following treatments should be considered to mitigate this risk:

- Inlet wingwalls – precast wingwalls are designed to form a stable terminus for pipe networks and will provide an anchor and erosion resistant surface for overland flows cascading from above.
- Riprap and Planting - can provide erosion resistance for substrates vulnerable to frittering erosion by cascading overland flows. This can be in addition to a primary outlet treatment such as a precast wingwall, in order to protect knickpoints higher up the face.

4.0 Outlets

Outlets should be designed to address all flow conditions, to be safe, and to protect the receiving environment. Low energy discharges can be promoted by outlet design, sizing the outlet pipes large, and reducing head through drop outlets. Providing downstream energy dissipation will be required to compensate for higher velocities and allow for flow transitions from engineering structures to more natural flow regimes.



Figure 12: Outlet with Weir and High Level Intake

4.1 Outlet Flow Management

A large category of outlets are manhole riser outlets that can include low flow orifices and multistage weirs with high flows entering across the entire rim of the manhole (Figure 12). Key design issues include debris, access (for maintenance and preventing unauthorised access) and safety.

As many of these outlets discharge from a stormwater pond to a stream or coastal area, steep outlet pipe grades and the potential for downstream erosion are common. Key design practices should include:

- Try to obtain as much energy dissipation as possible within the service outlet manhole itself (Section 4.4.5). This could include installing baffle blocks or having a sump within the base of the manhole to dampen flow energy.
- Outlets should discharge downstream in the dominant direction of flow in order to avoid erosive turbulence, or ‘waterblasting’ of the opposite bank. The preferred approach is to align the outlet (and channel recovery reach) at no more than a 45° angle to the stream.

Where this is not possible, riprap could be placed on the opposite bank to a minimum height of 300 mm above the elevation of the pipe crown, depending on channel width.

- Incorporate flow expansion or channel recovery reaches (Section 4.4.1). As the flow area expands, flow velocity will reduce to maintain continuity (Equation 1).
- Treatment devices (such as ponds, wetlands, online devices, sand filters, etc.) should include a gravity drain, if possible, to facilitate maintenance activities.
- Consider installing prefabricated polyethylene (PE) bends on small culvert outlets to direct water in the direction of flow.

4.1.1 Orifice and Low Flow Outlets

Orifices are a specific type of outlet that convert potential energy (e.g. elevation head) to kinetic energy (velocity) and by their nature have low volume, high velocity flow. Considerations include:

- Generally service outlets should have orifices no smaller than 50 mm to avoid blockage. This requirement can be relaxed for orifices to be no smaller than 30 mm for multiple orifice outlets (e.g. multistage outlets or perforated level spreader pipes, or low flow control on rain tanks).
- Orifices or low flow outlets should be located a minimum of 150 mm from the base of a pond (100 mm above the base of a rain tank) to prevent resuspension of sediment.
- Low flow outlets or orifices are prone to blockage. If the design includes a reverse sloping pipe (Figure 13) or a siphon, then water will be withdrawn below the water surface and the outlet will be less prone to blockage by floating debris.
- It is recommended that low flow outlets or orifices be designed to mitigate the adverse temperature effects associated with ponds or unshaded channels. By inclusion of a siphon, baffle plate, or reverse sloping pipe, the outlet can pick up the lower, cooler water than the very uppermost warmest water at the surface that would spill over a weir outlet.
- However, reverse sloping pipes are poor for fish passage. They will be best utilised when there is no upstream habitat, for example when connected to an entirely reticulated system or other offline pond.

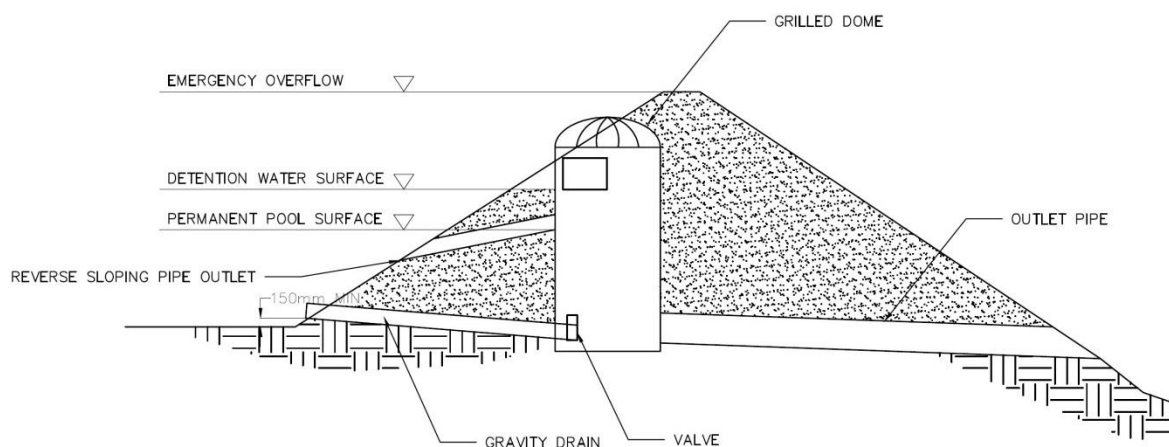


Figure 13: Riser Outlet

4.1.2 Spillways and Overland Flowpaths

Treatment devices, particularly ponds and tanks, often include a storage function and in storm flows may need to discharge in excess of their primary outlet capacity. Devices including rain gardens, soakage and sand filters rely on infiltration and there are times when the filtration/infiltration capacity may not keep pace with the inflow rate. While these discharges occur at a reduced frequency, they must be accommodated as they have the potential to create erosion and hydraulic turbulence. Therefore high flow bypasses, overflows, and overland flowpath conveyance should be incorporated into most treatment device design.

4.1.3 Check Dams

Check dams provide one means of reducing flow velocity and erosion and controlling channel grade. They are utilised in swales and potentially in overland flow paths, emergency spillways artificial channels, and ephemeral gullies where the soils are erodible.

The top of the check dam, perpendicular to flow, should be parabolic in shape. The centre must be at least 200 mm lower than the ends to ensure flow passes over, and not around, the check dam.

Typically check dams should be spaced so that the elevation of the toe of the upstream check dam is at or below the elevation of the crest of the downstream dam. Table 3 provides spacing parameters for rock check dams using this approach, taken from Table 1.4 in TP90 (ARC, 1999).

Rock for check dams should be sized according to expected flow velocities within the channel to prevent rock becoming mobilised. Typically, a mix of 100–300 mm diameter washed rock is appropriate, assuming a relatively small contributing catchment no greater than 1.0 ha. Otherwise larger diameter rocks will be required so they are not dislodged by high velocities. Rock placement should ensure larger stones are placed in the base and on the downstream side of the check dam for stability.

Table 3: Rock Check Dam Design

Slope	Spacing between Dams, m	
	450 mm Centre Height	600 mm Centre Height
2% or less	24	30
2% to 4%	12	15
4% to 7%	8	11
7% to 10%	5	6
Over 10%	Utilise stabilised channel	Utilise stabilised channel

4.2 Stage Discharge Outlets

Stage discharge outlets are part of treatment devices that include attenuation functions.

4.2.1 Weirs

For completeness, the following outlet design equations have been included. Unless referenced otherwise, the following equations have been taken from ARC (2003).

4.2.1.1 Drop Inlet

$$\text{Circular inlet} \quad Q = 3.6\pi rh^{3/2} \quad \text{Equation 4}$$

$$\text{Box weir} \quad Q = 7.0wh^{3/2} \quad \text{Equation 5}$$

Where;

- Q = discharge through the outlet, $\text{m}^3 \text{s}^{-1}$
h = elevation head acting on outlet (for orifices, acting on orifice centreline), m
w = length of the side of a square box weir, m
r = radius of inlet, m

These equations apply only for sharp-crested weirs where $h/r \leq 0.45$ (or, for a box inlet, $h/w \leq 0.45$; weir controlled flow). For $h/r > 0.45$, the weir becomes partly submerged, and for $h/R > 1$ the inlet is fully submerged. Risers built of concrete pipe may be considered as sharp-crested circular weirs.

4.2.1.2 Broad Crested Weir

$$\text{Trapezoidal weir} \quad Q = 0.57(2g)^{1/2} \left(\frac{2}{3}Lh^{3/2} + \frac{8}{15}Zh^{5/2} \right) \quad \text{Equation 6}$$

Where;

- L = horizontal bottom width of outlet, m
h = depth of design flow, m
Z = horizontal/vertical side slope, i.e. 1:Z

ARC (2003) provides an approximation to the broad crested weir equation (Equation 7).

$$Q = 1.7Lh^{3/2} \quad \text{Equation 7}$$

4.2.1.3 Sharp Crested Weir

Douglas *et al.* (1985) gives Equation 8 for sharp crested rectangular weirs.

$$Q = \frac{2}{3}CL\sqrt{2g}h^{3/2} \quad \text{Equation 8}$$

Where;

- C = coefficient of discharge to account for energy losses and contraction of the cross section of flow at the weir bottom and sides

The coefficient of discharge, C, will vary dependent on both the ratio of the channel width to weir width, and the ratio of head over the weir, to channel depth below the weir (U.S. Dept. of the Interior Bureau of Reclamation, 2001).

Alternatively, ARC (2003) provides an approximation for a sharp crested weir equation (Equation 9).

$$Q = 1.8Lh^{3/2} \quad \text{Equation 9}$$

4.2.1.4 V-Notch Weir

Douglas *et al.* (1985) gives Equation 10 for sharp crested v-notch weirs.

$$Q = \frac{8}{15} C \sqrt{2g} \tan \frac{\theta}{2} h^{5/2} \quad \text{Equation 10}$$

Where;

θ = V-notch angle, degrees

C = coefficient of discharge to account for energy losses and contraction of the cross section of flow at the weir bottom and sides

The coefficient of discharge, C, varies with the V-notch angle. For a 90° V-notch weir C = 0.58 is appropriate (Shen, 1981). Alternatively, C can be calculated using Equation 11:

$$C = 0.607165052 - 0.000874466963\theta + 6.10393334 \times 10^{-6}\theta^2 \quad \text{Equation 11}$$

4.2.1.5 Orifice Equations

A variety of options are available for outlet designs based upon orifice openings.

Single orifice	$Q = 0.62A(2gh)^{0.5}$	Equation 12
----------------	------------------------	-------------

Multiple orifices at the same elevation	$Q = n0.62A(2gh)^{0.5}$	Equation 13
---	-------------------------	-------------

Vertical slot extending to water surface	$Q = 1.8wh^{3/2}$	Equation 14
--	-------------------	-------------

Vertically spaced orifices (situated h_1 , h_a , h_b from surface of pond, each orifice area A)	$Q = 0.62A(2gh_1)^{0.5} + 0.62A(2gh_a)^{0.5} + 0.62A(2gh_b)^{0.5}$	Equation 15
---	--	-------------

Pipe (area A)	$h = \left(\frac{1.5Q^2}{2gA^2} \right) + h_f$	Equation 16
---------------	---	-------------

Where;

A = area of orifice, m²

g = gravitational acceleration, 9.81 m s⁻¹

h = elevation head acting on orifice centreline, m

n = number of orifices

w = width of the vertical slot, m

h_f = pipe friction loss, m

4.2.1.6 Perforated riser with uniform holes

Los Angeles Department of Public Works (2009) provides design and sizing guidance for a perforated riser (Figure 14).

Discharge from perforated riser with uniform holes at equal spacing	$Q = C_p \frac{2A_p}{3H_s} \sqrt{2gH}^{3/2}$	Equation 17
---	--	-------------

Simplified version to iterate	$Q = kH^{3/2}$	Equation 18
-------------------------------	----------------	-------------

the hole size and riser height,

$$k = C_p \frac{2A_p}{3H_s} \sqrt{2g} \quad \text{Equation 19}$$

Where;

- Q = riser discharge, $\text{m}^3 \text{s}^{-1}$
 C_p = discharge coefficient for perforations, use 0.61 (County of Los Angeles Dept. of Public Works, 2009)
 A_p = cross-sectional area of all holes, m^2
 H_s = distance between bottom of lowest hole and top of highest hole, m
H = distance from bottom of lowest hole to water surface elevation, m

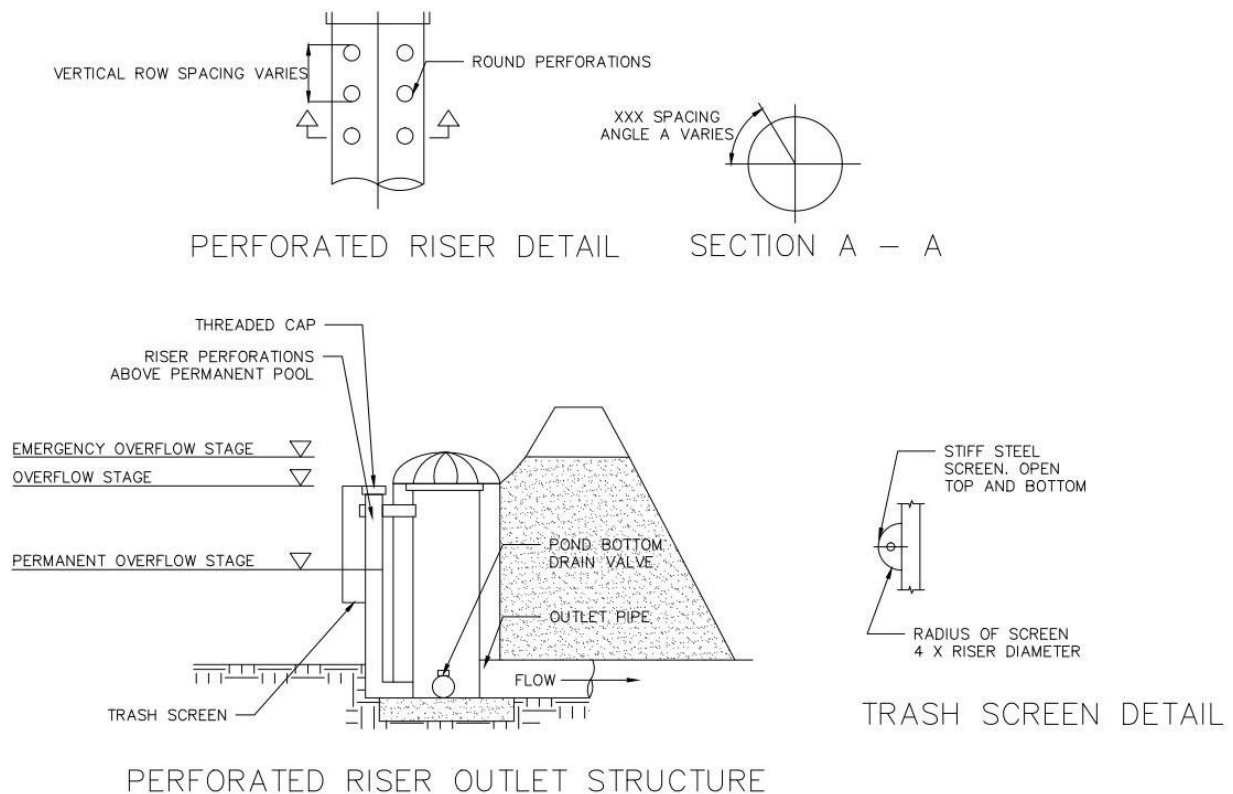


Figure 14: Perforated Riser Outlet

4.3 Underdrains

Some treatment devices, such as rain gardens, utilise underdrains as a means of outlet discharge. Underdrains are also included in some devices, such as swales, which have conditions unsuitable for complete infiltration, such as contaminated land or low permeability subgrades.

Underdrains may also reduce the use of other outlet structures. For example bioretention cells discharge to an underdrain, but also have an overflow directly connected to the underdrain so the overflow is not a completely separate structure.

A perforated pipe-aggregate underdrain is common in stormwater treatment. It typically consists of a geotextile lined trench with adequate slope to drain properly with a perforated pipe (usually plastic) placed within and porous/granular backfill to allow ready entry of water from the layer above.

Another type of underdrain is the French drain. The French drain consists of fabric wrapped, coarse porous backfill in a trenched installation. No pipe is used except for a short length of pipe as an outlet. Similarly, the drainage layer in living roofs relies on a sized coarse aggregate layer or drainage mat and does not necessarily utilise pipes.

Examples of treatment devices that may incorporate underdrains into their design are:

- Sand filters
- Bioretention (rain gardens)
- Swales
- Pervious paving
- Living roofs
- Infiltration trenches

For each treatment device, locally applicable guidance for underdrain design is included in the specific device design guideline.

Underdrains are difficult to inspect and keep clear and may be prone to blockage, primarily due to migration of fines causing clogging of the filter layer. Therefore underdrains typically include a geotextile and/or a pervious transition layer.

The geotextile may be either in the form of a filter 'sock' directly around a perforated pipe underdrain, or as a separation layer between a pervious transition layer and the layer above (also refer to Section 5.3.1.1). Where the geotextile directly covers perforations in the drain, only a small area is available for flow which may lead to clogging. If possible, allow as large a surface area of flow through geotextile layers as possible for water to enter the underdrain.

Alternatively, a pervious transition layer may be used (without a geotextile) to separate the underdrain from both the undisturbed soil below and the layer above. A transition layer is comprised of a properly sized aggregate intended to trap fines within its pore spaces. It has the added benefit that the aggregate layer can provide additional storage volume. Refer to guidance for the specific treatment device for sizing.

It is also possible to have both ends of a perforated-pipe underdrain terminate in a manhole or chamber such that there is access for flushing to clear the pipe, if necessary.

Underdrains expel low energy outflow, and are therefore less likely to cause erosion than pipe outflow from hydraulically efficient smooth pipes. However, because the discharge from underdrains is limited by the surrounding porous materials, there should always be an alternate overflow drainage path.

4.4 Energy Dissipation

While proper siting and design of inlets and outlets can reduce the potential for erosion, in many cases formal energy dissipation devices are required if the downstream environs (whether natural stream or treatment device) do not have an adequate ability to withstand erosive forces, or if the forces are significant.

For discharges to natural streams or gullies the erosion potential can be evaluated by calculating the culvert exit velocity and comparing it to the velocities that cause erosion in different channel materials (Table 1). If the potential for erosion is likely (and velocities cannot be otherwise lowered) then energy dissipation is required.

There are many types of energy dissipation devices including flow transitions, riprap aprons, in line outlet weirs and drop structures, concrete aprons with or without baffles, hydraulic jump basins, broken back culverts, etc.

Froude numbers (F_o) are useful in identifying what type of energy dissipation is needed.

$$\text{Froude number} \quad F_o = \frac{v}{(g \times d_p)^{0.5}} \quad \text{Equation 20}$$

Where;

v = velocity of flow in pipe, m s^{-1}
 g = gravitational acceleration, 9.81 m s^{-2}
 d_p = depth of flow in pipe, m

The following guide can be used in selecting energy dissipation based on Froude numbers:

- Generally applicable to rectangular open channel sections and pipes that are not flowing full.
- When F_o is equal to 1, flow is critical and no hydraulic jump can occur.
- Outlets with $F_o < 1.7$ are likely to need standard outlet structures (headwall and apron or similar) with some channel protection and/or flow expansion. In this case the downstream depth is roughly twice the incoming depth and the exit velocity is about half of the upstream velocity.
- Outlets where $1.7 < F_o < 3$ would likely need a riprap or concrete baffle block arrangement.
- Outlets with $F_o > 3$ would need forced hydraulic jump basins. Hydraulic jumps occur when shallow, fast flow with high kinetic energy (e.g. velocity head, $v^2/2g$) is converted to slower flow with potential energy (e.g. elevation head, h) being dominant.
- For high velocity flows with $F_o > 3$, or large vertical drops, specific and detailed design of energy dissipation outlets is likely necessary. In this case the designer is referred to a classic technical resource *Hydraulic Design of Energy Dissipaters for Culverts and Channels*, HEC14 (USDOT, 2006) where much of the information in this section is taken from.

4.4.1 Channel Recovery Reaches

Outlets entering natural streams should be set back from the main channel to minimise energy dissipation within the stream itself, minimise effects on opposite banks, and potentially avoid geotechnical issues. Generally a headwall and wingwalls are required, especially if the outlet is recessed into a slope, to prevent slope erosion and facilitate smooth flow transition.

If there is enough room, a longer tributary reach where the stream channel width exceeds pipe diameter can help lower velocities through flow expansion, provide habitat and minimise consenting and requirements associated with works within the watercourse. Rather than piping to the receiving water body, ephemeral stream gullies are ideal for providing setbacks and positions for energy dissipation while retaining the overland flow path (and potentially habitat) function. As a minimum, outlets should be located far enough back to prevent the energy dissipater intruding on the channel.

Channel recovery reaches aim to prevent erosion of receiving environments. In the coastal environment, a conventional set back may not be appropriate, consider locating the outlet away from the active beach system, for example at or near an adjacent headland.

Flow velocities in the reach should be less than about 0.8 m s^{-1} (Table 1) unless the channel is lined.

Longitudinal slopes greater than 5% will likely require check dams, or grade control structures such as sheet piling, gabions, log drops, etc. to maintain a stable grade and reduce gully head cutting and erosion. Tributary reaches with steep longitudinal slopes also need to have an incised cross section to prevent “channel wandering” where flows spill outside of the reinforcing material footprint and erode soil alongside the designed channel.

Figure 15 demonstrates an embedded culvert, with large riprap in the channel which slowly dissipates energy over a long reach. The riparian planting increases the roughness of the reach, providing more gradual energy loss in addition to other ecological benefits (shading, bank stability etc.).



Figure 15: Riprap Channel Obscured by Riparian Planting

4.4.2 Riprap

Riprap is used to provide a hard surface lining that is not subject to erosion as well as providing energy dissipation (Figure 16, Figure 17).



Figure 16: Riprap with Check Dam at Pond Spillway



Figure 17: Riprap Protection and Dissipation and Pipe Outfall

Riprap comes in a variety of rock types and sizes depending on the quarry. It is usually provided (and specified) as a range of sizes such as 400–250 mm where 100% of the material is 250 mm or larger and no material is greater than 400 mm. D_{50} , often used in riprap sizing calculations, is the median

diameter of the riprap range. Material larger than about 250 mm is often classified as boulders; however care must be taken, as quarries or providers may define sizing differently.

Angular rock has a much greater angle of repose than rounded rock and should be specified on slopes. Attention to installation of rock, including interlocking of larger boulders, can improve the durability of riprap protection.

The first step in specifying riprap is determining the design storm discharge velocity. For streams, this would generally be the 100-year event. For treatment device outlets this will typically be the 10-year event. Riprap aprons used in temporary works may be designed based upon the discharge velocity for the 2-yr event. When an outfall is located in a coastal environment, wave energy must also be considered when sizing riprap.

There are many methods of riprap sizing however a review of these methods determined the existing method expressed in ARC (2003) is an optimal method for efficiency for continued use in the Auckland region. The median diameter of riprap required is given by Equation 21:

$$\text{Median riprap diameter} \quad d_{50} = 0.25 \times D_o \times F_o \quad \text{Equation 21}$$

Where;

- d_{50} = median riprap diameter, m
- D_o = pipe diameter, m
- F_o = Froude number, Equation 20

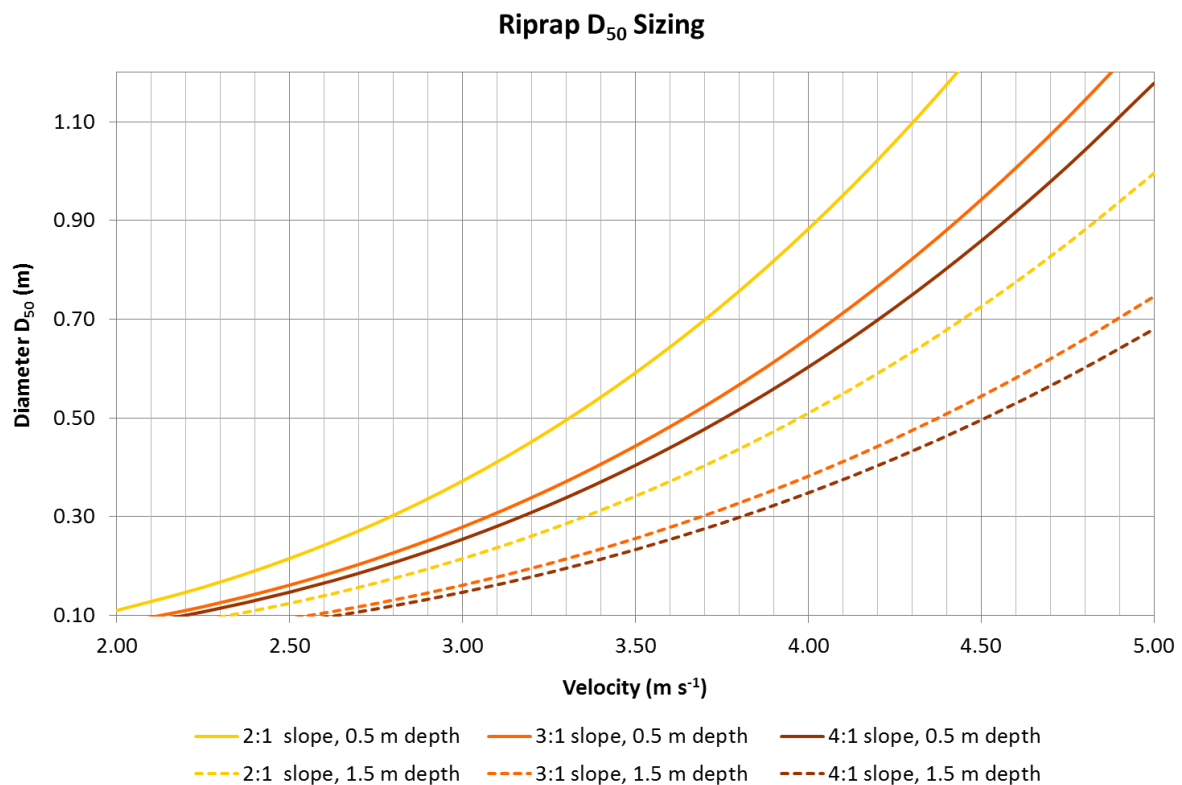


Figure 18: Simplified Riprap Sizing Chart

Alternatively, Figure 18 has been developed based upon HEC-11 methodology (USDOT, 1989) which was developed for protection of channel sides (not specifically energy dissipation at outlets). Figure 18 provides sizing guidance for angular riprap in channels with side slopes from 2:1 to 4:1 and either 0.5 m or 1.5 m channel water depth. Side slopes steeper than 2:1 are not included as steeper slopes can become unstable making custom design necessary. The method assumes:

- Rock riprap specific gravity is 2.65
- Stability factor is 1.2
- Rock riprap angle of repose is 40°, indicative of angular rock

Appendix 1 presents larger versions of the charts, with an additional chart for 1.0 m channel water depth.

The recommended minimum size of riprap is 150 mm. The thickness of the riprap is recommended to be 1.5 to 2 x D_{50} . The thickness should not be less than D_{100} and not less than 300 mm. Riprap should be underlain with geotextile so it doesn't 'sink' into the softer underlying soil.

Guidance for the length of riprap necessary may be found in Section 4.4.3. However, for natural streams the use of riprap should be minimised to reduce adverse effects (visual, substrate or fish passage, for example).

Riprap may also be grouted in place with a weak sand cement grout (e.g. 7 MPa) which can reduce the size and thickness of riprap needed. However, the use of grouted rock should generally be confined to situations where rock of suitable size is not economic or available or where a smoother surface is required (for safety or flow efficiency). This is because this type of monolithic structure can be susceptible to undermining or tomos.

Riprap can be quite obtrusive and the visual impacts can be softened through planting. Hessian bags filled with weak concrete mix may also provide architectural alternative to riprap (Figure 19).



Figure 19: Hessian Bags filled with Weak Concrete

4.4.3 Aprons

An apron provides an armoured surface to prevent erosion at the transition from a pipe or box culvert outlet to a natural channel (Figure 20). It may be the only energy dissipater or act as additional protection at the exit of other energy dissipation devices. Aprons may also be used to spread the flow of water to sheet flow where no natural receiving water is present.

As discussed previously, reductions in velocity will reduce erosion potential and thus the size of apron needed. Overall, the visual impact of the energy dissipation will decrease. As such, mechanisms to reduce velocity prior to discharge are encouraged, for example rapid expansion into pipes of a larger size, or stilling basin designs.

4.4.3.1 Riprap Aprons

The riprap apron is one of the most commonly used devices for outlet protection, primarily for culverts 1500 mm or smaller, with or without a standard wing wall. Riprap aprons manage the transition from an outlet to the stream channel by increasing roughness and flow width to reduce flow velocity. They are typically less expensive and easier to install than concrete aprons or energy dissipaters. In addition, riprap is flexible and adjusts to settlement; it also serves to trap sediment. Protection is provided by increasing roughness and having sufficient length and flare to dissipate energy by expanding flow area and reducing velocities.

However, if the apron is too short, or otherwise ineffective, it will simply move the location of potential erosion downstream. Riprap aprons should not be used to change the direction of outlet flow and should be constructed, where possible, at zero percent grade for the length of the apron.



Figure 20: Standard Wing-wall Outlet with Apron, Fencing, Planting and Downstream Riprap

The key design elements of the riprap apron are the length and width of the apron (Figure 22), and riprap size and thickness. Riprap size and thickness should be as specified in Section 4.4.2. The width

of the area protected is given by Equation 22 and the length of outfall protection is given by Equation 23 (ARC, 2003).

Apron width $W_a \geq 3D_o$ Equation 22

Apron length $L_a = D_o (8 + 17 \times \log F_o)$ Equation 23

Where;

L_a = apron length (m)
 W_a = apron width (m)
 D_o = pipe diameter (m)
 F_o = Froude number (Equation 20)

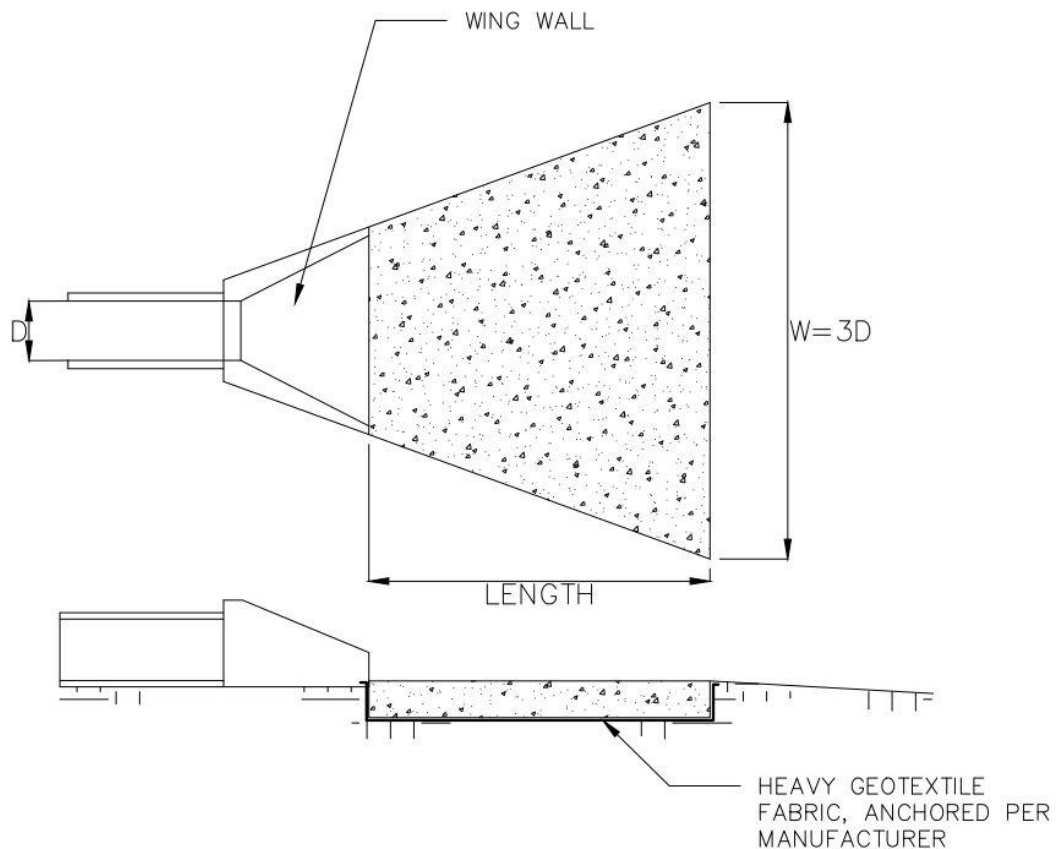


Figure 21: Riprap Apron Design Dimensions

Figure 22 provides sizing guidance for a riprap apron length (Equation 23) based on pipe diameter and flow velocity. The sizing chart assumes:

- Depth of flow in the pipe is equal to the pipe diameter
 - This scenario is the most critical in erosion protection
 - May not apply if the pipe is inlet controlled
- Tail water depth is half the outlet height or less

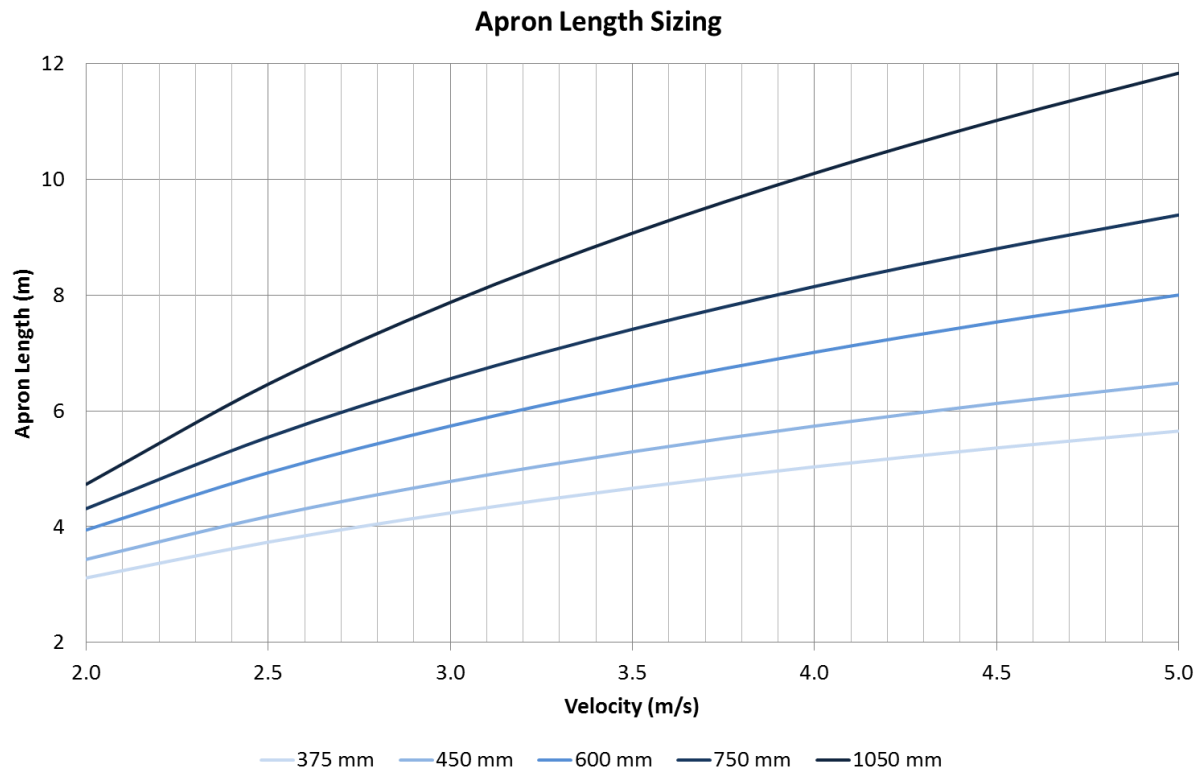


Figure 22: Apron Length Sizing Based on Flow Velocity Exiting the Culvert

A geotextile should be placed between the riprap and the underlying soil to prevent soil movement into and through the riprap. Riprap should extend up both sides of the apron and around the end of the pipe or culvert at the discharge outlet at a maximum slope of 2:1 and a height not less than the pipe diameter or culvert height and should taper to a flat surface at the end of the apron.

4.4.3.2 Concrete Aprons

Concrete aprons with rocks embedded (Figure 23), or constructed baffle blocks (also referred to as impact blocks/columns) provide energy dissipation by effectively breaking up and spreading flow from the outlet.



Figure 23: Concrete Aprons with Baffle Blocks Embedded for Energy Dissipation

While riprap is recommended as the preferred option, concrete aprons with rocks or baffle blocks embedded may be used where a lot of energy needs to be dissipated in a short length as they are relatively short and compact for the amount of energy they dissipate.

Typical baffle block arrangement aligns the first row of blocks so that one block is placed along the centreline of each culvert outlet (Figure 24). Subsequent rows are arranged so that each block is located along the flow path of the jet deflected around the block immediately upstream. Control of bed scour at the downstream end of the outlet structure usually requires the use of additional riprap protection as a transition from the hard concrete to natural channel.

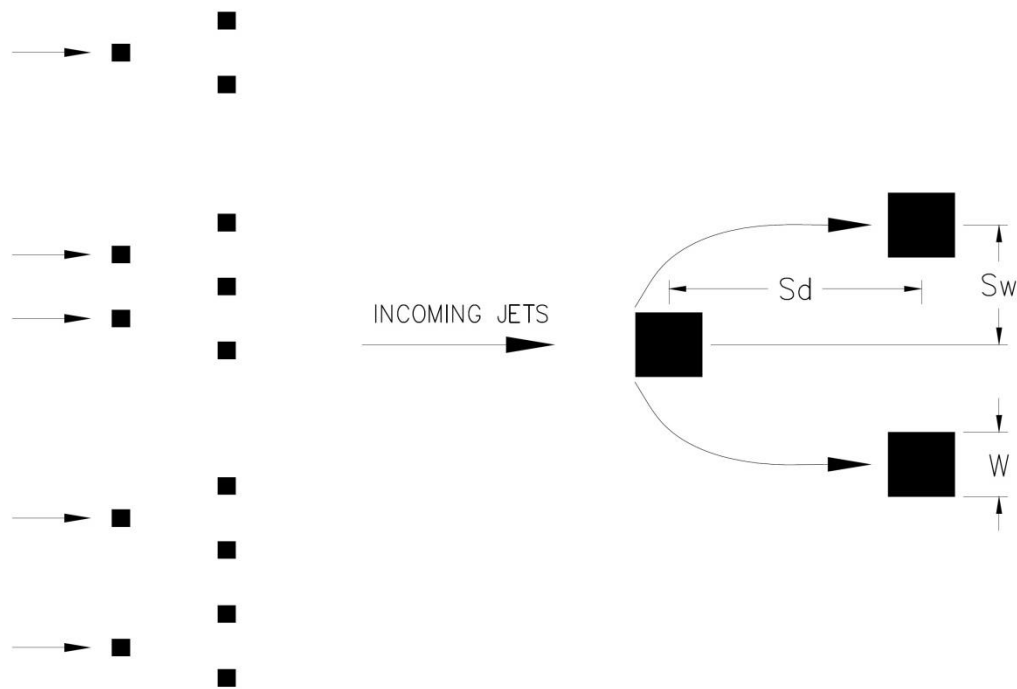


Figure 24: Typical Baffle Block Arrangement and Spacing for Single or Double Outlet Jets

Theoretically, in order for the baffle blocks to be effective at full flow, the blocks' height should be equal to the height of the pipe or culvert, however practically this may cause excessive turbulence or spray therefore a height no more than half the diameter of the pipe is recommended. Optimal baffle block spacing to allow the free flow of debris, where practicable, should be sized as per Equation 24 and Equation 25, and Figure 24.

Row spacing	$S_d = 4R_h + d$	Equation 24
-------------	------------------	-------------

Block width	$S_w = 2R_h + \frac{w}{2}$	Equation 25
-------------	----------------------------	-------------

Where;

R_h = hydraulic radius of the culvert, in full pipe flow = $\frac{1}{4}$ diameter of the pipe, m.

w = baffle block width, m.

d = theoretical baffle block depth, equal to the height of the outlet, m.

S_d = spacing of two consecutive rows of blocks, Figure 24, m.

S_w = spacing between two impact blocks in different but consecutive rows, Figure 24, m.
Excludes the first row, where spacing is determined by the spacing of the approaching jets.

Culvert wing walls (or other armour) should extend downstream of all the baffle blocks, to deflect flow back into the channel.

Baffle blocks have one major drawback in that they may collect floating and suspended debris, leading to damage of the baffle blocks. To function properly, blocks must be appropriately spaced to minimise debris collection, and regularly cleaned.

Concrete aprons should incorporate mesh reinforcement (at a minimum) into their structure and baffle blocks should be formed as part of the apron or grouted in place using a minimum of 12 mm reinforcement bars. Specific design by a structural engineer may be required.

For rocks embedded into concrete aprons, placement may be random. As a guide:

- Rocks should generally be embedded by 50%
- Retain at least $D/6$ depth of concrete under the rock, where D = equivalent rock diameter
- Rocks should be $D/2$ apart in all 6 directions when using a hexagonal pattern

For exit velocities greater than 5 m s^{-1} , an alternative energy dissipater design should be considered. Refer to *Hydraulic Design of Energy Dissipaters for Culverts and Channels*, HEC 14 (USDOT, 2006).

4.4.4 Stilling Structures

A range of techniques are available to create a body of water at the discharge point from a network that would aid in dissipation of energy:

- Outlet control is the main stilling element associated with treatment devices. Elevated water levels during live detention storage can contribute to energy reduction, as discussed in Section 2.4 Hydraulic Grade Design: Inlet and Outlet Control.
- Specific discussion regarding stilling basins (hydraulic jump basins) is not included herein as specific and detailed design is necessary (Section 4.4 Energy Dissipation). For situations with Froude numbers >3 , techniques such as stilling basins can be designed with reference to *Hydraulic Design of Energy Dissipaters for Culverts and Channels*, HEC14 (USDOT, 2006)
- Commonly employed structures that offer some energy dissipation through stilling include bubble up pits and drop outlets.

Bubble-up pits, or stilling manholes, rely on a pre-cast manhole placed at the outfall with a reduction in outlet cross-sectional area to provide an elevated water level under high flow conditions. These may be designed to surcharge without overflowing, or to overflow in design storm conditions.

Bubble-up pit outlet configurations may contain multiple pipes as seen in the example in Figure 27, which can be designed using orifice equations such as in Section 4.1.1. Sumps (300 mm deep) or Polyethylene (PE) or stainless steel plates are useful for mitigating erosion on the manhole base where there is cascading or high velocity incoming flow, and specific design of anchoring may be required. High level overflows are required either consisting of an open grate or hinged manhole lid to mitigate safety issues from public access.

Drop outlets provide for large changes in elevation; the incoming pipe invert elevation is significantly higher than the outlet invert elevation. Drop outlets are often combined with bubble-up pits, as indicated in the example in Figure 25, Figure 26, and Figure 27 to reduce both potential (elevation head) and kinetic (velocity head) flow energy.

Drop outlets are useful when the alternative is a steep pipe grading into a sensitive environment (Figure 27). However, the deeper a manhole is, the larger the diameter required and excessively deep manholes may require platforms to assist maintenance access, etc. Engineering standards often prohibit use of excessively deep manholes for operational, especially safety, reasons.

Drop outlets should only be used where fish passage is not required as they create a barrier to fish passage. The example provided in Figure 27 was installed on a 30° slope, fish were not found in the

area, and there was no possible upstream habitat for fish. Refer to Section 5.1.4 for further discussion on fish passage.

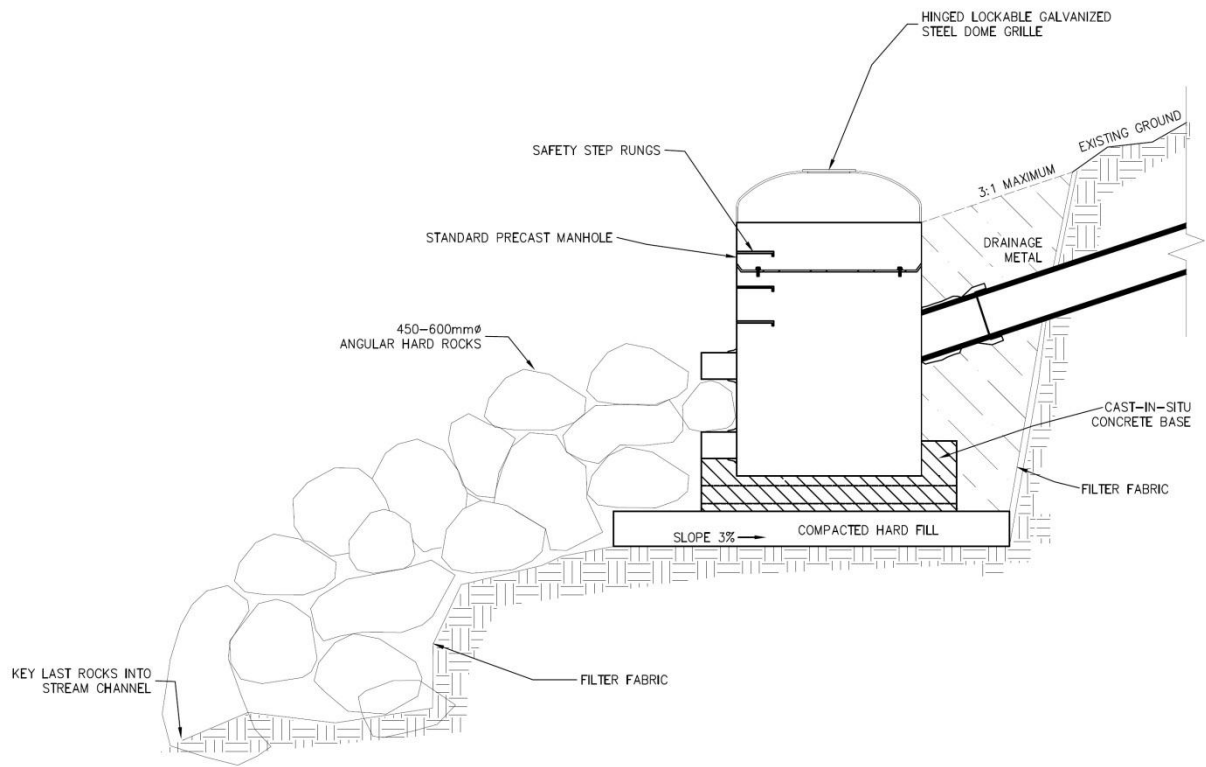


Figure 25: Bubble-up Pit Incorporating Drop Structure with Multiple Outlets (long-section)

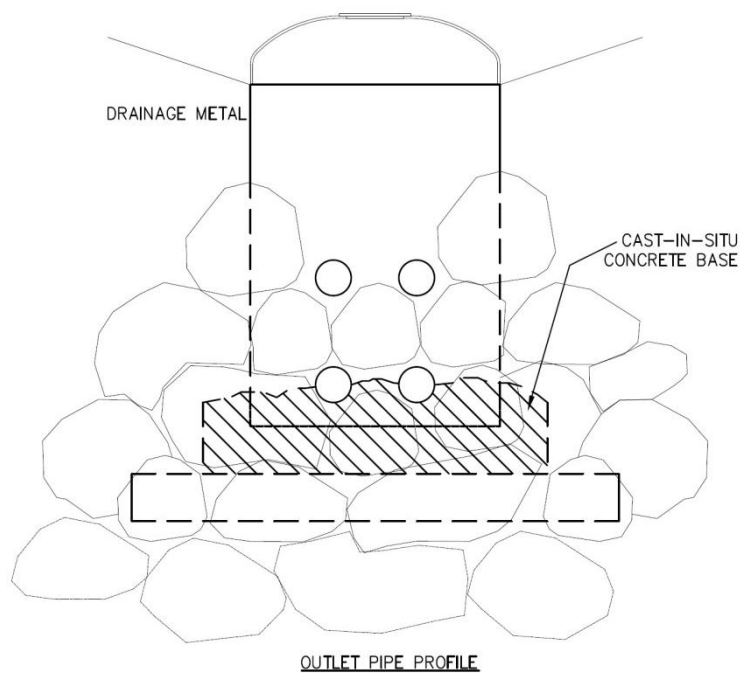


Figure 26: Bubble-up Pit Incorporating Drop Structure with Multiple Outlets (profile)



Figure 27: Bubble up Pit in Bush Gully Looking Downstream (left) and Upstream (right)

Plunge pools are the scour holes formed below pipe outlets. If stable, they provide a ‘natural’ stilling basin and can reduce downstream erosion, however they are problematic in a number of areas including fish passage and are not recommended.

4.4.5 Network energy dissipation

There may be opportunities to design upstream pipe networks to reduce velocities before the point of discharge to a treatment device or outfall. This may be achieved by increasing pipe grade further upstream or installing drop manholes, enabling flattening of the grade of the downstream pipe approaching the outfall. Alternate alignments can provide for lower slopes within the network. Increasing the pipe size can also provide a wider cross-sectional area with reduction in velocity for a given flow, particularly for flows greater than the 10 year event where surcharging of pipes may be occurring. Broken back culverts are a technique where the flattening of the downstream section of a culvert forces a hydraulic jump, requiring specific design as provided in *Hydraulic Design of Energy Dissipaters for Culverts and Channels*, HEC14 (USDOT, 2006).

5.0 Design Considerations

5.1 Environmental Outcomes

There are a lot more aspects to consider in inlet and outlet design than merely energy dissipation. Designing to achieve environmental benefits can help support whole of catchment ecological values. Ideally, design should move away from hydraulically efficient systems that provide only one function, and often sever ecological links, and towards resilient systems that provide multiple benefits and have an element of adaptability or redundancy.

5.1.1 Ecological Considerations

The best method for promoting ecological values is to protect the systems already present. Therefore, outlets and erosion protection should have as small a footprint as practical. For example, dissipating energy within the network or through a bubble up manhole incorporating fish passage would have less adverse effects than the disturbance and vegetation clearance needed for a long extent of riprap.

Outlets should be set back from natural channels to minimise riparian vegetation clearance and main channel erosion (also refer to Section 4.4.1).

Habitat niches exist at a variety of levels within an ecological community, from root zones and litter layers, through to understorey shrubs and emergent trees. It is possible to introduce materials to optimise habitat diversity for invertebrates, birds, lizards, and frogs in the form of plants, logs, rocks, and leaf-litter.

Variable aquatic conditions provide for diverse life cycle stages of aquatic fauna. This may include cool pools, oxygenating riffles, overbank or island refuge areas, soft and rocky substrates, and organic food sources. The culvert in Figure 28 has been retrofit with rock and gabion bank protection to stop bank slumping and erosion, and fish-friendly rock riffles for bed protection.

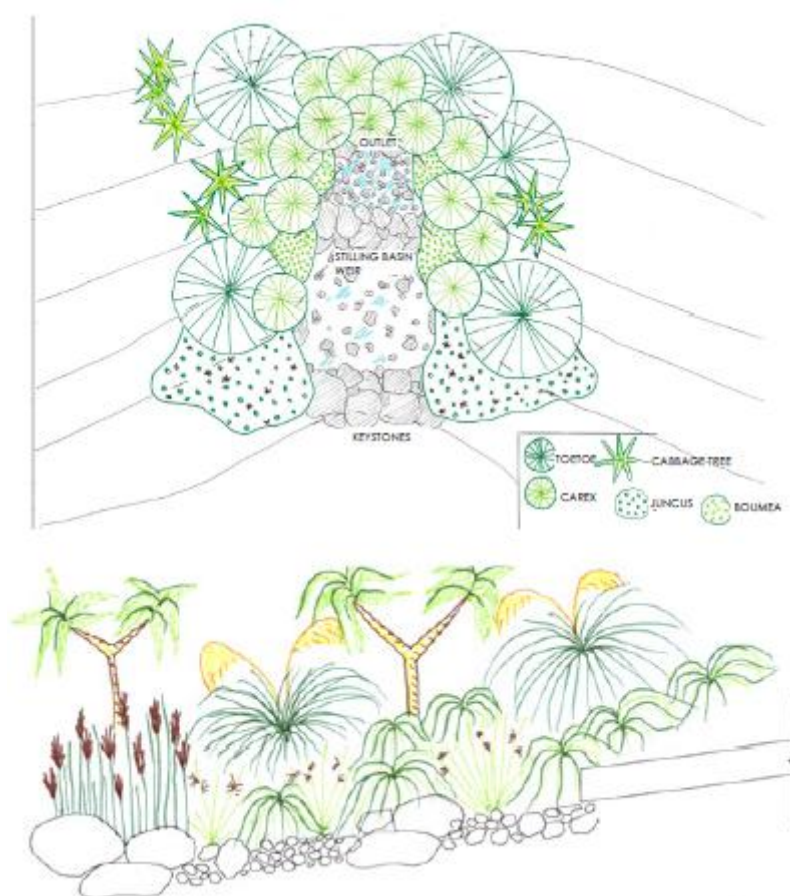


Figure 28: Outfall with Channel Rock Protection and Gabions to Protect Opposite Bank

5.1.2 Planting

In addition to ecological and habitat benefits, in the context of inlets, outlets and energy dissipation, plants provide a myriad of other benefits including filtering stormwater as part of a treatment train, hiding obtrusive structures, integrating structures within a landscape, providing 'soft' access barriers, and reducing water temperatures. Figure 29 demonstrates a riparian planting plan to reduce the visual impact of the outlet and riprap lined channel, in addition to providing bank stabilisation.

Landscape design should capitalise on natural succession processes, provide for buffer zones, and specify the appropriate spacing/density of plants. The Riparian Zone Management Strategy for the Auckland Region (ARC TP148) includes guidance on appropriate planting for varying riparian conditions.



Plant species		Size	Zone	Density (plants/m ²)	% cover	No. of plants
<i>Carex flagelifera</i>	Tussock	PB5	Freshwater env.	0.25	20	16
<i>Cordarteria fulvidia</i>	Toe toe	PB5	Transition area	1	20	5
<i>Baumea articulata</i>	Rush	PB5	Transition area	0.5	20	8
<i>Juncus maritimus</i>	Sea rush	PB5	Saltwater env.	0.25	20	16
<i>Cordyline australis</i>	Cabbage tree	PB5	All	2	20	3
					100	48

Figure 29: Outfall Planting Plan

However, plant selection should consider effects on infrastructure design and maintenance. For example, plants with large root systems should not be planted on top of headwalls where they can cause damage to the structure. Plants such as raupo, that produce significant detritus, should be avoided upstream of grided inlet structures which can clog.

One novel approach for softening hard structures, such as gabion baskets or riprap, is to incorporate geotextile 'socks' filled with soil to provide a medium to install plants.

5.1.3 Pest Management

The management of invasive plant species in stormwater devices is best achieved through installation of appropriate plant species and applying a good maintenance regime, especially during the first two years of plant establishment, to avoid weeds from overtaking desirable plants. Regardless, it should still be expected that weed management is an important and ongoing process.

Open, high nutrient, stagnant water creates excellent mosquito breeding and larval habitat and can be avoided by maintaining water movement through stormwater devices (or preventing no-flow areas) to prevent the formation of pools of stagnant water. In general, even very minor turbulence is detrimental to larvae and serves to raise oxygen levels and improve water quality. Establishment of vegetation will also create shading, thereby cooling the water temperature and reducing mosquito habitat.

5.1.4 Fish passage

One of the greatest threats to native fish is lack of fish passage through structures. About 50% of native fish species are diadromous, meaning that they migrate between fresh and salt water as part of their life cycle. In the Auckland region the most common native species are Banded kokopu, Shortfin eel, Longfin eel, Common bully, Inanga, Redfin bully, and Cran's bully. These fish species have swimming modes that include higher speed, short duration burst modes, slower prolonged or sustained modes, and some species have the ability to climb on wetted surfaces. Swimming ability is influenced by the type of species, water temperature, and the size of individual fish.

Any inlets and outlets associated with in-line stormwater devices (that have the potential to prevent the up or downstream migration of fish species), must include measures to cater for the passage of fish species that one would find upstream of the stormwater device under natural conditions. Recognising the habitat values of stormwater wetlands, and the historic degradation and loss of freshwater habitats across the Auckland region, off-line wetlands discharging into natural environments (streams, creeks and coastal marine areas) must also include fish passage measures as described above. Timing of fish migrations (outside the scope of this document) is also important, and TR2009/084 recommends that fish passage be assured for 90% of the flows that occur between the main September to February fish migration period.

Key design elements for fish passage include:

- Minimise vertical fall heights. Even 50–100 mm can be a barrier for some species. Stacking appropriately sized rock (refer Section 4.4.2) can mitigate some falls, with the longitudinal slope of the placed rock ramp being no more than 1:5.
- Water velocities should be minimal, or there should at least be a region of low velocity flow. TR2009/084 recommends 50–100 mm width of flow having a velocity less than 0.3 m s^{-1} with velocities of 1 m s^{-1} being a barrier to all species.

- Culverts or outlet aprons should be formed so that there is some depth of flow and a wetted margin is maintained. Aprons can be formed with sills to form resting pools and a v-shaped dip to provide an area of adequate flow depth. Culverts should not project outside headwalls.
- Smooth culverts can pose problems for fish passage. This can be improved by incorporating some 'roughness' into the culvert base, attaching a corrugated substrate to the base, or installing baffles, depending on culvert size (refer to ARC TR2009/084 for design details).
- Fish passage through weirs is improved if weirs are broad crested with rounded or eased edges. Rock or rock embedded concrete ramps can be included to dissipate energy, eliminate vertical falls, and provide a wetted surface.
- Designs should include riparian planting to reduce water temperature increases.

Further information on fish passage is in TR2009/084 (Stevenson and Baker, 2009).

5.2 Social and Cultural Outcomes

Social and cultural outcomes include providing for the wellbeing of the community. In the context of inlet and outlet design, this means providing for safe, aesthetic structures that can provide more than hydraulic benefits. Developing ancillary social and cultural outcomes can give projects an instant public appeal and contribute to their success.

5.2.1 Risk and Safety

Fast flowing water and the scale of large commercial or public stormwater facilities presents a number of safety and other risks that should be considered during design.

By far the biggest safety risk is drowning. Open-ended culverts can be attractive to children, while manholes can be extremely dangerous if the lids become dislodged.

However, other safety risks should not be overlooked. These include falls from steep banks or hidden headwalls. Even shallow but high velocity surface flooding during large events when overland flow paths are engaged can cause severe falls (Section 5.2.1.4). Inadequate handrailing or balustrading on observation decks and boardwalks can pose fall risk, particularly to small children. There are also public health risks associated with excessive stagnant water and contact with contaminated water such as waste water overflows. Mosquitos present a nuisance problem, especially in residential areas.

Aside from public safety, other risk associated with stormwater devices includes safety risk to workers during maintenance activities, stability risks, and environmental risks. Stability risks include piping and tomos due to inadequate geotextile or drainage layers under structures, lack of cutoff collars in steep pipe trenches, water saturating slopes and causing bank slumping, and erosion.

The key ways to reduce risk can be characterised as:

- Removing the risk
- Isolating the risk, or
- Mitigating the risk

Foremost is removing the risk from the design, secondly isolating the risk (usually through installing barriers), or mitigating the risk. These considerations are discussed further in the following sections.

5.2.1.1 Safe Batter Design

A number of factors need to be considered in safe batter design. The base geology and/or the material to be used in construction must be considered in the design. The most effective batter slope is the natural angle of repose of the soil material. Public safety must be taken into account. Where pedestrian access is allowed, batter slopes above and below water should be extremely gentle (e.g. 1V:6H). Alternatively, dense vegetation planting/fencing may be used to restrict access. Where machinery is used for maintenance, slopes should be limited to approximately 1V:4H or 1V:5H. An increase in batter slope increases the associated site risk.

5.2.1.2 Fencing

Fencing should generally be included in designs where there is the potential of a fall greater than 1 m (typical at the top of headwalls). However, in recreational reserves or other public areas, fencing may also be needed for a wider range of situations and the designer should consider this and discuss with the asset owner and regulator.

Adults recognise the risks around stormwater assets, such as falls from an obscured headwall. Thus, “safety” fencing around stormwater assets has historically intended to prevent accidental entry. However, children will not necessarily comprehend or recognise the hazard nor understand the intention of the fence to separate them from a hazard. More curious children will climb through to see what is on the other side. As such, fences aimed at stopping young children gaining access to stormwater assets may require design quite different to the type of “safety” fence that would be used with adults in mind.

For example, it may be more effective to place a fence around a playground for young children adjacent to a stormwater channel than merely fencing the channel.

It is important to consider what population will be potentially ‘exposed’ to the stormwater asset:

- Is it in a residential area or a reserve?
- Is the reserve active or passive?
- Is there surveillance?

It may be possible to selectively fence a perceived ‘unsafe’ area, while using fencing, planting, and signage to guide reserve users to an observation platform where they can more safely interact with a wetland environment (for example).

The “Fencing of Swimming Pools Act 1987” (NZDBH, 1987) provides design guidelines for fences around swimming pools and this guidance could be considered when designing barriers for stormwater assets. This guidance indicates that:

- Fence height should be at 1.2 m measured from the finished ground level to the top of the top rail.
- The gap between the bottom of the fence and the ground should not exceed 100 mm at any point (but also consider whether a greater gap will be necessary to pass potential overland flows).
- The gap between verticals shall be no greater than 100 mm.

Location of fences should also take into account visual amenity. For example, fences around ponds should be located off embankment crests. Fence colour should also be selected to blend with the surrounding environment and minimise visual impact.

As it is often impossible to completely surround the hazard of a stormwater inlet or outlet with fencing, it may be more appropriate to avoid falling hazards through safe batter design or to limit access through planting. Planting may also help reduce water temperatures. Flax, in particular, provides a natural, thick barrier that can be used to restrict access.

5.2.1.3 Limiting Access

If the culvert size is greater than about 600 mm, limiting potential access may need to be considered. One solution would be a smaller sized multi-barrelled culvert inlet and outlet arrangement; however, debris is generally more likely to be trapped at the inlet of a multi-barrelled culvert as compared with an equivalent single barrel culvert. Therefore, in this situation, one must also consider the type and size of debris that may be encountered as well.

Inlets and outlets also need to be of a similar configuration to prevent debris being trapped within the culvert. For this reason, generally inlets should not be larger than outlets. However, there are exceptions, such as bubble up chambers and attenuation outlets, and if these are large enough for entry, safety risk should be considered and addressed.

Outlet grilles can be used to prevent access into culverts from downstream but they must have a corresponding inlet screen to control debris and upstream ingress.

However, both inlet and outlet grilles are prone to blockage. Where alternate solutions for restricting access are possible, the use of grilles should be avoided. If a grille is the most appropriate option, there must be adequate access to allow for maintenance clearing of debris; hinged grilles with fracture bolts are also an appropriate design element to release blockages that may otherwise cause surcharge and upstream flood risk.

Alternate methods to restrict public access are:

- Dense planting to provide a barrier (with the added benefit of providing shading, thus mitigating thermal enrichment of the water)
- Fence the first 2-5 m downstream of an outlet

The overall intention is to consider solutions that take into account the site as a whole, incorporating not only stormwater management functionality, but community outcomes and aesthetic appeal while retaining health and safety at the fore.

5.2.1.4 Overland and Surface Flows

One of the best methods for reducing risk associated with inlets and outlets is to ensure the system has adequate emergency spillways and overland flow paths.

If there is a potential conflict with pedestrians or cyclists for frequent overland, surface, or stream flows a design consideration of limiting the product of the flow depth times velocity to $0.4 \text{ m}^2 \text{ s}^{-1}$ should be employed (I.E. Aust, 1987). Although this guideline appears simplistic, the $0.4 \text{ m}^2 \text{ s}^{-1}$ depth-velocity product provides a low hazard for adults and most children (Shand et al., 2010). Flow depth and velocity are the two most important factors influencing stability, with Shand et al. (2010)

proposing a maximum flow depth of 0.5 m, and a maximum velocity of 3.0 m s^{-1} to maintain low risk for most children. Maximum flow depth can increase to 1.2 m and still present a low risk to adults.

The depth-velocity limit pertains directly to overland flows. In the context of inlets and outlets, it is important to be aware of pedestrian stability, particularly where inlets or outlets are in publically accessible locations. Design may require fencing, or limiting of access, if recommended limits may be exceeded at the inlet or outlet. Loss of stability may occur in lower flows when adverse conditions are encountered such as uneven or slippery bottom conditions, flow conditions with floating debris, unsteady flow, or poor visibility.

It is also important to assess whether any drainage systems have the potential to surcharge above ground level (through system flooding during high flows or blockage) and whether manhole covers have the potential to become dislodged. Grilles are unlikely to become dislodged unless impacted by large fast moving debris or where there is the potential for head to build up and the grille is blocked. Where there is potential for manhole covers to dislodge, they should be (retro)fitted with hinged or grilled lids.

5.2.2 Community Outcomes

While a well-functioning stormwater system provides direct community benefits through stormwater conveyance, there is more that can be considered. While bridges and platforms have specific associated costs, many improved community outcomes can be accomplished with only minor additional cost to a stormwater project. Providing community outcomes can also support resource consent applications and mitigate some of the adverse effects often associated with stormwater infrastructure. Community outcomes that can be developed through design include:

- Improved access and recreation
- Provide landscape features
- Provide for cost-effective operation
- Foster appreciation of natural environmental values
- Develop opportunities to see and hear water
- Provide opportunities to increase stewardship values (e.g. through community planting)
- Show information on catchments and stormwater treatment (educational signage)
- Promote pride in community infrastructure
- Promote pride and connectedness with the natural environment.

Figure 30 shows a current photo followed by a concept drawing for a potential stream daylighting project. While addressing stormwater conveyance, this example also provides significant habitat and amenity improvements in line with the range of community outcomes listed previously.



Figure 30: Example Stream Daylighting Concept

5.2.2.1 Combining with other Structures

Consider if value can be added or negative impacts mitigated through incorporating inlet or outlet design into other structures.

Bridges and viewing platforms as shown in Figure 31, Figure 32 and Figure 33 provide a good method for disguising large outlets or weirs. In many cases, as the foundation is part of the stormwater structure, the added cost of platforms is relatively minor when compared with the amenity value provided. Inlets and outlets provide a point of interest in the water cycle as they are associated with moving water including noise and meditative value.

Alternatively, in the coastal environment it may be possible to incorporate an outlet into a boat ramp, to minimise the number of manmade structures.

Where there are multiple points of discharge, consider combining discharges to a common point, via a common structure. When working in a publically accessible area, such as reserve or coastal marine area, it is important to locate the structures in such a position as to not create an obstacle to public access to, from, or along the area.



Figure 31: Cycleway Across Forebay Weir



Figure 32: Viewing Platform Hides Wetland Weir Detail



Figure 33: Pond Outlet Hidden Under Viewing Platform

5.2.2.2 Surface Treatments

The ‘devil is in the detail’ is particularly apt when discussing inlets, outlets, and energy dissipation and finish is the Achilles heel of many projects. It is important to ensure the appearance of the structure does not detract from its immediate surrounds. For example, the use of appropriate materials such as locally sourced rock and/or coloured and sculpted concrete forms may be appropriate.

The poor finish on the concrete weir and cascade in Figure 34 completely detracts from what could have been a lively landscape feature. The concrete should be compacted, screed and floated (e.g. smoothed while wet), with all exposed corners rounded.

Concrete can be coloured to a more natural earth tone by adding readily available iron oxide pigments. Wet concrete can be readily textured to look like natural rock or stamped with a geometric or fish shape (for example) to form an imprint on the surface. The culvert apron in Figure 35 includes shell to give this coastal outfall a more natural finish.

Concrete headwalls or manholes can be coloured green (Figure 27, page 37) to blend with the environment. Vegetation is also extremely useful for hiding concrete structures so they are less intrusive.



Figure 34: Poor Finish on Concrete Weir



Figure 35: Culvert Apron with Cement, Sand and Shell Natural Finish

The use of rock instead of a precast headwall may better match the natural bank slope and provides a natural appearance (Figure 36 and Figure 37). Stone pitching or facing concrete with natural brown or blue rock can also improve the appearance of a structure. Alternative landscaping materials such as confined earth retaining structures (Figure 38) can facilitate vegetation and allow the asset to blend into the landscape.



Figure 36: Outfall Energy Dissipation with Natural Finish



Figure 37: Grouted Rock Headwall



Figure 38: Outfall with Riprap and "Living Wall" Confined Earth Retaining Structure

Naturalising structures with vegetation can significantly improve aesthetics. However, safety and ease of maintenance must still be considered. Figure 38 shows two views of the same outfall; while the outlet may appear hidden (right), the large riprap apron (left) means the outfall will be easily locatable. The design incorporates long grass in fitting with the rough and natural surrounding area. However, if the structure was located in a manicured park a different approach would be needed as this grass could not be regularly mowed.

Incorporation of artistic designs in inlets and outlets can provide an attractive addition to a landscaped area. The appliqué on the grille to the left in Figure 39 stands it well apart from other less attractive examples.



Figure 39: Attractive and Unattractive Grilled Domes

5.2.2.3 Education and Signage

Educational opportunities that can be integrated into stormwater projects include:

- Incorporating community planting in the works
- Involving schools through site tours or by explaining the purpose of the works
- Providing press releases or information to media about important or interesting projects
- Providing interpretive signage relating to the environment and water cycle issues

Signage can be as predictable as identifying caution or hazard areas, providing ownership or maintenance contact details, or describing the function of the device. As an educational feature signage could be expanded to also include community branding and science or conservation education.

5.3 Economic Considerations

5.3.1 Materials

Proper materials will ensure that treatment devices are robust and have the best operational life. Not all materials are created equal and the designer should specify what gauge wire or weight geotextile (for example) is to be used. Contract documents should require development and submittal of methodology and quality documentation to ensure that proper installation methods will be followed.

Coastal settings may have specific requirements so that structures can resist corrosion or wave energy effects.

5.3.1.1 Geotextiles

“Geotextiles” covers a wide range of organic or synthetic materials that have a variety of uses. Geotextiles provide separation between fine and coarse materials and help prevent riprap, for example, from ‘sinking’ into a softer underlying clay substrate, or prevent fines from infiltrating and clogging drainage metal. In some cases they can replace thicker, more expensive granular drainage materials. They also distribute local stresses and increase soil bearing capacity which is important in some of Auckland’s weak clay soils. Geotextiles are also used to help stabilise unvegetated slopes, or as a weed mat to suppress undesirable plant growth.

Geotextiles should generally be specified for beneath gabions and reno mattresses, under riprap, and as a separation layer between native soil and granular backfill around manholes and inlet/outlet structures. Geotextile separation layers or filter socks are also recommended to be installed over underdrain piping in rain gardens and potentially other applications (refer to Section 4.3).

Geotextiles are made of natural fibres, polypropylene, polyester, or even metal and either woven or nonwoven (felt-like). Nonwoven geotextiles are often ‘needle punched’ to improve permeability. They can be two or three dimensional.

Natural fabrics such as coir mat, jute mesh, coconut matting, or hessian cloth are intended to disintegrate over time and are used in landscape erosion protection applications (not for material separation or to improve soil bearing capacity).

In order for geotextile fabrics to do their job over time, it is important that manufacturer's installation instructions regarding lapping of fabric, burying/securing fabric edge, and pinning/anchoring are followed.

5.3.1.2 Gabions

Gabions are wire mesh baskets filled with rocks, that are used to form weirs, retain channels, and protect banks from erosion. Reno mattresses are a special wider, flatter kind of gabion used as a flexible foundation for gabions or as a channel lining. In the Auckland region gabions have been used to form gabion seepage structures (Figure 40) and incorporated into an outfall detail comprising channel protection with a flow-through 'check dam' arrangement (e.g. Wairoa Filter).



Figure 40: Gabion Basket Outlet

Gabions are formed onsite which may make construction easier. Because of the wire mesh structure smaller rock can be used as compared with riprap. However, debris (especially grass) can collect on gabions, and they can rust, or the basket wire may break over time (allowing rock to spill out).

Gabions are made of mild steel and are often zinc coated (hot dip galvanised). However, a Zn/Al alloy is more robust and should be specified. A PVC polymer can also be applied over the alloy coating and provides further protection from rust. While this coating provides additional protection, gabions may still not be suitable in coastal areas due to salt water corrosion and release of zinc into water.

Wire size is also an important specification to consider. A wire diameter of 3 mm is considered too light weight for erosion protection applications and wire sizes of 3.7, 4 or 4.5 mm should be specified.

As with all material applications, manufacturer's installation instructions need to be followed during construction.

5.3.2 Operational Outcomes

The main objectives of operation and maintenance are to maintain asset condition and function, keep the asset safe, estimate future maintenance requirements, and minimise environmental effects. To achieve these objectives the design, execution, and materials of a system and the environment it sits in are extremely important. Important aspects of design that contribute to good operational outcomes include:

- Less is best – Is a large, expensive, complicated asset necessary or are there better low impact, low maintenance solutions?
- Standard is more understood than unique – Engineering and industry standards have experienced some ‘test of time’ and are often better understood by operators. However, ‘one size does not fit all’ so be aware of when a specific or alternative design will provide better benefits. Additionally, traditional inlet and outlet standards may lack visual or ecological amenity and it is a goal of modern stormwater management to provide multiple benefits.
- Design for minimal maintenance – For example, reverse slope outlet pipes that withdraw water from below the surface where floatables could otherwise collect and block the outlet.
- Provide the ability for maintenance access – This is necessary especially where grilles need periodic clearing. Dome grilles on manholes may also need access hatches to access the manhole. Pipe sizes 600–900 mm may be considered problematic because they are too large to self-clean and too small to manually clean, possibly consider multiple cells.
- Incorporate a pond (or other treatment device) dewatering outlet in a manhole service outlet for maintenance and sediment removal operations. This can be as simple as a capped or valved tee connection.
- Provide a good standard of construction – Satisfactory cover on reinforcing, champhered edges on formed concrete, dry and stable subgrades, antiseep collars on pipes laid on steep grades, etc.

Figure 41 shows a simple outlet formed from a downturned PVC bend to prevent floating material from clogging outlet. Figure 42 shows low flow outlet (to the left) with an articulated pond drain to be used for pond maintenance. The drain can be opened from the surface via the handle and armature arrangement.



Figure 41: Downturned Bend on Simple Outlet



Figure 42: Looking Inside Pond Service Outlet Chamber

5.3.2.1 Debris Management

Key maintenance tasks include inspecting outlet protection on a regular basis for erosion, sedimentation, scour or undercutting; repairing or replacing riprap, geotextile or concrete structures as necessary to handle design flows; and removal of rubbish, plant material, or sediment.

Debris management is very complicated because the designer must consider whether the debris floats or sinks, the size of the debris, the size of the culvert or pipe, the upstream entry and downstream exit configurations, access, maintenance, and system operation if a blockage occurs or during severe storm events.

Figure 43 and Figure 44 are two different examples of debris grilles. The first figure shows a retrofitted grille on a pond weir outlet; the grille is poorly constructed with too small openings and this has resulted in a tunnel/seep forming underneath and to the right of the weir structure. Figure 44 shows an effective grille with the grille surface area much larger than the culvert cross-sectional area and the configuration facilitates 'self-cleaning' to an extent.



Figure 43: Poorly Built Retrofitted Debris Grille



Figure 44: Debris Grille

If significant amounts of debris are expected or the inlet is critical with no secondary overland flow, two screens/grilles may be needed with the larger mesh openings located several meters upstream of the main inlet grill. Figure 45 and Figure 46 show multiple debris catchers upstream of large inlet structures.



Figure 45: Effective Debris Fencing Upstream of Critical Inlet



Figure 46: Large Inlet Structure with Maintenance Access and Numerous Grilles

5.3.3 Material Sustainability

Design of stormwater treatment devices, including specific design for inlets and outlets, has traditionally been prioritised and designed using a predominantly economic focus. Growing awareness of holistic design approaches and sustainability concepts, such as low impact development and water sensitive design, mean current design processes ideally consider a broader range of impacts including economic, environmental (see Section 5.1), social/community and cultural (see Section 5.2) impacts.

In terms of economics, traditional life cycle costing considered capital as well as operational costs over the design life of the structure. However, consideration of the sustainability of materials used within inlet and outlet infrastructure can also be an important consideration in helping to achieve sustainable outcomes from infrastructure creation.

When selecting materials it is important to look beyond what is immediately obvious. Life cycle analysis (slightly different from traditional life cycle costing) aims to find the total energy necessary for the extraction and processing of raw materials, manufacturing of the system, transportation of materials and equipment to the site, construction and operation of the system, maintenance, and the final decommissioning of the system. The total energy required is often referred to as “embodied energy” and encompasses two aspects: initial embodied energy and recurring embodied energy. The initial embodied energy is the energy necessary to acquire raw materials and to process, manufacture, transport, and install these materials for a project. Recurring embodied energy is the energy required to maintain, repair, restore, refurbish, or replace materials during the life of a project.

Selection of sustainable materials, where possible, will assist in minimising embodied energy. Forum for the Future (2012) uses five principles to define a sustainable material:

- Resource efficient - Materials choice should maximise reuse and recycling, minimise the use of natural resources and production of wastes, and optimise for durability and ease of maintenance.
- Low environmental impact - Materials should have a low environmental impact through minimising discharges to air, water, and land, eliminating the use of hazardous substances to the environment, and eliminating degradation of ecosystems throughout their lifecycle. Ideally, materials selection will promote biodiversity and retain existing ecological features
- Minimise risks to human health and employee welfare – Throughout the material’s lifecycle, health and safety risks to the workforce and local communities should be eliminated or minimised to an acceptable level. The material’s manufacturing, construction and maintenance processes as well as final asset design should strive to benefit local communities and minimise any negative impacts, such as nuisance impacts, heavy road transport, and amenity/aesthetics.
- Provide benefits to local communities - Where appropriate, materials should enable sustainable design solutions providing enhancements and benefits to the local environment and community such as enabling amenity space in the design, fostering local community groups and provision of access to pedestrians and cyclists.
- Enable or assist sustainable design solutions - Opportunities should be identified to improve operational efficiency or promote the use of innovative materials and construction techniques.
- Some simple points to consider for greater resource efficiency are:

- Natural materials (i.e. plants, aggregate) will have less embodied energy than manufactured materials (i.e. concrete, steel).
- Transportation of materials increases embodied energy; specification of locally available products in a design (whether natural or manufactured) will reduce embodied energy.
- While vegetated inlet or outlet designs may have substantially lower initial embodied energy than hard engineering solutions utilising materials such as concrete and steel, they will potentially have greater recurring embodied energy than an equivalent hard engineering solution due to the required maintenance of a planted system.
- In situations where hard engineering may be the only solution, it is important to identify where opportunity can be taken to improve materials sustainability. For example, concrete using industrial by-products such as fly ash or blast furnace slag to supplement the portion of cement used prevents these wastes going to landfill and reduces the CO₂ embodied energy in the concrete (Ashley & Lemay, 2008).

While the scope for sustainable materials and minimising embodied energy may be limited in the design of inlets or outlets, it is essential to at least consider the full range of impacts during options analysis. A paradigm shift from conventional stormwater management techniques to a more sustainable design philosophy means that environmental, social, and cultural impacts must all be considered in conjunction with financial concerns.

6.0 Approaches to Design

The inlet and outlet options given in Sections 3.0 and 4.0 have been combined with the design considerations of Section 5.0 to develop design checklists that can guide selection of techniques to meet objectives for inlet or outlet design situations. Please refer to Appendix 1 Table A1 for the Inlet and Outlet Hydraulic Energy Management Checklist, and Table A2 for the Inlet and Outlet Design Considerations Checklist.

7.0 Conclusion

This report is intended to provide a basis for design for inlets and outlets that provides for non-erosive discharges and allows treatment devices to operate as they are intended. Its overall purpose is to represent a chapter in the new GD01, the forthcoming revision of the former Auckland Regional Council Technical Publication 10 (TP10), Stormwater management devices: Design guidelines manual. This report can offer a sound basis for developing the new guidance, with minor revisions to reduce the overall document size and focus its message. It is recommended that the following adjustments be made:

- The scope of the introduction and background (Chapter 1) would be reduced as the chapter would sit in the context of the whole TP10 document and much of this information would be included in other chapters.
- The technical background (Chapter 2) regarding fundamental energy relationships and equations and also process descriptions of sedimentation and erosion could be reduced in scope.
- Similarly, the various weir formulae provided in Section 4 could be eliminated (especially if included elsewhere in TP10) or incorporated into an appendix.
- A number of the design considerations in Section 5, for example ‘education and signage’ only just touch on a broader topic. Another example is fish passage where there are other more comprehensive technical publications. These and other subsections should be reviewed to verify that they provide sufficient information, direct the reader to a more suitable resource, and/or should be deleted.
- The design checklists are provided to help identify key issues and promote robust design. These could be separated into several lists, or formed into a table of considerations for incorporation into inlet and outlet sections, sections 3 and 4.

8.0 References and Further Reading

Andrew, R.M. and Vesely, E.T. (2008) Life-cycle energy and CO₂ analysis of stormwater treatment devices. *Water Science and Technology*. 58(5) pp. 985-993.

Ashley, E. and Lemay, L. (2008) Concrete's Contribution to Sustainable Development. *Journal of Green Building*, 3(4) pp. 37–49.

Auckland Council (2012) Auckland Council Regional Plan: Air, Land and Water operative in part.

Auckland Regional Council (1999). Technical Publication 90 – Erosion and Sediment Control Guidelines for Land Disturbing Activities, Prepared for Auckland Regional Council.

Auckland Regional Council (2001) Technical Publication 148 – Riparian Zone Management Strategy for the Auckland Region, Prepared for Auckland Regional Council.

Auckland Regional Council (2003). Stormwater Management Devices: Design Guidelines Manual, Second Edition. Technical Publication 10, Auckland Regional Council.

Brisbane City Council (2003). Stormwater Outlets in Parks and Waterways, Version 2.

County of Los Angeles Department of Public Works (2009) Stormwater Best Management Practice Design and Maintenance Manual: For Publicly Maintained Storm Drain Systems.

Douglas, J.F., Gasiorek, J.M., & Swaffield, J.A. (1985) *Fluid Mechanics*. Second Edition. London: Pitman Publishing Limited.

Forum for the Future (2012) Sustainability Assessment for Civil Engineering Materials (Version 2.0). Produced by the e21c program in collaboration with Environment Agency, British Waterways, Halcrow, Interserve, and Galliford Try.

Hathaway, J.M and Hunt, W.F. (2006). Level Spreaders: Overview, Design, and Maintenance. NC Cooperative Extension Urban Waterways Series, AG-588-09 W. Available at: <http://www.bae.ncsu.edu/stormwater/PublicationFiles/LevelSpreaders2006.pdf>

Institution of Engineers, Australia (1987) *Australian Rainfall and Runoff*, Vol. 1&2. (Ed: Pilgrim, D.H.) Institution of Engineers, Australia.

Miselis, P., Goodfellow, K. (2010). Stormwater Outfall Structures Literature Review. Prepared by AECOM New Zealand Ltd. for Auckland Regional Council.

NZDBH (1987) Fencing of Swimming Pools Act 1987, Reprint as at 1 April 2008. Administered by the Department of Housing and Building. Viewed online 26 Mar 13 at <http://www.legislation.govt.nz/act/public/1987/0178/latest/DLM124442.html>

NZTA (2010) Stormwater Treatment Standard for State Highway Infrastructure. Published by the New Zealand Transport Agency.

O'Sullivan, A.D. (2012) Life Cycle Assessment of Stormwater Treatment Systems. Accessed 30 November 2012 from <http://calendar.oregonstate.edu/event/68771/>.

Shand, T.D., Cox, R.J., Smith, G., and Blacka, M. (2010). Appropriate Criteria for the Safety and Stability of People in Stormwater Design. Stormwater 2010 - Stormwater Industry Association National Conference, 9-12 November 2010, Sydney, Australia

Shaver, E. (2000). Low Impact Design Manual for the Auckland Region. Technical Publication No. 124 (TP124). Auckland Regional Council.

Shen, J. (1981). Discharge Characteristics of Triangular-Notch Thin-Plate Weirs. U.S. Geological Survey Water-Supply Paper 1617-B, Washington, D.C.

Stevenson, C.; Baker, C. (2009). Fish Passage in the Auckland Region – a synthesis of current research. Prepared by NIWA for Auckland Regional Council. Auckland Regional Council Technical Report 2009/084.

SUDAS (2013). Iowa Statewide Urban Design and Specifications: Design Manual, Chapter 7 – Erosion and Sediment Control. Accessed from

<http://www.iowasudas.org/manuals/manual.cfm?manual=design>

US Department of the Interior Bureau of Reclamation (2001). Water Measurement Manual, Third Edition. Accessed from http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm

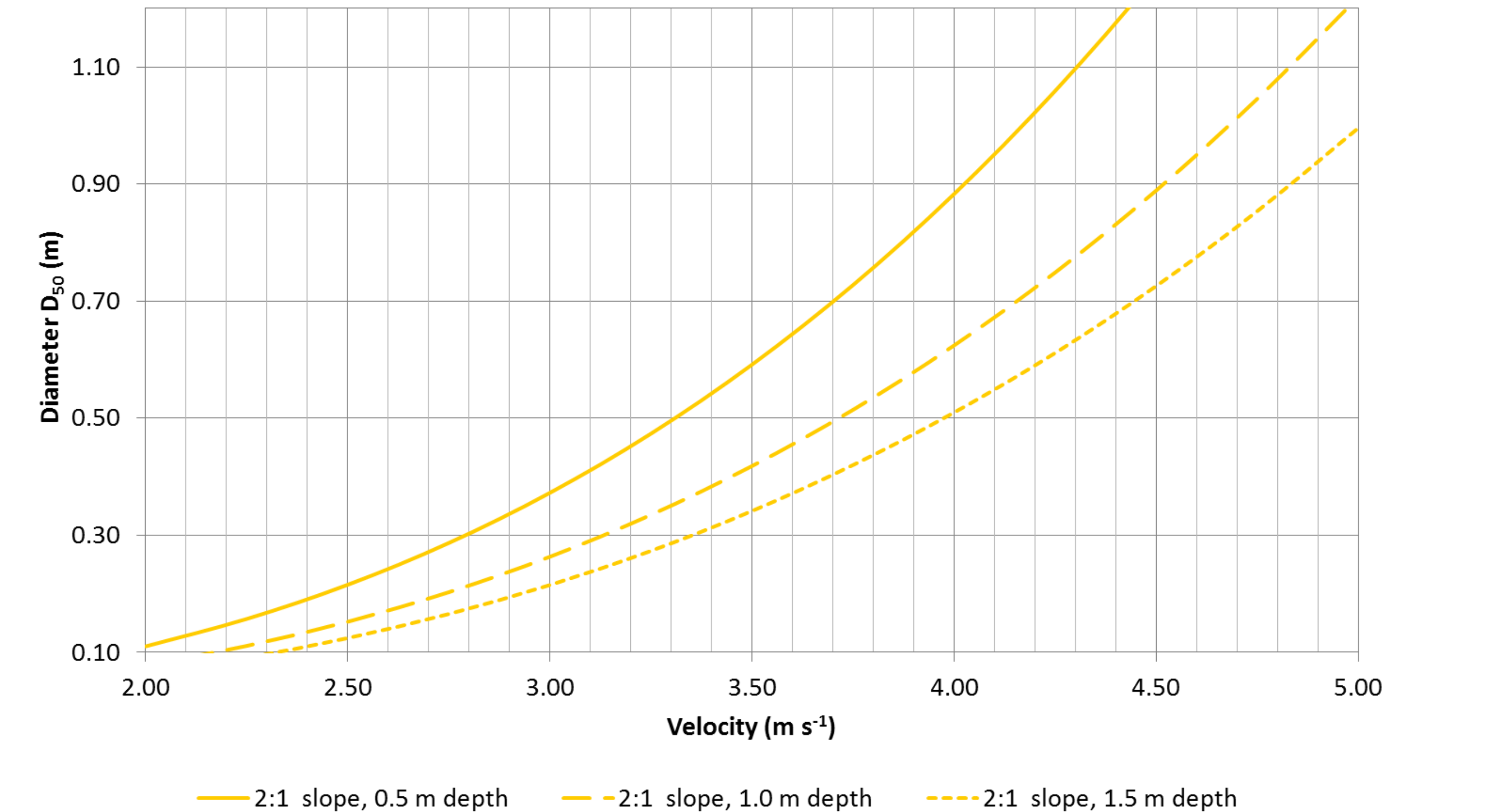
USDOT (1989). Hydraulic Energy Circular No. 11, Design of Riprap Revetment. Published by the United States Department of Transportation, Federal Highway Administration.

USDOT (2006). Hydraulic Energy Circular No. 14, Third Edition, Hydraulic Design of Energy Dissipaters for Culverts and Channels. Published by the United States Department of Transportation, Federal Highway Administration.

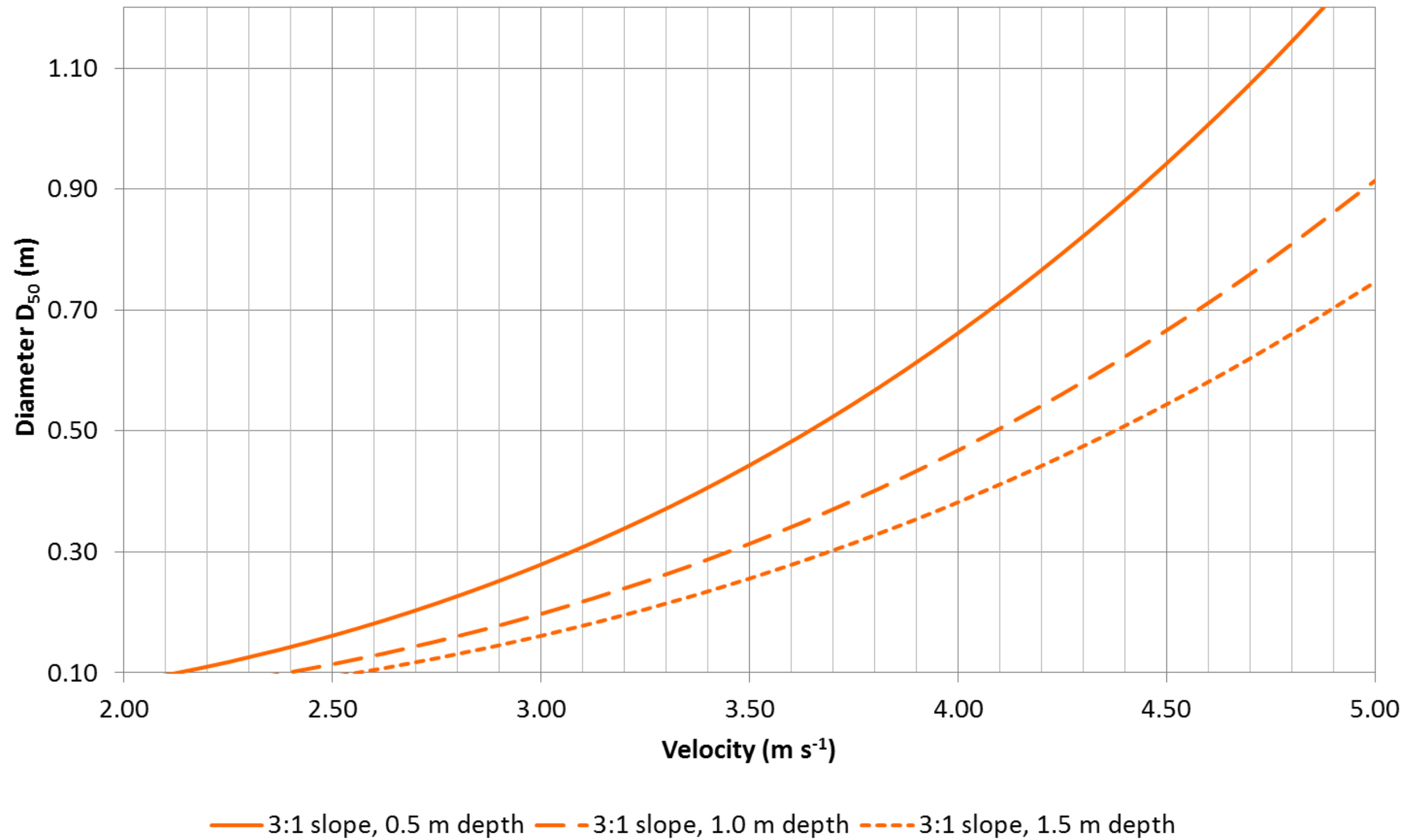
USDA NRCS (2012) Illinois Urban Manual: A Technical Manual Designed for Urban Ecosystem Protection and Enhancement. Developed by the Association of Illinois Soil and Water Conservation Districts, Illinois Environmental Protection Agency and the United States Department of Agriculture Natural Resources Conservation Service. Accessed from <http://aiswcd.org/IUM/index.html>

VA DCR (2011). Virginia Department of Conservation and Recreation Stormwater Design Specification No. 2: Sheet Flow to a Vegetated Filter Strip or Conserved Open Space.

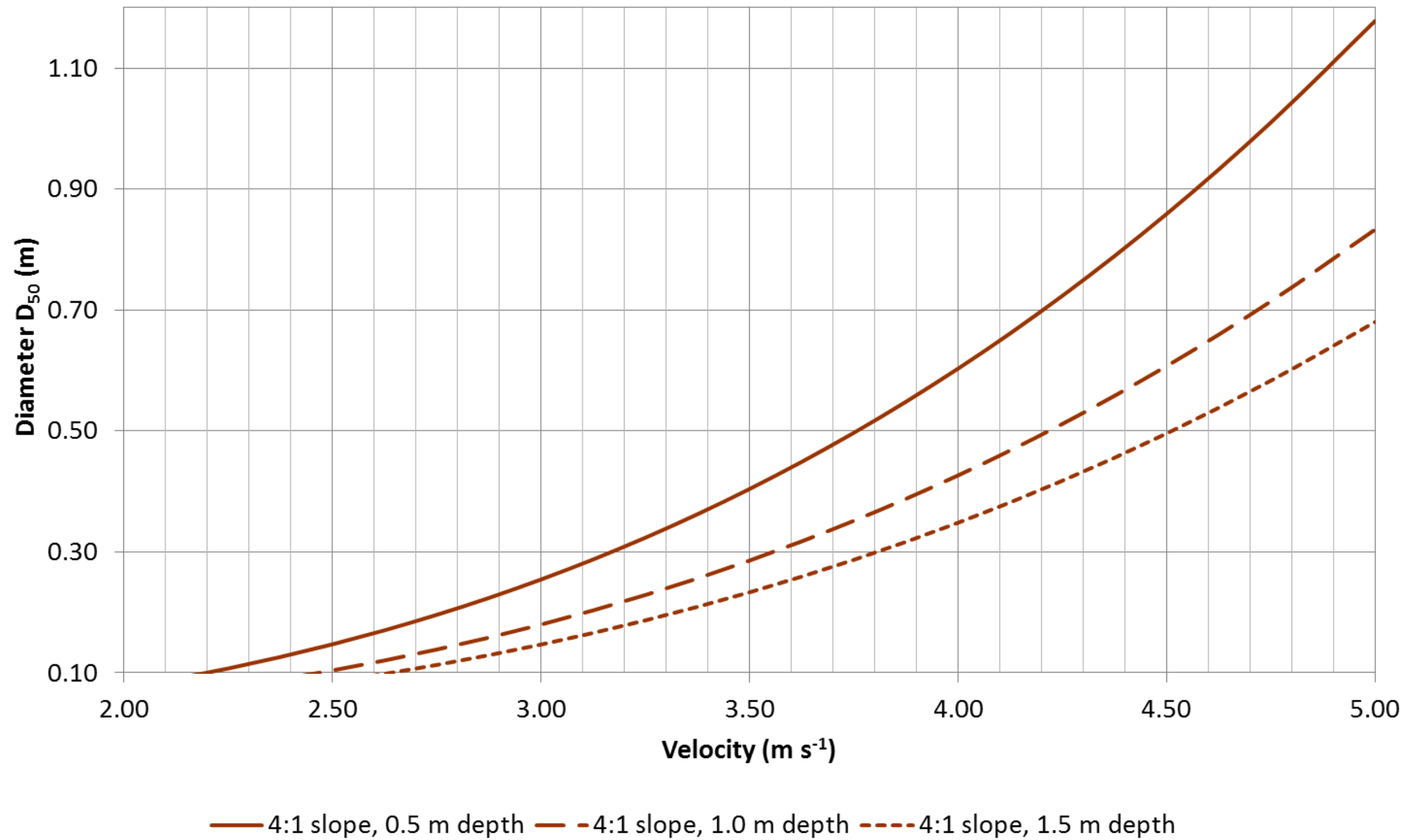
Riprap D_{50} Sizing - 2:1 Slope



Riprap D_{50} Sizing - 3:1 Slope



Riprap D_{50} Sizing - 4:1 Slope



Appendix B Design Checklists

Table 4: Inlet and Outlet Hydraulic Energy Management Checklist

ISSUE	METHOD	APPLICABLE?	TECHNIQUE TO CONSIDER	APPLICATION					CONSTRAINTS										OPPORTUNITIES				CONSIDERATIONS
				Inlet	Culvert under inlet control	Outlet	Culvert under outlet control	Receiving water outfall	Limited available space	Traffic and pedestrian safety	Safety to maintenance operators	Maintenance access limitations	Potentially high capital cost	Potential for blockage	Environment integration	Potentially significant receiving environment effects	Construction difficulties	Fish passage requirements	Amenity	Habitat enhancement	Improved access	Improved treatment	
HIGH FLOWS?	Distribute Flow	Y/N	Level spreader	✓	✓	✓		✓	✓				✓	✓		✓				✓	Must be level May need downstream erosion protection		
			Flow spreading trench	✓		✓		✓	✓			✓			✓					✓	Ground water elevations Potential pore space blockage over time		
			Flow expansion, increase cross sectional area	✓		✓	✓	✓	✓	✓			✓	✓	✓			✓	✓			Erosion control Habitat disturbance Safety issues?	
			Inflow via filter strip or landscaped area	✓	✓																✓	Soil type Ground water elevations Maintenance, mowing of frequently wet area	
			Kerb cuts to disperse flow	✓						✓												Volume of runoff, overland flowpaths Location of kerb cuts - traffic issues and flow capture	
			Vanes or baffles	✓	✓	✓	✓							✓	✓	✓	✓				✓	Maintenance requirements, debris accumulation	
	Divert peak flows	Y/N	Provide alternative flow path for peak flows	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓							Existing overland flowpaths Upstream and downstream effects		
			Flow splitter	✓	✓					✓	✓	✓		✓	✓	✓	✓					Existing overland flowpaths Upstream and downstream effects	
HIGH VELOCITIES?	Reduce head	Y/N	Drop inlets/manholes /outlets	✓	✓	✓					✓	✓	✓	✓			✓	✓			Quantity and location required to reduce head Tailwater conditions Debris accumulation		
	Dissipate energy	Y/N	Submerged inlet	✓	✓							✓									Inlet capacity Sediment resuspension		
			Riprap apron	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓						Debris accumulation Geotextile underlay needed? Rock size		
			Concrete apron, impact blocks	✓	✓	✓	✓				✓			✓	✓	✓	✓					Debris accumulation Geotextile underlay needed?	
			Stilling Basin (Hydraulic jump basin)			✓	✓		✓								✓					Specific detailed design required	
			Recovery/transition reach			✓	✓	✓				✓		✓				✓	✓	✓	✓	Maintenance requirements	

ISSUE	METHOD	APPLICABLE?	TECHNIQUE TO CONSIDER	APPLICATION					CONSTRAINTS										OPPORTUNITIES				CONSIDERATIONS
				Inlet	Culvert under inlet control	Outlet	Culvert under outlet control	Receiving water outfall	Limited available space	Traffic and pedestrian safety	Safety to maintenance operators	Maintenance access limitations	Potentially high capital cost	Potential for blockage	Environment integration	Potentially significant receiving environment effects	Construction difficulties	Fish passage requirements	Amenity	Habitat enhancement	Improved access	Improved treatment	
	<u>Reduce erosivity</u>	Y/N	Planting	√	√	√	√	√	√						√				√	√		√	Consider appropriate plant species for environment, soil conditions, water table, salt water
			Check dams	√	√	√		√							√	√		√		√		√	Debris accumulation Geotextile underlay needed? Rock size
			Riprap, gabions	√	√	√	√	√	√			√			√	√	√	√					Debris accumulation Geotextile underlay needed? Rock size Visual impact
FLOW MANAGEMENT REQUIREMENT?	<u>Inlet/outlet configuration</u>	Y/N	Low flow and orifice			√	√					√		√		√	√						Debris accumulation Maintenance requirements Blockage potential Appropriate exit velocity for downstream environment
			Weirs, stage discharge outlets	√	√	√	√	√			√	√				√		√					Design objectives Blockage potential
			Underdrain	√	√	√	√	√				√		√			√					√	Ground water elevations Potential pore space blockage over time
			Vary culvert roughness				√										√	√					Appropriate materials

Table 5: Inlet and Outlet Design Considerations Checklist

ISSUE	METHOD	APPLICABLE?	TECHNIQUE TO CONSIDER	POTENTIAL APPLICATION									CONSTRAINTS/ CONSIDERATIONS									OPPORTUNITIES				COMMENTS AND FURTHER CONSIDERATIONS	WELLBEING				
				Treatment device inlets, outlets and/or outfalls	Ponds	Wetlands	Rain Gardens	Sand Filters	Infiltration/ Soakage	Swales	Oil Water Separators	Raintanks	GPT	Limited available space	Traffic and pedestrian safety	Safety to maintenance operators	Maintenance access limitations	Potentially high capital cost	Potential for blockage	Environment integration	Potentially significant receiving environment effects	Construction difficulties	Fish passage requirements	Amenity	Habitat enhancement		Improved access	Improved treatment	ENVIRONMENTAL	CULTURAL	SOCIAL
EROSION POTENTIAL?	Distribute Flow	Y/N	Level spreader	√		√	√	√		√		√		√			√	√		√					√	Must be level May need downstream erosion protection	√				
			Flow expansion, increase cross sectional area	√										√		√	√	√					√	√			Erosion control Habitat disturbance Safety issues?	√			
			Inflow via filter strip or landscaped area	√	√	√	√	√	√				√												√		Soil type Ground water elevations Maintenance, mowing of frequently wet area	√		√	
	Divert peak flows	Y/N	Provide alternative flow path for peak flows	√	√	√	√	√	√	√	√	√	√	√	√		√	√		√						Existing overland flowpaths Upstream and downstream effects	√				
	Reduce head	Y/N	Drop inlets/outlets	√											√	√				√	√					Quantity and location required to reduce head Tailwater conditions Debris accumulation	√				
	Dissipate energy	Y/N	Submerged inlet	√	√	√		√			√				√												Inlet capacity Sediment resuspension	√			
			Riprap apron	√											√		√	√		√	√						Debris accumulation Geotextile underlay needed? Rock size	√			
			Concrete apron, impact blocks	√												√	√		√	√		√					Debris accumulation Geotextile underlay needed?	√			
			Hydraulic Jump basin	√										√								√					Specific detailed design required	√			√
			Recovery/transition reach	√		√				√				√			√					√	√	√		√	Maintenance requirements	√		√	
	Reduce erosivity	Y/N	Planting	√	√	√	√			√				√			√						√	√		√	Consider appropriate plant species for environment, soil conditions, water table, salt water	√		√	
			Check dams	√						√							√	√			√			√		√	Debris accumulation Geotextile underlay needed?	√			

ISSUE	METHOD	APPLICABLE?	TECHNIQUE TO CONSIDER	POTENTIAL APPLICATION										CONSTRAINTS/ CONSIDERATIONS										OPPORTUNITIES				COMMENTS AND FURTHER CONSIDERATIONS	WELLBEING			
				Treatment device inlets, outlets and/or outfalls	Ponds	Wetlands	Rain Gardens	Sand Filters	Infiltration/ Soakage	Swales	Oil Water Separators	Raintanks	GPT	Limited available space	Traffic and pedestrian safety	Safety to maintenance operators	Maintenance access limitations	Potentially high capital cost	Potential for blockage	Environment integration	Potentially significant receiving environment effects	Construction difficulties	Fish passage requirements	Amenity	Habitat enhancement	Improved access	Improved treatment		ENVIRONMENTAL	CULTURAL	SOCIAL	ECONOMIC
																												Rock size				
			Riprap, gabions	√	√	√				√				√				√	√	√	√							Debris accumulation Geotextile underlay needed? Rock size Visual impact	√			
	<u>Inlet/outlet configuration</u>	Y/N	Low flow and orifice	√	√	√	√				√				√		√	√	√					√			Debris accumulation Maintenance requirements Blockage potential Appropriate exit velocity for downstream environment	√				
			Weirs, stage discharge outlets	√	√	√	√			√						√	√					√			√			Design objectives Blockage potential	√			
	<u>Alter entrance conditions</u>	Y/N	Vary culvert roughness	√																√	√						Appropriate materials	√				
	WATER QUALITY EFFECTS?	<u>Debris traps</u>	Y/N	Grilles	√	√	√	√	√	√		√			√							√				√			Maintenance inspection frequency Amount, type of debris Upstream and downstream effects during blockage Safe access for maintenance Need to restrict access on both upstream and downstream ends of culvert	√		
Booms to segregate floatables				√	√													√			√				√			Maintenance inspection frequency Amount, type of debris Safe access for maintenance Visual effects	√			
Baffles				√	√			√	√		√			√				√	√	√	√				√			Debris accumulation	√			
<u>Avoid resuspension</u>		Y/N	Inlets & outlets positioned above	√	√	√	√			√	√	√				√								√			Expected sedimentation depth					

ISSUE	METHOD	APPLICABLE?	TECHNIQUE TO CONSIDER	POTENTIAL APPLICATION										CONSTRAINTS/ CONSIDERATIONS										OPPORTUNITIES				COMMENTS AND FURTHER CONSIDERATIONS	WELLBEING			
				Treatment device inlets, outlets and/or outfalls	Ponds	Wetlands	Rain Gardens	Sand Filters	Infiltration/ Soakage	Swales	Oil Water Separators	Raintanks	GPT	Limited available space	Traffic and pedestrian safety	Safety to maintenance operators	Maintenance access limitations	Potentially high capital cost	Potential for blockage	Environment integration	Potentially significant receiving environment effects	Construction difficulties	Fish passage requirements	Amenity	Habitat enhancement	Improved access	Improved treatment		ENVIRONMENTAL	CULTURAL	SOCIAL	ECONOMIC
			sedimentation zone																													
	<u>Retain floatables & high temperature surface layer</u>	Y/N	Reverse slope pipe or siphon	√	√	√					√			√	√		√				√		√		√		Maintenance inspection frequency Amount, type of debris Upstream & downstream effects during blockage	√				
RECEIVING ENVIRONMENT POTENTIALLY AFFECTED?	<u>Stream protection</u>	Y/N	Ensure outlet set back & discharge is aligned with stream flow	√										√	√		√	√		√	√	√				Erosion protection and energy dissipation for transition		√	√			
			Grade control structures	√						√				√	√			√			√			√		Poor levels result in inefficiency Avoiding debris accumulation Habitat effects	√					
	<u>Habitat design</u>	Y/N	Introduce materials to optimise habitat	√	√	√	√				√			√			√			√	√	√	√	√	√	Catchment specific characteristic Durability, long term benefit cost Visual impact	√	√				
			Provide variable aquatic conditions	√	√	√				√					√			√		√	√	√	√	√	√	Site specific species to consider	√	√	√			
			Include suitable planting and landscaping	√	√	√	√			√				√	√			√					√	√	√	Plant species appropriate for environment, soil conditions, water table, salt water, maintenance requirements	√	√	√			
			Allow for plant maintenance to ensure good success rate and minimise weeds	√	√	√	√			√													√	√	√	Weedmat, mulch, fertiliser to minimise long term maintenance and replacement costs Maintenance appropriate to plant species/ location/ soil conditions	√					
			Avoid creating stagnant areas that encourage mosquitos	√	√	√	√	√		√													√	√		Catchment specific flows Low flow drainage, weep holes	√		√			
			FISH PASSAGE REQUIRED?	<u>Design considerations</u>	Y/N	Eliminate/ minimise vertical fall heights	√	√	√										√	√		√	√		√		Species Varying flow conditions	√	√			

ISSUE	METHOD	APPLICABLE?	TECHNIQUE TO CONSIDER	POTENTIAL APPLICATION										CONSTRAINTS/ CONSIDERATIONS										OPPORTUNITIES				COMMENTS AND FURTHER CONSIDERATIONS	WELLBEING			
				Treatment device inlets, outlets and/or outfalls	Ponds	Wetlands	Rain Gardens	Sand Filters	Infiltration/ Soakage	Swales	Oil Water Separators	Raintanks	GPT	Limited available space	Traffic and pedestrian safety	Safety to maintenance operators	Maintenance access limitations	Potentially high capital cost	Potential for blockage	Environment integration	Potentially significant receiving environment effects	Construction difficulties	Fish passage requirements	Amenity	Habitat enhancement	Improved access	Improved treatment		ENVIRONMENTAL	CULTURAL	SOCIAL	ECONOMIC
			Minimise water velocities	√	√	√								√				√		√	√	√	√		√		√	Refer to techniques for minimising velocities	√	√		
			Provide some depth of flow in culverts	√	√	√														√	√	√			√			Upstream and downstream effects Culvert capacity	√	√		
			Provide wetted margin	√	√	√													√	√	√	√			√			Varying flow conditions Materials	√	√		
			Refer to TR2009/084	√	√	√																√			√			Design to meet specific objectives	√	√		
LOCATED IN PUBLIC SPACE OR POTENTIALLY PUBLIC ACCESS?	<u>Provide protection against falls</u>	Y/N	Fencing around headwalls or where potential to fall 1 m or more	√	√	√				√				√	√	√		√		√		√				√		Additional safety features/access limitations in public space may be needed.		√	√	
			Limit flow depth times velocity to 0.4 m s ⁻¹ across accessways and footpaths	√										√	√	√		√	√	√	√			√		√		Frequency of flow Type of public access		√	√	
			Provide safe batters	√	√	√				√				√	√	√			√							√		Soil and geotechnical characteristics	√	√	√	
			Dense barrier planting	√	√	√	√			√				√	√	√				√					√	√	√	Plant species appropriate for environment, soil conditions, water table, salt water, maintenance requirements	√	√	√	
	<u>Limit culvert access</u>	Y/N	Consider multi-barrelled smaller inlets/outlets	√	√	√								√	√	√	√	√	√	√	√	√						Cost vs. benefits Blockage potential Maintenance requirements		√	√	
			Safety grille	√	√	√													√	√		√						Maintenance inspection frequency Amount, type of debris Upstream & downstream effects during blockage Safe access for maintenance Need to restrict access on both upstream & downstream ends of culvert		√	√	

ISSUE	METHOD	APPLICABLE?	TECHNIQUE TO CONSIDER	POTENTIAL APPLICATION										CONSTRAINTS/ CONSIDERATIONS										OPPORTUNITIES				COMMENTS AND FURTHER CONSIDERATIONS	WELLBEING			
				Treatment device inlets, outlets and/or outfalls	Ponds	Wetlands	Rain Gardens	Sand Filters	Infiltration/ Soakage	Swales	Oil Water Separators	Raintanks	GPT	Limited available space	Traffic and pedestrian safety	Safety to maintenance operators	Maintenance access limitations	Potentially high capital cost	Potential for blockage	Environment integration	Potentially significant receiving environment effects	Construction difficulties	Fish passage requirements	Amenity	Habitat enhancement	Improved access	Improved treatment		ENVIRONMENTAL	CULTURAL	SOCIAL	ECONOMIC
ARE MAINTENANCE ISSUES MINIMISED?	<u>Provide safe access</u>	Y/N	Hinged grilles with fracture bolts	√	√	√				√									√	√			√					Maintenance inspection frequency Amount, type of debris Upstream & downstream effects during blockage Safe access for maintenance Need to restrict access on both upstream & downstream ends of culvert		√	√	
			Adequate site access for contractor and maintenance vehicle (where possible & during storm flows)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√				√			√			Cost vs. benefits Frequency of maintenance requirements Alternative low maintenance options considered		√	√	
			Provide platform & safe maintenance access for deep manholes	√	√			√	√		√		√				√								√			Access to platform Depth of manhole		√	√	√
			Ensure emergency spillways/overland flow paths in place for peak flows	√	√	√								√	√	√		√		√	√	√	√			√		Frequency of flow Type of access needed		√	√	
			Gravity drains for servicing	√	√	√		√			√	√	√					√							√			Debris accumulation Maintenance requirements Blockage potential				√
	<u>Minimise blockage potential</u>	Y/N	Debris grilles	√	√	√				√									√	√			√		√			Maintenance inspection frequency Amount, type of debris Upstream & downstream effects during blockage Safe access for maintenance Need to restrict access on both upstream & downstream ends of culvert		√	√	

ISSUE	METHOD	APPLICABLE?	TECHNIQUE TO CONSIDER	POTENTIAL APPLICATION										CONSTRAINTS/ CONSIDERATIONS										OPPORTUNITIES				COMMENTS AND FURTHER CONSIDERATIONS	WELLBEING				
				Treatment device inlets, outlets and/or outfalls	Ponds	Wetlands	Rain Gardens	Sand Filters	Infiltration/ Soakage	Swales	Oil Water Separators	Raintanks	GPT	Limited available space	Traffic and pedestrian safety	Safety to maintenance operators	Maintenance access limitations	Potentially high capital cost	Potential for blockage	Environment integration	Potentially significant receiving environment effects	Construction difficulties	Fish passage requirements	Amenity	Habitat enhancement	Improved access	Improved treatment		ENVIRONMENTAL	CULTURAL	SOCIAL	ECONOMIC	
			Consider reverse slope pipe	√	√											√		√	√	√				√					Maintenance requirements				√
VISUAL IMPACTS?	<u>Reduce visual impact</u>	Y/N	Use surface treatments (coloured/patterned concrete/pavers etc.)	√	√	√	√			√					√		√		√			√							Permeable surfaces Safety slippery surfaces		√	√	
			Low impact design: natural materials in line with natural contours where possible	√	√	√	√			√				√		√		√					√						Durability	√	√	√	
			Colour/paint headwalls	√	√	√	√			√						√								√						Maintenance requirements Material durability, e.g. salt water/fresh water/UV		√	√
	<u>Improve amenity value</u>	Y/N	Use vegetation to hide/enhance structures	√	√	√	√			√				√									√	√		√			Plant species appropriate for environment, soil conditions, water table, salt water, maintenance requirements	√	√	√	
			Make a visual feature of the site if possible	√	√	√	√			√				√										√					Design Appropriate materials Visual, landscape effects		√	√	
																													Safety during planting Supervision Tasks suitable for community efforts	√	√	√	
ARE COMMUNITY BENEFITS POSSIBLE?	<u>Provide educational information</u>	Y/N	Incorporate community planting post construction	√	√	√	√			√						√						√							Design Appropriate materials Community input		√	√	
			Provide educational signage	√	√	√	√	√	√	√	√	√	√					√						√					Design Appropriate materials Community input		√	√	
	<u>Provide recreational benefits</u>			Utilise structures (bridges, viewing platforms, decks etc.) to hide outlets/spillways	√	√	√	√								√	√		√		√		√	√	√				Design Appropriate materials Safety fencing, balustrades, etc.		√	√	
HAVE THE CORRECT MATERIALS BEEN SELECTED?	<u>Design safety</u>	Y/N	Identify specific requirements for all materials	√	√	√	√	√	√	√	√	√	√			√				√		√						Long term material durability Cost Environmental Durability, e.g. salt water, UV, etc.	√	√	√	√	

ISSUE	METHOD	APPLICABLE?	TECHNIQUE TO CONSIDER	POTENTIAL APPLICATION										CONSTRAINTS/ CONSIDERATIONS										OPPORTUNITIES				COMMENTS AND FURTHER CONSIDERATIONS	WELLBEING				
				Treatment device inlets, outlets and/or outfalls	Ponds	Wetlands	Rain Gardens	Sand Filters	Infiltration/ Soakage	Swales	Oil Water Separators	Raintanks	GPT	Limited available space	Traffic and pedestrian safety	Safety to maintenance operators	Maintenance access limitations	Potentially high capital cost	Potential for blockage	Environment integration	Potentially significant receiving environment effects	Construction difficulties	Fish passage requirements	Amenity	Habitat enhancement	Improved access	Improved treatment		ENVIRONMENTAL	CULTURAL	SOCIAL	ECONOMIC	
																													Maintenance requirements				
			Ensure contract documentation includes detailed methodology, quality and material specifications relevant to manufacturers specifications	√	√	√	√	√	√	√	√	√	√				√					√		√	√	√	√	√	√	Material durability Cost Sediment and erosion control during construction Ease of installation	√	√	√
	<u>Life cycle costs</u>	Y/N	Consider embodied energy of the design	√	√	√	√	√	√	√	√	√	√										√	√					Consider raw materials, transportation of materials & equipment to site, construction, operation, maintenance, & final decommissioning of the system	√	√	√	√