Design of Inlets, Outlets and Coastal Outfalls in the Auckland Region

Guideline Document GD08

Version 1 Draft

July 2025

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Preface

What is the purpose of this document?

This guideline document, *Design of Inlets, Outlets and Coastal Outfalls in the Auckland Region* (GD08), provides design guidance for Auckland Council stormwater inlets, outlets and coastal outfalls. It focuses on design considerations for stormwater inlets, outlets and coastal outfalls to achieve:

- Resilient stormwater infrastructure
- Safety in Design
- Positive social and environmental outcomes from stormwater infrastructure
- Alignment with the Auckland Unitary Plan and other relevant Auckland Council-family documents.

GD08 is an update of TR2013/018 – *Hydraulic Energy Management – Inlets and Outlet Design for Treatment Devices* (Buchanan, A., Clarke, S., & Voyde, E., 2013) and supersedes that document. It is not a design manual containing extensive equations and worked examples. Instead, it focuses on mostly qualitative design considerations for inlets, outlets and coastal outfalls. For the theoretical design basis, the designer is expected to be a suitably qualified and experienced person, and the user should consult the relevant reference material.

Note that this document has been prepared for use in the Auckland region. While many of the principles are universal and can be used elsewhere, the technical specifications have been developed for the geology, geography, climate, receiving environments and context of Auckland. Auckland Council therefore disclaims any responsibility for use of GD08 outside of the Auckland region.

What new inclusions and approaches are in this guideline document?

The key new inclusions and approaches in this document, relative to TR2013/018, are:

- Focus on qualitative design considerations instead of theoretical design equations
- Design considerations for inlets and outlets for a wider range of stormwater infrastructure, not limited only to those for stormwater treatment devices
- Design considerations for coastal outfalls
- Update of design considerations to reflect current Auckland Council recommended practices
- Enhanced coverage of Safety in Design, covering all stages of the project life cycle
- Additional guidance on whole-of-life costs.

Who was consulted in the preparation of this guideline document?

Extensive consultation was undertaken in the development of this guideline, including:

- Internal workshops and consultation with Auckland Council's stakeholders
- External workshops with, and input from, industry through a focus group of recognised stormwater and coastal practitioners, contractors and council/government staff.

Future revisions

Auckland Council intends to provide future revisions to this guideline periodically in response to changes in legislation, policies, technologies, national standards and feedback from industry. There is a feedback form available to download along with this document which can be sent to wsd@aucklandcouncil.govt.nz.

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1.0 Introduction

1.1 Background

Inlets and outlets, as seen in Figure 1-1, convey stormwater flows between elements of the stormwater network including the natural watershed, piped stormwater networks, stormwater management devices and the receiving environment. Being critical components of the stormwater network, their design needs to:

1) Provide a resilient, effective and smooth transition for stormwater flows between the upstream and downstream network.
2) Consider both the upstream and downstream hydraulic requirements (flow, velocity, depth, turbulence, energy, etc.).
3) Allow for, and safely manage, storm discharges that exceed the design flows for built infrastructure.
4) Not be a hazard to the public, operators or property.
5) Not adversely impact upon the engineered or natural environment (visually, through scour and erosion, block fish passage, flooding, or detrimentally affect aquatic habitat).
6) Be able to be maintained safely in a cost-effective manner.

This document outlines the design process, approach and key considerations for inlets, outlets and energy dissipation devices which should be adapted to site-specific conditions. The terminology of inlets and outlets used within this document is presented in Section 1.6 below.

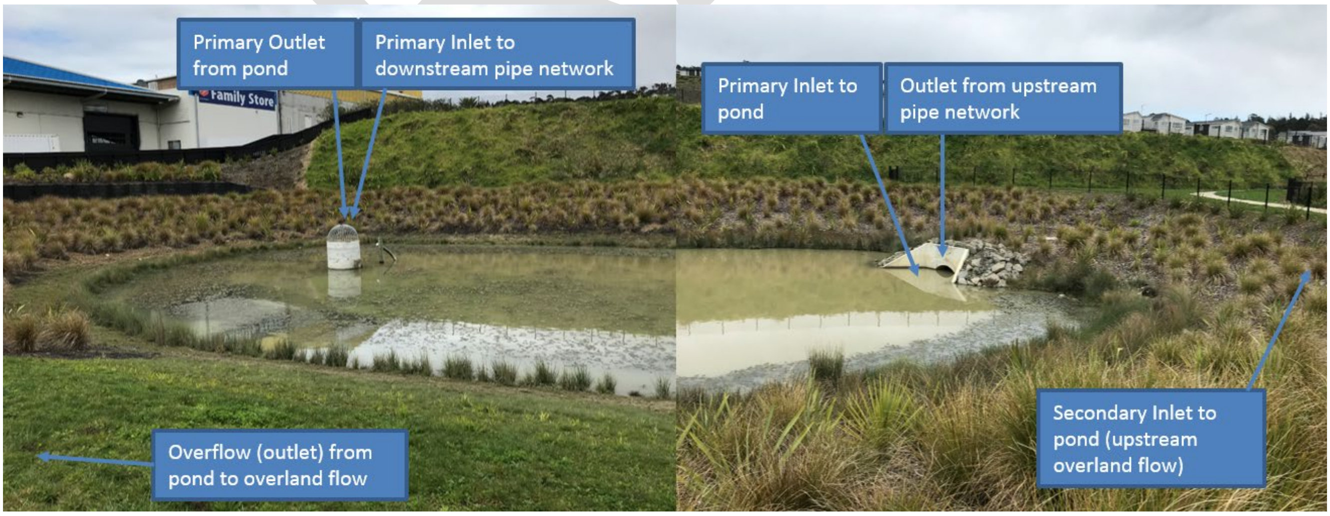


Figure 1-1: Example of inlet/outlet components

1.2 Who should use this document?

This document is aimed at providing guidance when inlets and outlets, including coastal outfalls are a consideration to:

- Engineers for the planning, locating and design of inlet and outlet structures
- Regulatory Officers who will be approving the resulting designs
- Asset owners
- Consenting authorities for inlets and outlet assets
- Land developers.

1.3 When and why to use this document?

Inlets and outlets are critical parts of the stormwater network and often interface with public spaces and the natural and built environments. Poorly designed inlets and outlets can lead to:

- Safety hazards for the public and operators
- Poor environmental outcomes (landscape and urban design effects, erosion, sedimentation, ecological damage, pollution, noise and vibration)
- Unsatisfactory durability, performance and safety of the stormwater network
- Increased flooding of property and sensitive infrastructure
- Poor investment of capital and excessive ongoing maintenance and operating expenses.

GD08 aims to support planners, designers, asset owners and consenting authorities to identify risks and issues associated with stormwater inlets and outlets, so that these can be addressed during the design process by removal, isolation, or mitigation. It is intended to be used in conjunction with the wider Auckland Council framework of guideline documents (GD series), technical reports (TR series) and practice notes (PN series).

Key documents in the Auckland Council framework are*:

- The Auckland Code of Practice for Land Development and Subdivision Chapter 1: General Requirements
- Stormwater Code of Practice (Version 4.0 – 2024)
- The Auckland Unitary Plan (updated 2018)
- GD01: *Stormwater Management Devices in the Auckland Region* (GD 2017/001)
- GD04: *Water Sensitive Design for Stormwater* (GD 2015/004)
- GD05: *Erosion and Sediment Control Guide for Land Disturbing Activities in the Auckland Region* (GD 2016/005)
- GD10: *Coastal Hazard Assessment in the Auckland Region* (GD 2022/010)
- GD13: *Freeboard for the Auckland Region* (GD 2024/13)
- GD15: *Climate Change Scenarios* (GD 2024/015)

- PN02: *Trash and Security Screens for Culverts* (PN 2017/002)
- NDC: Auckland Regionwide Network Discharge Consent (Auckland Council, 2019).

*Reader to source the latest version of the documents available from Auckland Council.

1.4 Energy dissipation and the need for this document

Inlets and outlets often experience or create high-velocity flows, turbulence or standing waves (hydraulic jumps) that result in the erosion of natural stream or channel banks, or the foreshore. Unprotected natural stream banks in Auckland have a very low threshold for high water velocity and are susceptible to erosion. This can cause flooding, damage the environment, ecology and habitats as well as erode or undermine structures. The outcome can be expensive and hazardous, with failures requiring ongoing maintenance intervention and liabilities. It is estimated that 70% of sediment reaching our harbours and marine environment is due to stream erosion. Energy dissipation of high-velocity flow, turbulence, and hydraulic jumps is a critical issue that needs to be given special consideration during the design process.

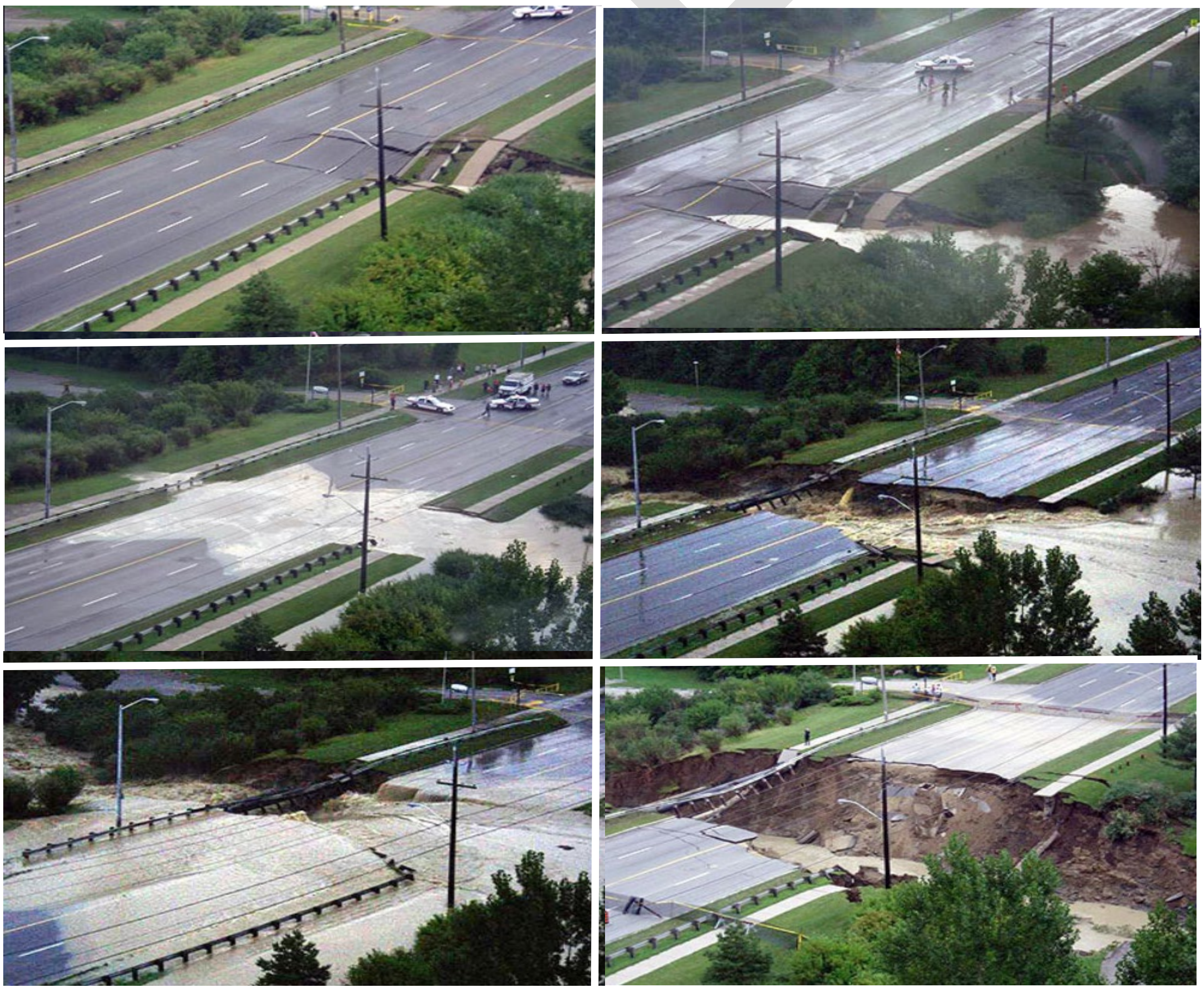


Figure 1-2: Example progression of culvert wash-out during a large storm (*Photos courtesy Jane-Finch.com*)

Some parts of the stormwater network (such as stormwater treatment devices) will have specific requirements for energy dissipation to ensure they function as intended (e.g. settlement of pollutants, treatment and evenly distributed loading).

The maximum pipe and culvert design velocities accepted in the Auckland Council Stormwater Code of Practice (4.5 m/s for the 10-year ARI event) are set for piped flows and not outlets. Flows will need to be attenuated at the outlet to prevent excessive scour and erosion when discharged to natural environments. In most cases, these velocities will require significant energy dissipation to protect the natural environment, aquatic habitats, the structure and other structures/infrastructure in the vicinity.

1.5 Types of inlets and outlets

Different devices will require different types of inlets and outlets and energy dissipation. Table 1-1 gives an overview of commonly used types of inlet and outlet structures for different stormwater management devices and stormwater network elements. Several other variations of inlet and outlet structures are possible depending on their local situation and requirements.

Table 1-1: Commonly used inlet and outlet structures

Device	Inlet	Outlet
Culverts	• Culvert inlet headwall	• Culvert outlet headwall • Stilling basins • Bed friction • Impact dissipaters • Plunge pools
Infiltration, biofiltration and pervious paving	• Sheet flow/level spreader • Bubble-up catch pit or manhole	• Underdrains with orifice-controlled outlet
Pipelines	• Pipe inlet • Manhole riser	• Outlet headwall • Stilling basins • Bed friction • Impact dissipaters • Plunge pools
Rain tanks	• Downpipes from roof	• Pipe connection to water supply • Perforated pipe/level spreader

Device	Inlet	Outlet
Swales	• Pipes • Bubble-up catch pit or manhole • Sheet flow/level spreader • Kerb cuts	• Manhole riser • Underdrains
Wetlands and ponds	• Pipe inlet • Overland flow • Flow splitters/bypasses	• Manhole riser with weir and orifice outlets • Emergency spillway
Coastal outfalls	• N/A	• Bubble-up catchpit / manhole • Diffuser manifold • Naturalised channels • Riprap outlet protection • Flap gates/Backflow prevention

1.6 Definitions

In the context of this document, inlets, outlets and other key terms are defined as follows:

Table 1-2: Definitions

Device	Definition
Backflow	• The flow of water back up a stormwater network from an outlet due to excessively high tailwater conditions, such as a storm surge on a coastline.
Coastal outfall	• A coastal outfall is an outlet which discharges into the coastal receiving environment. This may be via an estuary, wetland or beach system.
Dams	• Dams are defined as structures which either permanently impound surface water or temporarily impound surface water as its primary function. They include weirs but exclude culverts, rain gardens and culvert headwalls. • For the purposes of this document refer to the Building (Dam Safety) Regulations and Building Act for the definition of Classifiable Dams or those that fall under national safety legislation, guidelines and require specialist engineering assessment under the New Zealand Dam Safety Guidelines (NZSOLD) as a large dam. • Structures associated with classifiable dams are not addressed by this design guidance.
Energy dissipaters	• A stormwater energy dissipator is a structure or device designed to reduce the velocity and energy of stormwater as it exits a drainage system. It prevents erosion and downstream damage by dispersing the flow, using methods such as riprap, stilling basins, or baffles. • These are used at both inlets and outlets to protect the device or the receiving environment from scour and erosion caused by high volume and velocity flows.

Device	Definition
Flood plain	• The area of land that is inundated by runoff from a specified rainfall event, with an upstream catchment generation 2 m^3/s or greater of above-ground flow, considering: ○ Any increases in impervious areas that would arise from changes in land use enabled by the policies and zonings of the plan. ○ The effects of climate change over a 100-year timeframe with respect to the frequency and duration of rainfall events and a 1 m sea-level rise. ○ Assuming that primary drainage is not blocked. • Excludes constructed depressions and pits within Special Purpose – Quarry Zone.
Foreshore	• The area where the land meets the coastal waters and is regularly inundated between high and low tides.
Inlet structures	• Inlet structures are considered to be the inlet point for flow entering the specific element under consideration. For example: ○ Inlet to a culvert (i.e. transition from an upstream stream to a culvert pipe) ○ Inlet to a stormwater management device (i.e. a transition from a pipe outlet to a pond) ○ Inlet to a stormwater pipe (e.g. a scruffy dome) ○ Inlet to a wetland (e.g. a transition from a pipe outlet to a wetland). • The purpose of the inlet is to transition flow from an upstream portion of the stormwater network into the section under consideration to: ○ Avoid excessive headloss, turbulence, debris/sediment traps ○ Prevent scour that may damage the structure or surrounding environment ○ Present flow to the downstream stormwater network in a manner that allows it to perform its function. • Allow for safe bypass of the downstream structure in the event of blockage, failure or capacity exceedance.
Inlet structures/outlet structures	• These are flow-conveying transitions between two different elements of the stormwater network of a different nature. • The terms inlet and outlet are potentially interchangeable as the outlet from a pipe system can be described as the inlet to a pond or drain.
Overland flow	• The path through natural land contours, excluding a permanent watercourse or intermittent river or stream, where surface runoff will flow, with an upstream contributing catchment exceeding 4000 m^2. • These paths often lead water towards stormwater inlets, drainage channels, or other points where it enters the stormwater management system.
Private stormwater network	• Any component of the stormwater network that drains water from premises on private land to the receiving environment, or up to the point where it connects to the public stormwater network. • This includes pipes, gutters, downpipes, catchpits, swales, subsoil drains, stormwater treatment devices, rainwater tanks and any stormwater management device or redundant stormwater system.

Device	Definition
Public stormwater network	• Any stormwater pipe of drain, land drainage work, stormwater management device or treatment facility, vested in or under the control of Auckland Council. • Any stormwater pipe of drain, land drainage work, stormwater management device or treatment facility, declared by Auckland Council to be a public drain under Section 462 of the Local Government Act 1974. • The stormwater assets of other public entities such as Auckland Transport, Auckland Council Community Facilities and the NZ Transport Agency are not considered ‘public’ in the context of this document. They may be owned by a public entity but are not ‘public’ assets that can be connected to.
Secondary flowpath	• The route taken by stormwater runoff when the primary system capacity has been exceeded or is blocked.
Stormwater	• Rainfall runoff from land, including constructed impervious areas such as roads, pavements, roofs and urban areas which may contain dissolved or entrained contaminants, and which is diverted and discharged to land and water.
Stormwater management device	• A device or facility used to reduce stormwater runoff volume, flow and/or contaminant loads prior to discharge, e.g. rain gardens, pervious paving and tree pits.
Stormwater outfall	• A stormwater outfall is a specific type of stormwater outlet where stormwater is discharged directly into a natural water body, such as a river, lake, or ocean. It is the final point of the stormwater drainage system, where collected and conveyed stormwater is released into the environment, often requiring special design considerations to minimize environmental impact on downstream ecosystems.
Stormwater outlet	• Considered to be the outlet point for flow leaving the piped stormwater network. The following are examples of outlets: ○ Outlet from a culvert (i.e. transition from a culvert pipe to a downstream drain) ○ Outlet from a stormwater pipe to a drain, stream or the coastal environment ○ Inlet to a stormwater management device (i.e. a transition from a pipe outlet to a pond). • The purpose of an outlet structure is to transition flow from the section of the stormwater network under consideration to a downstream section (often a natural environment or channel) and to: ○ Avoid excessive headloss, turbulence, debris/sediment traps ○ Dissipate energy to prevent scour that may damage the structure or surrounding environment. • Present flow to the downstream stormwater network in a manner that allows it to perform its function.

1.7 Exclusions

This document does not provide guidance for the following:

- Bridges or structures crossing waterways, streams, rivers, flood plains and overland flow paths that have piers or abutments that will stand within the water. These structures are classified as bridges and are excluded from this document.
- Bridges, culverts, inlets and outlets owned and operated by third parties (e.g. the NZ Transport Agency, KiwiRail, etc.). These organisations will have their own design standards and guidance documents.
- Inlets and outlets associated with structures in classifiable 'dams', e.g. spillways, intakes, emergency spillways, bell-mouth type spillways and fuse-plugs. These are specialist structures and are not covered in this document.
- Sizing of energy dissipation structures on the foreshore for the protection of wave scour or forces.

1.8 How to use this document

This document is divided into key sections:

Section A2 **General design considerations**	• This section provides a structured series of critical design considerations that need to be clearly defined and understood prior to commencing detailed design. • These considerations should be documented and agreed upon by the planner, designer, ultimate asset owner and the consenting authority. • These should influence the design approach and ultimately the location, route, layout and type of the structures to be designed. • This section also includes the basis for assessing erosion and acceptable velocities for natural channels.
Section A3 **Design guidance**	• This section provides general design guidance for inlets, outlets, coastal outfalls, energy dissipation structures and surface treatments.

This document is intended to be used by suitably qualified and experienced persons, as defined in *The Auckland Code of Practice for Land Development and Subdivision Chapter 1: General Requirements* for the design of stormwater inlets and outlets. Figure 1-3 summarises how this document should be used.

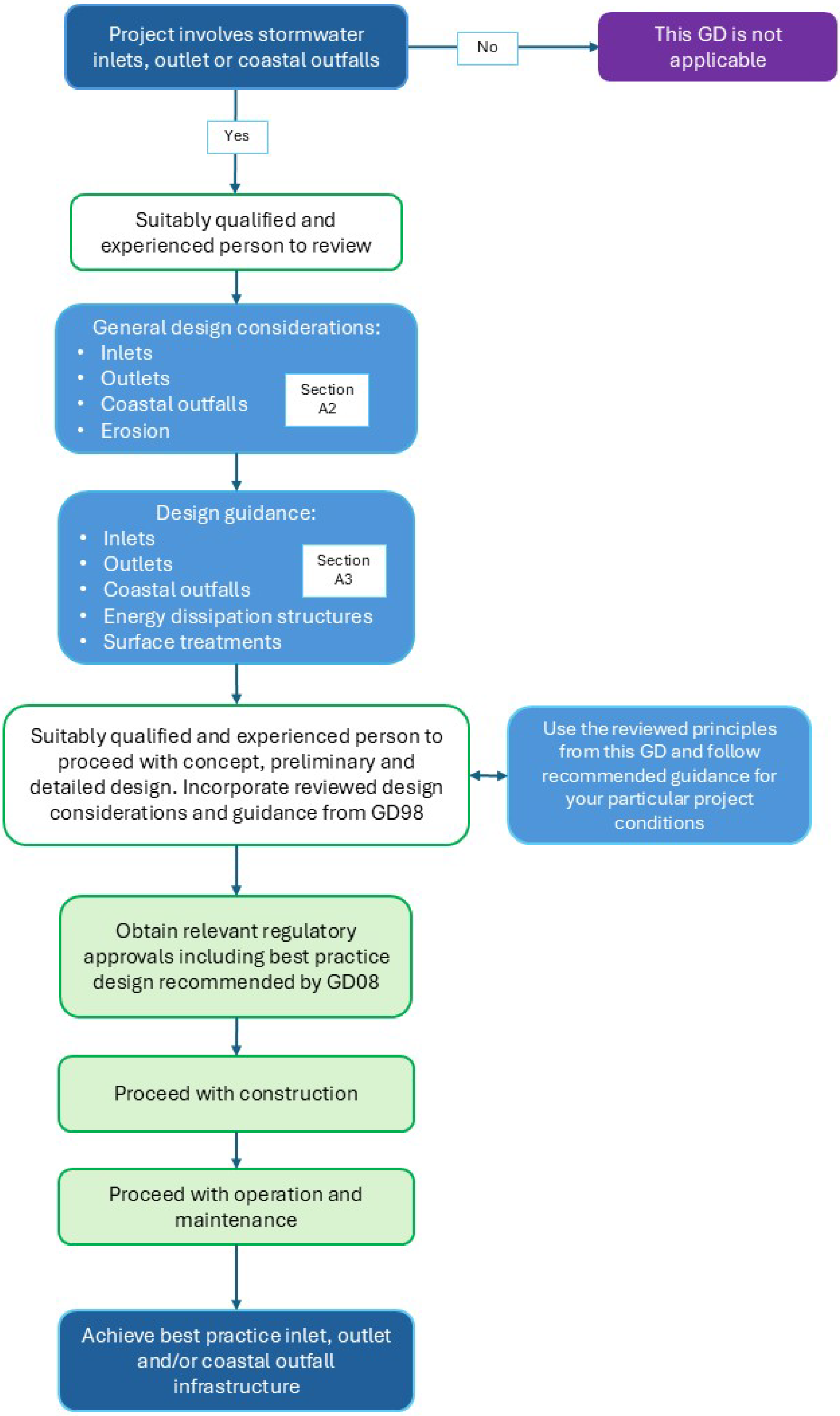


Figure 1-3: Process map for the use of this document

2.0 General design considerations

This section provides a structured series of critical design considerations that need to be clearly defined and understood prior to commencing detailed design. These are required to be documented and agreed upon by the planner, designer, ultimate asset owner and consenting authority.

2.1 Key guidance documents for the Auckland region

As this document forms part of and aligns with Auckland Council's philosophy of stormwater management, it should be read in conjunction with the latest version of the documents readily available:

- *The Auckland Code of Practice for Land Development and Subdivision*, Chapter 4: Stormwater, Auckland Council
- GD01: *Stormwater Devices for Stormwater Management*, 2017/001, Auckland Council
- GD04: *Water Sensitive Design for Stormwater*; 2015/004, Auckland Council
- GD05: *Erosion and Sediment Control for Land Disturbing Activities in the Auckland Region*, 2016/005, Auckland Council
- GD10: *Coastal Hazard Assessment in the Auckland Region*, 2022/010, Auckland Council
- GD13: *Freeboard for the Auckland Region*, 2024/013, Auckland Council
- GD15: *Climate Change Scenarios*, 2024/015, Auckland Council
- Guideline Document for *Developments and Activities on Closed Landfills*, Version 4.0 – 2023, Auckland Council (*to be issued*)
- *Dynamic Adaptive Pathways Planning: A Guide,* Auckland Council (to be issued)
- Auckland Unitary Plan
- Auckland Long Term Plan
- Auckland Council District Plan - Hauraki Gulf Islands Section
- Auckland Regional Land Transport Plan
- The New Zealand Coastal Policy Statement
- The Hauraki Gulf Marine Park Act
- Hauraki Gulf Islands District Plan
- The Freshwater Fisheries Regulations
- Landslide planning Guidance, *Reducing Landslide Risk through Land-Use Planning*, January 2024
- National Adaptation Plan
- Auckland Council Shoreline Adaptation Plans
- Interim guidance on the use of new sea level rise projections
- Proposed National Policy Statement – Natural Hazards Decision Making
- Climate Change Response (Zero Carbon) Amendment Act in 2019

- Emissions Reduction Plan
- *Coastal Hazard Assessment in the Auckland Region*, Guideline document 2021/010
- Resource Management (National Environmental Standards for Freshwater) Regulations
- *The Fish Passage Assessment Tool* (to meet the NPS-FM and NES-F) Ministry for Environment
- National Policy Statement for Indigenous Biodiversity.

The aim is to bring about integration with Auckland Unitary Plan's requirement to achieve a resilient and sustainable outcome under the principles of Water Sensitive Design and an Integrated Stormwater Management Approach.

In addition, GD01 and GD04 provide detailed design considerations that are aligned with the Auckland Council philosophy of stormwater management where cultural values, social needs and natural features are considered as part of the functional design of a stormwater network.

2.2 Auckland Unitary Plan

The Auckland Unitary Plan (AUP) combines the regional policy statement, regional coastal plan, and regional and district plans into a single combined plan for the Auckland region. It:

- Describes how the people and communities of the Auckland region will manage Auckland's natural and physical resources while enabling growth and development and protecting the things people and communities value
- Provides the regulatory framework to help make Auckland a quality place to live, attractive to people and businesses and a place where environmental standards are respected and upheld
- Is a principal statutory planning document for Auckland
- Other relevant planning documents include the Auckland Plan, the Auckland Long-Term Plan and the Auckland Regional Land Transport Plan
- Is prepared in accordance with the Resource Management Act (1991).

This document has an extensive number of provisions that will apply to stormwater infrastructure and the implications for any design need to be understood. It is important that the context and specific rules presented in the AUP are understood for the project area, upstream watershed, downstream environment and specific project locations as these may have critical project definition, route selection and design implications. It should be noted that for the Hauraki Gulf, the Hauraki Gulf Islands District Plan should also be considered, as this includes district planning requirements.

The basic requirements in the AUP for stormwater discharges are presented in Section E8. Stormwater – Discharge and Diversion. They include but are not limited to:

- The diversion and discharge must not result in or increase flooding and inundation of buildings on other properties in events up to the annual exceedance probabilities as defined in the Stormwater Code of Practice, including climate change. It must also not cause or increase nuisance or damage to other properties.

- Discharges from larger areas of impervious surfaces may also need to be managed by a stormwater management device and meet hydrology mitigation requirements by providing retention (volume reduction) and detention (temporary storage) requirements. Stormwater management devices must be provided to reduce or remove contaminants from the impervious area to the maximum extent by applying best practicable options. Please refer to the relevant Stormwater Management Plan and the AUP.

Further guidance can be found in the general standards within Section E8, noting additional requirements.

Where the outfall is located in the coastal environment, there are additional considerations in Chapter F of the AUP. The matters addressed include:

- Natural character, including disturbance of sediment and vegetation including mangroves; and avoiding the introduction of exotic species
- Ecological values including the need for restoration or rehabilitation
- Coastal processes and dynamics
- Public access including health and safety
- Amenity
- Mana Whenua values
- Coastal inundation and climate change
- The efficient operation of infrastructure
- Historic heritage
- Navigation.

It must be noted by designers that this information is presented for guidance only, is not exhaustive and that the current version of the AUP must be reviewed during the design process and at the time of application.

The following information is required to be collated from the AUP and documented for the project design process:

- Identify all zones that the project passes through, including designations.
- Identify all special features including ecological areas, outstanding natural landscapes, wetland management areas, flow management areas, environments, land protected for any reason (historic, heritage, special character, treating settlement, scheduled trees, etc.) that may be affected by the project either during construction or its long-term operation.
- Identify the environment, zones and special features at all discharge locations (outlets to the downstream environment including coastal environment, where relevant, or stormwater network) and all intakes (inlets from the upstream watershed to the project or stormwater network elements under consideration).
- Confirm and list all provisions relating to the project under consideration and all environments, zones and special features it may affect, and with which it must comply.
- Assess the degree of public access (particularly children).

2.3 Landowner approvals

Where an inlet or outlet is to be constructed on land not owned by the developer, the owner of the land must give their approval. If the land is public, there may be specific processes that need to be followed that are independent of resource consent processes and engineering approvals. Consultation may be required with public agencies such as Auckland Council (e.g. the Community Facilities Department), closed landfill asset owners, Auckland Transport, NZTA (Waka Kotahi), KiwiRail, and the Department of Conservation. This is not an exhaustive list. Developers should check who owns and administers the land and seek guidance from the appropriate agency.

If the outlet is in the coastal environment, there are additional steps to consider when seeking approvals. Under the Marine and Coastal Area (Takutai Moana) Act 2011 there is a requirement for engagement with applicants and holders of Marine Customary Titles. Where there is an application that covers the location of the proposed inlet or outlet, the applicant group must be notified and their views sought (s62 (3)). Where a Customary Title has been granted, the installation should be agreed in principle by the title holder group (s65(1)). Disputes should be directed to the Minister for Land Information (s64(4)).

When looking to request landowner approval, early contact with landowners is recommended (to be taken on a case-by-case basis).

Where the inlet or outlet is on reclaimed land, Land Information New Zealand (LINZ) is the administrator that can give approval on behalf of the Crown.

Where work is to be carried out below Mean High Water Springs, the notable affected parties should be identified and contacted, and relevant approvals / agreements should be obtained as/if appropriate.

2.4 Stakeholders

Stakeholders should be defined prior to developing the design as they may influence early route and option selection. Auckland Council can help confirm relevant stakeholders using previous catchment knowledge. They will include:

- The ultimate owner and operator of the system (usually Auckland Council, but not always). The asset owner will need to agree enduring conditions of resource consents for new discharge consents that are intended to be transferred to the asset owner. Resource consents for coastal or riverbed occupations that are intended to be vested as a public asset should provide for future maintenance access. The maintenance requirements should be discussed and agreed with the intended asset owner.
- Affected landowners (see above), Auckland Council and CCOs (e.g. ATEED, AT, Eke Panuku Development, Regional Facilities, and Watercare, etc.) the local board, local iwi, community and business groups. In some cases such as landfills, special attention will need to be undertaken to collaborate with their site owners, asset owners and operators.
- Holders of relevant resource consents. Healthy Waters holds a regionwide stormwater network discharge consent (NDC) which authorises the diversion and discharge of

stormwater associated with the public stormwater network. All outlets that are connected to, or will be vested as part of the public stormwater network, need to comply with the requirements of the regionwide NDC.

- Government organisations such as: the Department of Conservation (DoC), The Ministry for Environment (MfE), NZTA (Waka Kotahi), Kiwi Rail, NZ Defence Force, Civil Defence, District Health Boards, emergency services, etc.

Stakeholders will also include groups that may only be affected by certain phases of a project throughout its full design life. All phases of the project should therefore be considered when determining stakeholders including:

- Planning
- Consenting
- Design
- Construction
- Operation under normal conditions, storm conditions, extreme events and potential failure modes
- Maintenance
- Decommissioning.

2.5 Safety in Design

Safety in design is a philosophy that should be incorporated throughout any project development and/or monitoring. The considerations encompassed within safe design include (but are not limited to) the following:

- Pedestrian and public access to coastal and riparian areas, particularly children
- The risk of asset failure including grates, falling wingwalls and outlet structures, displaced riprap, trip hazards
- Appropriate materials and planting.

The Health and Safety at Work (HSWA) Act 2015 requires that a safety in design process is undertaken for all designs. Please refer to:

- Health and Safety at Work Act 2015
- Health and Safety by Design (Worksafe).

Public safety near a stormwater facility must not be compromised. All stormwater infrastructure must meet the safety requirements of Auckland Council's Codes of Practice, Auckland Council's Guideline Documents, Auckland Transport Design Manual, Auckland Transport Code of Practice and all related documents contained therein.

Auckland Transport provides a set of key principles for achieving safety in design in HS08-01, which underlies fundamental principles of the philosophy to which planned infrastructure works should adhere.

2.5.1 Safety in Design Process

To meet the requirements of the HSWA 2015, an assessment of the hazards and safety requirements for the planned infrastructure must be undertaken, agreed with Auckland Council and the asset owner and clearly documented. This assessment should include consideration of all lifecycle phases of the assets including construction, operation, maintenance, decommissioning and demolition.

This will then be used to assess the risk of critical portions of the design and to decide how the risk can be removed, isolated or mitigated, as part of the safety in design process. It is recommended that the hazards are reviewed regularly and as a minimum, at the following stages:

- Initial project definition/project planning (as some hazards/risks may be mitigated or removed by changing route, location of structures and ability to access for construction and maintenance)
- Concept development
- Preliminary design
- Detailed design.

Safety in design should then be reviewed during each of these live stages:

- Construction
- Operation and maintenance period
- Prior to decommissioning and/or demolishing.

The process in assessing safety hazards and safety in design throughout these project stages should be thorough and incorporate the following steps:

- Establishing the project context
- Risk Identification
- Assessing risk exposure
- Treating risks
- Handover of risks between stakeholders at each stage.

2.5.2 Safety in design reporting

A key aspect of assessing and maintaining safety in design is reporting and recording actions and risks associated with a design. The reporting of safety in design can best be achieved through the following documents:

Safety in Design Register	• The Safety in Design Register provides a structured record of identified hazards and associated mitigation measures as well as the affected parties. • It can be reassessed at key milestones throughout the design process to ensure its validity and suitability.
Safety in Design Report	• The Safety in Design Report offers a detailed account of the processes and evaluations undertaken to address potential safety risks. • It offers a proactive approach to mitigate hazards as well as guidance for potential works on site for stakeholders such as designers, operators and contractors.

Including reporting elements in project documentation enhances transparency between stakeholders, encourages shared accountability and promotes consistent risk management practices across all project stages. It is important to promote a healthy safety culture in asset design wherever possible. An effective safety in design consideration process should have continuity throughout all project design stages, e.g. identified risk aspects raised during asset construction may have residual risks associated beyond this stage. In this case, effective management of these risks would include continuity of accounting these items, such as via the Operation and Maintenance Manuals (O&M) and As-built Documentation.

2.5.3 Example safety hazards

Safety hazards should be subdivided into the following categories to aid assessment. Some examples are provided to aid assessment, but they are not exhaustive:

2.5.3.1 Key hazards occurring in normal conditions

Stormwater network	• In low-lying networks is there a risk of coastal surcharges inland during high tides? • Inadequately sized network causing up-stream flood risk or downstream velocity risk (i.e. erosion). • Blockage posing upstream flooding and downstream inundation risk.

Hazards due to the structure design and function under normal conditions (e.g. no rainfall)	These include:
	• Ease of access to the structure:
	  ○ Does it provide access to pipes or culverts that can be hazardous? Is the structure accessible to adults/children (e.g. near schools, parks, playgrounds, beaches)?
	  ○ Is maintenance access adequate, e.g. do maintenance staff need to traverse steep banks or mudflats, is the area subject to tidal inundation/wave action or will they be exposed to landslide risks while maintaining the inlet or outlet?
	• Drowning (high-velocity flow, pipes flowing full, deep ponds, open culvert inlets, etc.).
	• Pedestrian falling/slipping (steep banks, drops over 1 m, high-velocity flow).
	• Size of pipe (is the pipe large enough to entry for adults/children - usually > 600 mm?).
	• Confined spaces.
	• Stagnant water:
	  ○ Particularly on beaches where changing sand profiles may lead to pools forming.

Security screens	• Although screens can be used to prevent access into inlet or outlet structures, they are not generally preferred as they may cause potential blockages and therefore, increased flood risks. • Alternative options to restrict access and mitigate safety hazards should always be explored before the use of screens is considered. • Security screens can only be installed, if it is proven, following a comprehensive risk assessment, that a screen is the most appropriate option. There must be adequate access to allow for maintenance clearing of debris. • Vandalism/damage of screens must be considered a safety hazard. • Poorly designed screens may lead to additional safety hazards and must be avoided. • Blockage of screens by flood debris may cause flooding.

2.5.3.2 Hazards occurring in storm conditions

Hazards due to the structure design and function under storm conditions up to and including the design flow	• Change in hazards defined above due to storm conditions. • Allowance should be made for a predicted increase in storm intensities due to climate change. • Hydraulics (e.g. rolling standing waves) may trap swimmers or water users (e.g. kayakers, paddle boarders, recreation fishing, etc.). • Deep or high-velocity flow. • Debris and/or sediment loads may lead to blockage. • Unstable or rapidly varying hydraulics may cause pipe roll-waves to choke the pipe, cause surge or rapid air release/geysering (upstream or downstream). • Screens, structures or hydraulic configurations may trap people within the pipeline/culvert at the downstream end. • Ground/slope/bank stability hazards including piping, water saturating slopes, bank slumping, and erosion, can occur. • Flushing of contaminants from a network linked to closed landfills. • Discharge flows may cut off access either during a storm by flowing water, or post-storm if the beach has been scoured severely, i.e. from one section of the coastline to another. • Storm surge can elevate tail water levels backing up though the system or cutting off access to outlets. • Wave energy may transmit up a coastal outfall pipe causing pressure surges and surcharge. • Blocked stormwater inlets/outlets are unlikely to be cleared during a flood event, due to the additional safety risks involved in dislodging debris which may exacerbate surcharging within the network. • Velocity/energy control structures that are benign when dry or at low flows may become a hazard at high flows (e.g. baffles, dragon's teeth – see Figure 2-1).

Figure 2-1: 'Dragon's teeth' at an outlet structure

2.5.3.3 Hazards occurring during an exceedance storm (e.g. larger than design capacity/level of service)

This section covers hazards that may occur under extreme storm conditions when flows are likely to exceed the design flow. Any stormwater system has a maximum capacity, often defined by the return period of the design flow (e.g. a pipe network sized for a 10% AEP [10-year ARI]) and larger storms can cause upstream flooding and overland flow. Understanding the potential 'failure mechanism' that can result from large flows/depth and velocities is an important consideration during the design process. The uncertainty of future storm conditions due to climate change should be addressed here.

Define the failure mechanism	For example: • Flooding upstream • Flooding downstream • Overtopping • Outlet scour • Overland flow • Erosion/scour by overland flow • Inlet blockage • Barrel/pipe blockage • Foundation scour • Coastal cliff saturation resulting in erosion/subsidence • Property damage • Undermining coastal protection structures • Groundwater piping (e.g. flow through the soil around the outside of a pipe or structure, leading to erosion) • Channel migration • Debris/sediment accumulation • Hydraulic forces (pipe floatation, structure rotation/movement) • Pipe/structure material erosions (incorrect material selected for velocities experienced) • Screen blinding • Collapse • Liquefaction

	• Cliff instability • Bank scour/erosion • Exacerbation of failure mechanisms by climate change and poor resilience should be considered in design of inlets, outlets and associated structures.
Consequences	• What would be the consequence of this failure? • Could this result in the collapse of the road/walkway, severe surface scour and result in overland flow, dangerous ponding, flooded properties, block further discharge and damage to other services (e.g. electrical sub-stations)? • Erosion/scour of the outlet could undermine contaminated structures nearby, such as a closed landfill, particularly in coastal locations.  *Figure 2-2: Extreme storm overland flow due to culvert capacity being exceeded*
Erosion hazards	Erosion hazards at dams, reservoirs, detention ponds or other water retaining structures need to be carefully considered and any issues/risks determined, documented and discussed with Auckland Council: • Erosion to impoundment dams or ponds (either due to overtopping, spillway flows, dam/bank toe erosion, and piping failures) may cause dam failure/collapse and catastrophic loss of the detained volume. • Landslips (due to erosion/slope stability/overloading, etc.) surrounding the pond may also cause overtopping through displacement waves. This may also therefore cause dam failure/collapse and catastrophic loss of the detained volume. • The hazards and consequences (especially to the downstream catchment) of the potential events identified above must be considered and discussed with Auckland Council and may require specialist dam breach assessment or modelling. Particular consideration should be given to residential development, including access to dwellings, downstream of an embankment.

<table>
<tr><td></td><td>NB: As seen in Figure 2-3, special attention is required due to the high-risk nature of Certifiable Dams or detention ponds which is beyond the scope of this document.

Figure 2-3: Erosion of dam and spillway and building foundations during large storms</td></tr>
<tr><td>Manhole or other structure access covers/gratings</td><td>• These can be displaced as the result of an exceedance storm:
  ○ Open covers are clear trip/fall hazards into confined and inundated spaces, particularly for children.
  ○ If the open covers are beneath ponded stormwater or flow paths, they may be invisible to the public as they are obscured by muddy water, even if the flood water is very shallow.
  ○ The location of manhole and access locations must be considered along with whether they may be dislodged during storm events.
  ○ Where the risk to the public is identified, hinged self-seating manhole covers must be considered along with lockable safety grates to prevent people from falling into the space below.
  ○ It is important to note that air, compressed air, air/water mixes, and geysering from the rapid filling of stormwater systems may also displace manhole covers and this risk must be considered as part of a hazard assessment.</td></tr>
<tr><td>Overland flow routes/flood plain depths velocities and associated hazards</td><td>• These also need to be identified. This includes:
  ○ Low-lying properties/basements.
  ○ Beaches, intertidal flats and rock platforms.
  ○ Identifying sensitive, vulnerable residents/locations and essential services that may be affected (e.g. kindergartens, retirement homes, clinics, medical centres, schools, pedestrian underpasses, basements and underground car parks).
  ○ Critical infrastructure (e.g. underground rail stations, highway tunnels, hospitals, emergency service stations, ground-mounted electricity transformers, emergency evacuation routes, communication systems and civil defence centres).
• Assess the consequence of exceedance (flow, depth, velocity of overland flow) versus areas or infrastructure affected (e.g. sensitive, vulnerable or essential services).</td></tr>
</table>

	• It is critical to identify third parties affected by overland flow/flood plain related to the failure or capacity exceedance of the project (e.g. NZTA, AT, Kiwi Rail, NZ Defence Force, Civil Defence, District Health Boards, sewerage systems and emergency services, etc.). • The importance of normal services and extreme event recovery that may affect these parties is understood as mitigation of these risks may result in higher design standards. • Once the risks to these parties are understood, discussion must be held with Auckland Council about including these third parties within project communication and stakeholder groups. • These groups may also have defined approaches to assessing the risks and consequences to their assets and services.

2.5.3.4 Hazards due to the operational and maintenance of the structures/project

Operational and maintenance activities	• It is important to clearly define the operational and maintenance activities required for the structures under design including, access, inspection, cleaning, unblocking, grass-cutting, etc. in order to assess risks. These include: ○ Slips, trips and falls during access or working. ○ Adequate working space has been allowed. ○ Adequate space has been allowed for material storage/movement/dewatering of screen rakings. ○ Stability hazards include piping, water-saturated slopes, bank slumping, and erosion. ○ Is the structure periodically buried, e.g. by beach sand seasonal movement? ○ Risk of inundation/drowning/differential pressure hazards/visits during storm events. ○ Sudden release of pressure when unblocking outlets/check valves (particularly in a sandy environment). ○ Is the structure subject to tidal inundation restricting work periods? ○ Heavy lifting (grates/screen/hatches and manholes).

2.5.3.5 Hazards due to the construction of the project

Define hazards that may occur during the construction of the project and that may be controlled, mitigated or removed as part of the design process. Hazards considered in construction may include, but are not limited to:

General site access (Pre/during construction)	• Vehicle access restricted by existing access. • Access may be cut off due to erosion of access routes. • Working within or near to an intertidal area causing stranding on site and limiting work periods.
Drilling & associated ground works	• Potential structural instability / disturbance. • Impacts to local ecology caused by high noise and vibration. • Risk of drilling mud released into the environment, particularly with directional drilling. • Sand ingress to access ways, tools & machinery causing increased risk of errors and/or injury.

Physical works	• Geomorphological impacts due to changes in natural tidal flow, i.e. potentially creating erosion where there was none previously. • Storm events causing unpredictable delays and restrictions to work. • Excavations being filled in due to water movement, i.e. beach groundwater, river flows or tidal currents/wave action. • Construction impacts causing silt plumes during tidal cycles. • Works carried out in an open public setting, i.e. traffic management required to ensure no collisions with members of public and plant/machinery. • Disruption to wildlife, particularly on the coast with birds, penguins and seals.

2.5.3.6 Hazards due to the future decommissioning of the project

Once the hazard assessment is complete, then an assessment of how they can be addressed, either through removal, mitigation or control, must be undertaken. This may include changing the route or type of project.

Hazards considered as part of decommissioning are similar to construction hazards but may additionally include but are not limited to:

General site access (Pre/during construction)	• Bank/shoreline changes over the life of the structure. • Development of the surrounding infrastructure.
Abandonment of an asset in-situ (may be required if access or asset is untenable)	• Degradation of an asset may cause harm to the local ecology. • Unauthorised access to an abandoned asset by members of the public and associated hazards that present particularly as the asset deteriorates, i.e. risk of death or injury. • Contamination risk.
Physical works	• Limited access due to tidal fluctuation and access restrictions. • Implications to structural integrity of beachhead with removal of an asset / structure – any inclusion of structural stability management will have its own associated hazards to consider. • Geomorphological impacts due to changes in the coastal structure.

2.5.4 Assessing safety risks under normal conditions

Guidance for assessing the different safety risks of an inlet or outlet under normal conditions is covered below, or refer to existing documents.

Existing documents	• Trash and Security Screens for Culverts (Practice Note 2017/002, January 2017) – Section 4.0. • The New Zealand Building Code (Ministry of Business, Innovation and Employment), 2004. • Acceptable Solutions and Verification Methods: For New Zealand Building Code Clause F4 Safety from Falling - Ministry of Business, Innovation and Employment, 2017. • Auckland Code of Practice for Land Development and Subdivision. Chapter 7: Landscape, Auckland Council (2021). • HS08-01: Safety in Design. Health and Safety Procedure, Auckland Council (2016).
Fencing	• Suitable fencing is required as per the Auckland Transport Code of Practice for publicly vested assets and the New Zealand Building Code where assets are to remain private. • Gross pollutant traps, detention basin outlets and any other silt traps must be enclosed by fences that do not impede fish passage, do not impede floodwater and do not increase downstream flood risk.
Side slopes	• Side slopes around stormwater devices must be based on local conditions and safety risks. • Maintenance requirements of these devices must also be considered. • If an area needs to be mowed, the surrounding slopes must not be steeper than 1V:4H and preferably not steeper than 1V:6H. • Public safety must be taken into account; especially where a slip or trip on a slope may result in a fall over 1 m or a fall into water. • Downstream entry to a structure that may cause injury (e.g. culvert inlet, impact dissipator, dragon's teeth type stilling basins, pipe network and plunge drops) will increase the hazard and need to be considered. • Where pedestrian access is allowed, batter slopes above and below water should be extremely gentle/shallow (e.g. 1 vertical to 6 horizontal). • 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 hazard.

Limiting access to structures	Limiting access to structures can be by:
	• Dense planting to provide a barrier.
	• Fencing the first 2-5 m downstream of an outlet.
	• Outlet security grills. Screening the outlet of stormwater pipes is unacceptable due to the risk of people and debris being unable to escape when washed in. They will only be considered by Auckland Council in extreme circumstances.
	• Where no alternative exists, hinged racks with securing bolts that are designed to fail in shear are preferred. Grates must only be installed on the stormwater system outlets provided that:
	    ○ Possible debris loading from the upstream catchment is addressed.
	    ○ The consequences of potential system failure to downstream properties as a result of blockages must be investigated.
	    ○ All upstream inlets and access chambers are secured against unauthorised entry.

2.5.5 Assessing safety risks under storm conditions

<u>Existing documents</u>

- Trash and Security Screens for Culverts (Practice Note 2017/002, January 2017) – Section 4.0
- *Trash Screens and Safety Screen Guide* 2009 (Graham et al, Environment Agency, UK)
- Auckland Council Stormwater Code of Practice
- Landslide Planning Guidance, Reducing Landslide Risk through Land-Use Planning, January 2024
- National Adaptation Plan 2022
- Coastal hazards and climate change guidance 2024
- Proposed National Policy Statement – Natural Hazards Decision Making
- Climate Change Response (Zero Carbon) Amendment Act in 2019
- Emissions Reduction Plan 2022
- *Coastal Hazard Assessment in the Auckland Region*, Guideline document 2021/010, July 2022
- *Australian Rainfall and Runoff – Book 6*: Flood Hydraulics, Chapter 7 Safety Design Criteria (Advanced Draft, 2016). Indicative flow depth/velocity envelopes for children, adults, vehicles and buildings – this may be used in agreement with Auckland Council for other areas not covered under SWCoP (Section 4.3.5.6 and Section 4.3.5.7).
- Figure 2-4 (Smith et al., 2014 – from Australian Rainfall and Runoff – Book 6: Flood Hydraulics, Chapter 7 Safety Design Criteria).

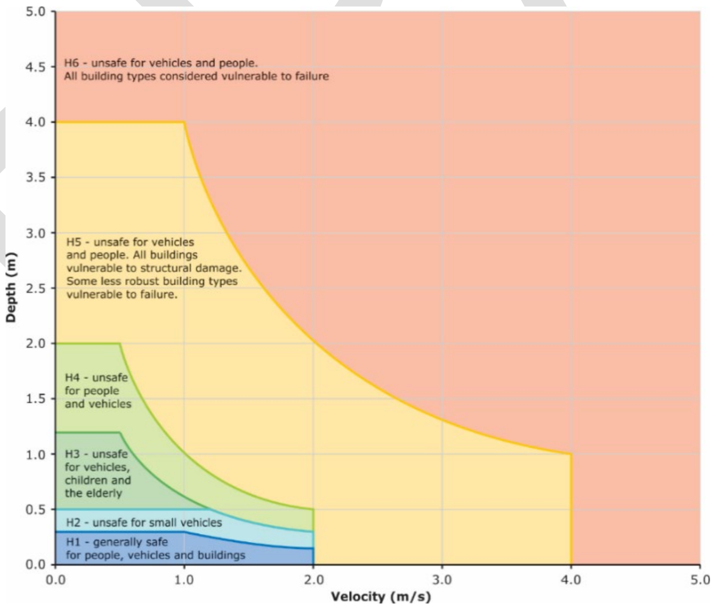


Figure 2-4: Example depth/velocity envelopes

(from Smith et al., 2014 – from Australian Rainfall and Runoff – Book 6: Flood Hydraulics, Chapter 7 Safety Design Criteria).

2.5.5.1 Guidance for assessing safety risks related to exceedance events

Existing documents

- Trash and Security Screens for Culverts (Practice Note 2017/002, January 2017) – Section 4.0
- *Trash Screens and Safety Screen Guide* 2009 (Graham et al, Environment Agency, UK)
- *Australian Rainfall and Runoff* – Book 6: Flood Hydraulics, Chapter 7 Safety Design Criteria (Advanced Draft, 2016)
    - Indicative flow depth/velocity envelopes for children, adults, vehicles and buildings.

It is important to understand the potential annual and total design life probability of exceedance of a storm event for the standard 100-year design life, as shown below:

Table 2-1: Design storm exceedance probability

Annual exceedance probability (AEP)	Storm event (Average recurrence Interval – ARI)	Probability of exceedance for 100-year design life
10%	10 years	99%
2%	50 years	87%
1%	100 years	63%
0.5%	200 years	39%
0.2%	500 years	18%
0.1%	1000 years	10%

This table is based on the assumption that the AEP/ARI of certain storms does not change over the life of the project. In reality, the estimated annual exceedance probability (AEP) for certain storm events does change as longer rainfall data sets become available. Climate change also has the potential to increase the frequency and therefore increase the AEP of larger storms, as well as extreme coastal water levels at outlets.

The probability of an event of a certain size being equalled or exceeded during a set design-life of a structure can be calculated using the following formula. The probabilities from Table 2-2 or Equation 1 can be used in conjunction with an assessment of consequence to determine the risk.

Design Storm Exceedance Probability

$$\textit{Probability of exceedance during asset lifetime} = 1 - \left(1 - \frac{AEP}{100}\right)^{DLA} \qquad \textit{Equation 1}$$

Where:

DLA = Design life of the asset (years)

AEP = Annual exceedance probability (%)

Table 2-2: Design storm exceedance probability (100-year project life)

Likelihood/ probability	Likelihood/ probability	Description
100%	Certain	Risk will occur
75-99%	Almost certain	Risk event expected to occur in most circumstances
50-74%	Likely	Risk event will probably occur in most circumstances
20-49%	Possible	Risk event could occur at some time
5-19%	Unlikely	Risk event could occur at some time
1-4%	Rare	Risk event may occur only in exceptional circumstances

Consequences are defined on a scale of:

- Extreme
- Major
- Moderate
- Minor
- Insignificant.

Definitions of consequence values should be determined in accordance with the asset owner's risk management plan or framework. These are used in conjunction with the likelihood/probability from Table 2-2 to then assess the overall risk in Table 2-3.

Table 2-3: Design storm exceedance probability

	Likelihood/ probability					
Impact/ Consequences	Rare	Unlikely	Possible	Likely	Almost Certain	Certain
Extreme	Medium	High	High	Extreme	Extreme	Extreme
Major	Medium	Medium	High	High	Extreme	Extreme
Moderate	Low	Medium	Medium	High	High	Extreme
Minor	Low	Low	Medium	Medium	Medium	High
Insignificant	Low	Low	Low	Medium	Medium	Medium

All identified risks and rated severities must be documented with risks associated with health and safety being clearly marked separately to financial/asset management risks (e.g. fall hazard is a safety risk whereas shallow, low-velocity flooding of a garage may only be a financial loss). Once the nature and severity of the risks for all operating conditions are understood, the designer must discuss and agree with Auckland Council and other relevant stakeholders, the risks that must be treated through standard risk reduction methods as required in the:

- Health and Safety at Work Act 2015
- Health and Safety by Design: Good Practice Guidelines (Worksafe NZ, 2018).

Risk reduction approaches which may be acceptable are:

- Avoidance, eliminated or removed
- Mitigation or reduction
- Isolated or controlled
- Risk sharing (e.g. insurance) – this is NOT appropriate for health and safety risks
- Risk-retention (e.g. self-insurance) – this is NOT appropriate for health and safety risks.

2.6 Social and cultural concerns

Design requirements should cover the well-being of the community including public health and safety, aesthetics and amenity considerations. These include consideration of:

- Sites and places of significance to mana whenua
- Customary interests
- Amenity including visual effects and visual cohesion with the environment in which the inlet or outlet is to be constructed
- Appropriate landscaping considerations, e.g. choosing construction materials, such as local rock to match the natural site look whilst maintaining material durability.

This list is not exhaustive and will require site-specific considerations.

2.6.1 Cultural and mana whenua values

2.6.1.1 Mana whenua values

Mana whenua values are intrinsic to the design, construction and management of stormwater networks and devices in the Auckland region, particularly the following:

- The understanding of mauri
- The importance of water
- The practical application of mana whenua values in the appropriate context.

Iwi management plans provide excellent resources for developing approaches to incorporating mana whenua values. The information provided in this guidance document does not replace any required need to consult with mana whenua.

Mana whenua and mauri

As kaitiaki, mana whenua have the responsibility of ensuring that the spiritual and cultural aspects of resources are maintained for future generations. This involves the on-going protection of mauri from damage, destruction or modification.

Mauri is a concept recognised by mana whenua as the connection between spiritual, physical and temporal realms. Loosely translated as the life force or life essence which exists within all matter, mauri sits at the very core of sustainable design for mana whenua and Te Ao Māori – the Māori worldview.

A key concern to mana whenua is the effect on the mauri of water caused by pollution of a stream, river, estuary, catchment or harbour. This can be due to sediment entering waterways, loss of riparian margins and the loss of native habitat to support native flora and fauna.

Degradation of freshwater quality can also affect the ability for customary harvest and manāki[1] due to depletion in, or in some cases the absence of, traditional mahinga kai[2] resources. Modification or destruction of wāhi tapu[3] and wāhi taonga[4] is another potential effect of freshwater degradation.

The revival and enhancement of mauri should be a focus during the design and construction phases.

The importance of water

Examples of different states and sources of water in the Māori context are provided below. It is also important to consider these as they relate to how the water is changed through urbanisation.

- **Wai-ora:** (pure water): This is water in its purest form
- **Wai-māori:** (freshwater): This is referred to as ordinary water which runs free or unrestrained and it has no sacred associations
- **Wai-kino:** (polluted): The mauri of the water has been altered through pollution or corruption and has the potential to do harm to humans
- **Wai-mate:** (dead water): This class of water has lost its mauri and is dead. It is dangerous to humans because it can cause illness or misfortune
- **Wai-tai:** (salt or water from the ocean): This term also refers to rough or angry water as in surf, waves or sea tides
- **Wai-tapu:** (sacred water): This is water that is used for ritual and ceremony.

Application of mana whenua values

Te Aranga Design Principles have been developed to provide a clear process for positive engagement with mana whenua to shape our built environment and acknowledge our position as a city distinguished by the world's largest population of Māori. The Te Aranga Design Principles arise from a widely held desire to enhance mana whenua presence, visibility and participation in the design of the physical realm and are founded on intrinsic Māori cultural values.

The Principles are intended as an enabling strategic foundation for mana whenua to adopt, customise and further develop in response to local context. The Principles also provide stakeholders

[1] The ethic of holistic hospitality whereby mana whenua have inherited obligations to be the best hosts they can be

[2] Traditional food sources

[3] Any place or feature that has special significance to a particular iwi, hapu or whānau including urupā (burial grounds), pā sites (historic settlements) or wāhi pakanga (historic battlefield)

[4] Anything considered to be of value including socially or culturally valuable objects, resources, phenomenon, ideas and techniques

and the design community with a clearer picture as to how mana whenua are likely to view, value and participate in the design and development of the built environment within their ancestral rohe[5].

The use of the Principles is predicated on the development of high quality, durable relationships being developed between iwi/hapū, their mandated design professionals and local and national government. Robust relationships between these groups provide opportunities for unlocking a rich store of design potential.

The Principles provide guidance around culturally appropriate design processes and design responses that enhance our appreciation of the natural landscape and built environment. These same underlying principles can also help inform culturally appropriate stormwater inlet, outlet and coastal outfall design.

2.6.1.2 Cultural and historic heritage

Any sensitive material that is discovered during activities in the coastal marine area must comply with the accidental discovery rule in the AUP F2.21.1.4, unless it is expressly provided for by a resource consent or other statutory authority. Sensitive material includes human remains and kōiwi, archaeological sites, Māori cultural artefacts, protected New Zealand objects (including fossils or sub-fossils), shipwrecks or other items that may contain oil, lava caves, and unknown material on or under the foreshore or seabed such as munitions, submarine cables and pipelines.

Due to the cultural significance of any receiving environment, such as a river, wetland or coast, early consultation, due diligence and consideration should be taken when implementing any infrastructure in coastal regions. This includes consideration of Sites and Places of Significance in the AUP, customary titles, and historic and archaeological sites.

2.6.2 Place

Inlet and outlet design is about both the character of the place in which they are sited, the detail around and of the inlet / outlet and how it fits within the environment. There is a relationship between the site and the surrounding land and water, that extends around and beneath the water's edge, whether that be a stream, a wetland, a river or the sea. There is also a relationship between people and the land around the site. These are places that will not just be seen by people, but used by people and are part of local communities.

Preferably natural integration of assets into the surrounding environment should be carried out as part of design, where it is deemed practical. Good design encompasses site context, natural and cultural values, and how people use the land and the water in a specific place. Landscape in relation to inlet and outlet design is the process of seeing the inlet or outlet as part of a whole system, embodying water quality through nature-based solutions (where practical) and envisages the resilience of natural systems to the effects of climate change and across generations over the

[5] rohe - the area over which iwi and hapū claim mana whenua

lifecycle of a project. In addition to key strategic documents noted in this guidance, the following documents, specific to landscape and place, are to be referred to, and noted:

- The New Zealand Institute of Landscape Architects - Tuia Pito Ora (NZILA), has developed Te Tangi a te Manu, Aotearoa New Zealand landscape assessment guidelines were first published in 2022 and will continue to develop as best practice for landscape assessment and design context emerges.
- Te Tangi a te Manu, NZILA (2022), outlines how landscape goes beyond aesthetics. Landscapes are an integral part of our identity as well as a natural system in which we are all reliant and should appreciate.
- The RMA Quality Planning Resource, 2013 is a key framework with regard to coastal management, legislation, guidance for planting and management and methodologies for coastal land development. The coastal environment is dynamic and sensitive. The framework covers present and future impacts of coastal outfalls in relation to landscape matters (sea-level rise, climate change, natural systems, perception by people, and the landscape extending beyond the visual) are all factors to consider and incorporate.
- New Zealand Urban Design Protocol (Ministry for the Environment, 2005).
- *Te Haumanu Taiao: Restoring the natural environment* (Auckland Council, 2023) is a guide published by Auckland Council focusing on ecological restoration in Tāmaki Makaurau. It aims to empower Aucklanders to achieve ecological restoration goals and enhance the region’s biodiversity. Developed in collaboration with Nga Iwi Mana Whenua o Tāmaki Makaurau, it incorporates principles such as kaitiakitanga (guardianship) and Te Mana o te Taiao (mana of the environment).

The investigation and exploration of relationships between people and the land, Iwi, social and cultural layers, biophysical landscape form, land use and regional landscape studies are covered by the Urban Design Protocol, Te Tangi a te Manu, the Auckland Design Manual and the AUP.

Design and integration of inlets and outlets should incorporate interaction with the environment and listening to what the land and people tell us. The multi-layered components of landscape add value by bringing people and the environment into the design and decision-making process bringing genuine engagement and thoughtful placemaking.

2.6.3 Aesthetics

Stormwater inlets and outlets are often heavily engineered structures and can be visible to the public. Where this happens (e.g. near walkways, paths) and in areas of high amenity (e.g. parks) or special character, careful aesthetic design may provide additional amenity benefits. Aesthetic considerations are discussed in:

- GD01: *Stormwater Management Devices in the Auckland Region*, Auckland Council 2017
    - Section C1.0 Technical Guidance: Plants and soils
- The Auckland Design Manual (Auckland Council) provides guidance for development and infrastructure in different settings of the natural and built environment in Auckland. Of particular reference to coastal outfalls and their sites are the following sections:

  - Sites and buildings, subdivision and neighbourhood design
  - Streets, parks and public realm
  - Design subjects – notably climate change and sustainability.

There are also links to relevant planning regulations, infrastructure technical guides and shoreline adaptation plans.

- Auckland Unitary Plan: Design rules and requirements for specific designated land use zones.

Figure 2-5 highlights an example of a coastal outfall which has been integrated into existing infrastructure. In this instance, the outfall blends in with a boat ramp already protruding from the shoreline beyond low tide. Where possible, engineers should aim to blend new structures into the existing landscape, and to maintain a seamless aesthetic.

Figure 2-5: Outlet installed to blend into surrounding aesthetic

Table 2-4 provides indicative guidance on the amenities of various Auckland locations and Table 2-5 presents a guide for levels of aesthetics required. This is initial guidance only and discussion with Auckland Council and stakeholders is required to agree on the level of aesthetic treatment, inlets and outlets should receive in particular areas.

Table 2-4: Guidance for amenity identification

Amenity	Examples	
High	• Where bathing and water contact sports are practised. • Highly visible and high pedestrian areas. • Coastal areas including areas landward of Mean High Water Springs (MHWS) where that land is physically connected, visually cohesive and has high intrinsic values associated with the coastal environment. • Watercourse passes through a formal park, reserve or beside a public picnic area or playground. • Designated natural heritage areas. • Areas of high cultural heritage or cultural value (including Tangata Whenua management areas and areas near Marae, significant sites, e.g. urupa, pā sites, maunga, middens (or other areas where artefacts may be buried) areas with mahinga kai significance).	• Areas designated as high amenity (that may normally be classed as lower amenity levels) by community groups (such as the Local Board, Wai Care). • Lake management areas. • Local centre zone. • Town centre zone. • Metropolitan centre zone. • Civic space zone. • Conservation zone.
Medium	• Popular footpath adjacent to watercourse. • Moderately visible and medium pedestrian accessed areas. • Areas for recreation and sport (non-immersion with water). • Watercourse passes through housing development of frequently used areas (bridge, pedestrian area, shopping area).	• Neighbourhood centre zone. • Community zone. • Single house, mixed housing suburban, and mixed housing urban zones. • Significant ecological areas, e.g. Marine 1 and Marine 2.
Low	• Heavy industry zone. • Light Industry zone. • Business park zone. • Defence zone.	• Minor port zone. • Seldom or never used for any amenity purpose. • Remote or inaccessible area.

Table 2-5: Example for aesthetics based upon amenity rating

Amenity	Guidance	Indicative Examples
High	• Locations likely to be extensively designed to enhance aesthetics/amenity of an area and potentially be 'statement' areas. Aesthetic design will therefore dictate the stormwater option selection/design significantly. • Discharge location along coastlines should be designed to avoid being situated centrally along a beach and to avoid points of severe erosion to align with a headland or other hard point where possible. • Concrete structures/outlets, wingwalls, inlets and screens may be required to be hidden or screened from public view. • Lighting may be required, depending upon the nature of the space. • Landscape/urban design architect input is mandatory for landscaping/planting design. • Architecturally designed fencing/ boardwalks. • Textured/patterned/architecturally designed grills/screenings/inlet gratings, where visible. • Colour/texture treatments required for materials to improve aesthetics. • Landforms shaped/contoured to blend features in, reduce vertical drops and reduce the need for fencing where safe to do so.	

Amenity	Guidance	Indicative Examples
Medium	• The aesthetic design may influence the stormwater option selection/design. • Landscape architect input recommended for landscaping/planting design. • Material finish may be treated to improve aesthetics where desirable. • Natural rock facades used to blend the structure into the environment (as shown in the adjacent examples). • Planting/landscaping to blend structures into the environment and enhance amenity where practical. • Large, visually imposing concrete structures/outlets, wingwalls, inlets and screens may be required to be hidden or screened from public view or disguised to resemble natural rock. • Landforms shaped/contoured to blend in features and reduce vertical drops and reduce the need for fencing where safe to do so.	  
Low	• Standard safety fencing to meet specifications/durability requirements. • Standard construction materials to meet specifications/durability requirements. • No specific landscaping or planting requirements above that required in the AUP. • Mitigation planting maybe required to replace removed vegetation.	

2.6.3.1 Colour and texture

The colour and texture of features constructed as part of an inlet or outlet should match the surrounding features.

Exposed concrete should be avoided or covered up where possible. When this is not possible and concrete will be visible, the designer should use special aggregates and/or coloured concrete as appropriate to the environment (i.e. to match local rock, and soils insofar as possible), e.g. Figure 2-6. Plain grey concrete is not preferred because it is too visually intrusive.

Where there is no other colour/texture theme in the surrounds, then a 6% black oxide concrete with basalt chip aggregate should be used where appropriate.

Figure 2-6: Examples of blending an outlet blending into the natural surroundings

2.7 Environmental issues

2.7.1 Water Sensitive Design

Auckland's *Water Sensitive Design for Stormwater* Guideline (GD04) provides guidance for the application of Water Sensitive Design (WSD). It applies a set of principles for land development aimed at reducing or minimising, negative environmental effects with an emphasis on appropriate location, layout and design.

Project outcomes are influenced by a myriad of factors including urban design, landscape amenity, and community concerns and aspirations. WSD ensures that stormwater management is key for good urban design and is targeted to where it can provide the greatest benefits, both for the community and land developer.

2.7.2 Stormwater contamination

Stormwater discharged into the environment via an outfall may be contaminated from various sources such as closed landfills, sewer overflows, and agricultural runoff. Possible contamination includes:

Landfill leachate	Potential contaminants from decomposing waste.
Pathogens	Bacteria and viruses from combined sewer overflows and animal waste.
Nutrients	Nitrogen and phosphorus from fertilizers and agricultural runoff.
Heavy metals	Lead, mercury, and other metals from urban runoff and industrial sites.
Chemicals	Pesticides, herbicides, and other hazardous substances from residential and agricultural areas.
Sediment	Soil and debris from construction sites and eroding streambanks.
Oil and grease	Automotive fluids from roads and parking lots.

Where these may be present, special considerations for stormwater outfalls may include:

Design and construction	• The detailed design should prevent the ingress of contaminants when not required. • This may involve the use of mitigation measures such as gas barriers, proper sealing of joints, and ensuring that outfalls are located away from areas with high contaminant concentrations.
Monitoring and maintenance	• Regular monitoring of gas levels and water quality at stormwater outfalls near contaminant sources, e.g. closed landfills, is essential. • Establish maintenance protocols to ensure that any detected issues are promptly addressed.
Adequate dispersion	• Contaminant dispersion may need to be evaluated during the design process, ensuring sufficient mixing so that contaminate concentration reaches an acceptable limit within an agreed distance from the outfall as per consent conditions.
Management of sources	• Management of sources may include appropriate leachate collection and treatment systems for closed landfills, increasing storage capacity above sewer overflows and separating stormwater and sewage systems. • Additional technical studies and assessments may need to be considered during the design process.
Public awareness	• Stakeholders, including developers and the public, should be made aware of the potential risks associated with stormwater outfalls which may contain contaminants. • Educational materials and clear signage can help in mitigating these risks.

2.7.3 Ecological considerations

To protect the existing system, outlets and erosion protection should have as small a footprint as practicable, e.g. dissipating energy within the network or through a bubble-up manhole would have fewer adverse effects than the disturbance and vegetation clearance needed for a long extent of riprap. Other considerations include:

- Outlets should be set back from natural channels to minimise riparian vegetation clearance and main channel erosion.
- Habitat niches exist at a variety of levels in an ecological community, from root zones and litter layers, through to shrubs and emergent trees. Consider the introduction of materials to optimise habitat diversity for invertebrates, birds, lizards, and frogs in the form of plants, logs, rocks, and leaf-litter.
- Upstream waters and coastal regions are likely habitat for key species, requiring thorough consideration and care.
- Variable aquatic conditions provide for diverse life-cycle stages of aquatic fauna, e.g. cool pools, oxygenating riffles, overbank or island refuge areas, soft and rocky substrates, and organic food sources.
- Planting can provide multiple 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.

2.7.4 Fish passes

If native fish can reach the base of the pond or wetland, a fish passage should be included. Any inlets and outlets that could prevent the upstream or downstream migration of fish species should incorporate measures to allow the passage of fish species that under natural conditions, would be found upstream of the stormwater device. Key design elements for fish passage are presented in Table 2-6.

The presence of types of fish species will require advice from an ecologist. Their mode of swimming and life stage will set the fish passage design requirements. Mana whenua are the source of the mātauranga Māori for the site, which in addition to what species are present, may provide other design considerations.

Fish passes may require careful consideration at shoreline outfalls due to the risk of blockage from sand as well as attracting wave forces. Site-specific assessment will be required to ascertain up and downstream ecology and practical design solutions.

Table 2-6: Fish passage design considerations

Element	Design consideration
Outlet structures	• Vertical outlet structures are commonly used in wetlands and may create a velocity barrier as well as a physical barrier for fish. • Potential fish passage through the manhole riser should be included or alternatively, a fish passage that bypasses the outlet structure entirely could be considered when designing wetland and dam structures.
Vertical fall heights	• Should be minimised. Stacking appropriately sized rock can mitigate some falls, with the longitudinal slope of the placed rock ramp being no more than 1:5. This will depend on what species are present as weak swimmers such as Īnanga will require much lower gradient (1:30 - NZFPG) or may require an alternative means for passage.
Water velocities	• Should be minimal or there should at least be a region of low velocity flow. • If flow velocities exceed 0.3 m/s, baffles (pipes ≥ 1.2 m diameter) or spat rope (pipes ≤1.2 m diameter) should be installed to create flow refuge for fish (spat ropes are generally only suitable for climbing species such as elvers, lamprey or some of the whitebait 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.
Culvert roughness	• 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.
Weirs	• 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.
Planting	• Designs should include riparian planting to reduce water temperature increases.
Fish friendly backflow devices	• A check valve or gate that is able to prevent the flow of water back up the stormwater network while still allowing for the migration of fish species. See Section 3.7.2.5 below.
Structures in and around wetlands	• Information should be provided in accordance with Section 62 of the NES for Freshwater Regulations 2020 relating to the size and location of the structure, the nature of the up and downstream water bodies and the impacts on fish passage.
Structures in and around streams	• Information should be provided in accordance with Section 62 of the NES for Freshwater Regulations 2020 relating to asset characteristics and ownership and the stream environment. There are specific requirements for flap gates, aprons and ramps. Passive flap gates are a non-complying activity.

Further guidance can be found in New Zealand Fish Passage Guidelines: For structures up to 4 m Revised December 2022 and by using the Fish Passage Assessment Tool to meet the NPS-FM and NES-F, Ministry for Environment 2022.

2.8 Outlet geometry

The location and alignment of outlets into the natural environment can cause erosion via a number of different mechanisms. To mitigate these issues, outlets should meet the following guidance:

No structure should extend into the channel or protrude beyond the bank line	• This includes the outlet pipe, wingwalls, headwalls, stilling basins, energy dissipation structures, walls, screens, access, working platforms, fences, retaining walls and protection aprons. • Any protrusion into the channel flow risks local turbulence and scour.
Should discharge from the toe of a coastal cliff	• The outlet should discharge in front of the toe of a coastal cliff to prevent the discharge flow from eroding the face and to avoid saturating slopes. • Care should be taken not to cause excessive velocities due to the change in elevation. • Cliff stability should be taken into account such that any anticipated erosion does not block/bury the outlet.
The outlet pipe should be as low as practical	• Ideally, the pipe invert level should align with the stream bed, such there is no fall for flow exiting the pipe. Any drop in the flow stream risks scour. • Steep banks or steep pipe grades approaching the outlet may require a drop structure or energy dissipation structure upstream of the lower, flatter outlet pipe. • This keeps high energy flows away from the vulnerable natural environment in an engineered and controlled location.
The outlet structure should be set back from the stream	• The designer should confirm that the geometry selected does not cause local bank or bed scour due to eddies and or turbulence. • All bank cuts should be smooth curves to minimise channel losses/turbulence.
Outlet angle	• The outlet should be angled such that the flow enters the stream without impeding the stream flow. • Where practical, the outlet flow should merge with the stream flow at 45^0 to the main channel flow. This minimises turbulence at the confluence of flows and direct flow jet impingement on the opposite bank and erosion. • The designer should consider the location of other existing or planned outlets to ensure the combination of flow plumes does not lead to additional erosion.
Location of outlet	• Should the outlet be the same location where upstream overland flow paths enter the stream/natural channel, then the bank should be contoured to determine and control the flow route into the 'main' stream. • Allowing a flow path around or over the outlet structure will lead to erosion. • The path of this flow from the top of the bank into the stream should be adequately protected against erosion for the velocities expected.

	• The flow route should avoid any drops and minimise velocity by reducing slope where possible. • In the coastal environment, the outfall location should consider options for combining with existing coastal outfalls. • In the coastal environment, discharge points should be directed to headlands or at the end of beaches (away from the more dynamic central beach area or dune systems). • Should consider any natural environmental variation such as beach level fluctuations and possible long-term shoreline recession, which may occur cyclically and result in outlet burial at times and exposure at others; or permanent exposure.

2.9 Construction

Specification of the intake/outlet materials should take into account the surrounding environment, particularly if located in a coastal environment exposed to salt water. If the specified material is concrete, special consideration is required for cover to reinforcement. Similarity, any metallic bolts, fittings and structures should be protected from corrosion through suitable coating systems such as galvanising and/or painting especially within the splash zone. Here, specified stainless steel is preferable, due to its low maintenance. If the metallic components are submerged, anodes may also be considered. AS 4997-2005 provides guidelines for the design of maritime structures including durability considerations and NZS 3101.1&2 (2006) provides further guidance regarding classification of structures situated by coastlines.

Degradation of structures such as gabions and geotextiles also have potential to cause water quality concerns around microplastics and corrosion byproducts which must be taken into account. Fabrics made from natural fibres such as hemp or wool could be considered, although some work is required to assess the performance of structures using these materials.

Engineers should ensure that adequate construction practices are maintained, in terms of efficacy and sustainability. It is imperative to incorporate best-practices – such as those outlined in Auckland COP – Chapter 1.

2.10 Maintenance

As maintenance is required for all devices, good design should result in lower long-term maintenance costs. Further information on maintenance of stormwater components can be found in:

- TR2010/052: *Construction of stormwater management devices in the Auckland region. Technical Report.* Auckland Council. (2010)
- TR 2010/053: *Operation and maintenance of stormwater management devices in the Auckland region.* Technical Report. Auckland Council. (2010).

Assets should be maintained in good condition and function, whilst minimising future maintenance requirements and environmental effects.

All maintenance aspects require discussion and agreement with the planned asset operator (this will normally be Auckland Council).

Important aspects of design that contribute to good operational outcomes include:

- Design for minimal maintenance, e.g. have reverse slope outlet pipes that withdraw water from below the surface where floatables could otherwise collect and block the outlet
- Provide safe maintenance access and working space for both the personnel and plant likely to be required to maintain the asset
- Where heavy debris loads are expected, allow for temporary debris storage/handling space
- Inlet and screen design should consider safe access during high flow or overtopping conditions for unblocking
- Where an outlet is located on a beach, appropriate check valves should be considered to prevent ingress of material into the pipe (see Section 3.7.2.4)
- Incorporate a dewatering outlet in a manhole for maintenance and sediment removal operations.

Safe, practical, and affordable maintenance

Remote sensing such as CCTV should be considered to provide condition assessments and monitoring, e.g. coastal outfalls employing remote assessments of sedimentation buildup for maintenance purposes. These techniques may reduce the need for higher risk activities such as diving, which would likely be required for outlets with submerged diffusers (see Section 3.7.1.3).

2.11 Erosion and scour

Natural channels, soil, earth, and grass stream/drain banks are easily eroded by stormwater flows, damaging the environment, ecology, and habitats. Erosion can undermine structures leading to expensive and hazardous failures or on-going maintenance intervention and liabilities. High flow-velocities can also erode and damage pipes and structures.

Typical types and causes of erosion, which may change for different flow conditions, include:

- Wave action (at outfalls into the coastal environment or large wind/wave-affected bodies of water)
- Turbulence/wave action due to flow transitions/standing waves/hydraulic jumps (hydraulic jumps can move/migrate as upstream flow changes and downstream hydraulic conditions vary)
- Inlet contractions/turbulence/vortex formation (can lead to settlement or rotation of wing walls/pipeline and ultimately failure)
- High velocity and turbulence of flow
- Weir flow or overland flow over the embankment (e.g. when a culvert is overtopped, flow down the steep bank the other side of the embankment to re-join the downstream flow can cause erosion leading to culvert and embankment failure)
- Outlet scour, structure undercutting or scour hole formation

- Saturated beach material is more easily erodible by coastal processes
- Scour around the pipe annulus as a result of piping
- Scour of the pipe material (high-velocity flow, mechanical action (high grit load), air entrainment or cavitation)
- Direct outlet jet striking bank walls or structures
- Bed scour caused by either the outlet jet striking the stream bed, poor boundary layer development within the upstream system or direct entrainment of bed material by the outlet jet
- Bank erosion (often at stream bends) and channel migration/avulsion (river/stream banks can change course
- Slope saturation.

2.11.1 Erosion

Erosion occurs through natural weathering, abrasion, lift caused by flow, corrosion, and transportation; these processes accelerate when urban runoff is concentrated. In addition to water velocity, the amount and degree of erosion are related to the soil type and whether it is colloidal, cohesive, or granular, or whether the land is highly vegetated, is subject to tomos (sinkholes) and other geologic phenomena. The slope of the banks and channel bed, and whether there is vegetation or other surface protection, also influences the progression and route of erosion.

Erosion from stormwater discharges typically takes the form of local scour in the vicinity of the pipe or channel outlet, or general downstream channel degradation which is due to increased stormwater runoff volumes from urbanisation within a catchment. For 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, erosion potential can be evaluated by calculating the outlet exit velocity and comparing it to the indicative velocities that cause erosion in different channel materials as listed in Table 2-8. Natural channel velocities are typically less than outlet velocities because the channel cross-section is larger than the pipe flow area and the roughness (frictional resistance) of the natural channel is greater than that of a concrete pipe. However, over a short distance from the outlet, channel characteristics adjust to a pattern controlled by the outlet velocity. More detail design considerations around erosion and sediment control for the Auckland region are provided in GD05.

Note that Table 2-8 velocities are general guidelines and site-specific factors such as channel grade, channel sinuosity, material compaction, age of channel, quantity and robustness of vegetation may affect erosion potential.

2.11.1.1 Reducing inlet erosion potential

Inlet design can reduce erosion potential by consideration of the energy and hydraulics of the inlet structure, and the upstream and downstream hydraulics.

Table 2-7: Inlet design issues

Issue	Considerations
Below grade/depressed inlets (including culverts)	• Often designed lower than existing channel grade to increase hydraulic capacity. • Increased grade will increase local flow velocities, especially during exceedance events when the water level heads-up. • These velocities should either be kept within non-eroding ranges (depending upon bank or stream material/soils/cover) or protection should be provided. • Protection may take the form of rip-rap/extended concrete or rock mattress aprons. • Swale design is covered in GD01 (Stormwater Management Devices in the Auckland Region GD 2017/001).
Approach velocity direction	• Where the approach velocity either from a channel or pipe is not aligned with the downstream system, erosion can occur outside of the bend. • Where the approach velocities exceed the maximum non-eroding velocity, protection will be required. This may take the form of riprap/extended concrete or rock mattress apron/extended inlet wing walls.
Super-critical approach flow	• High energy inlet flow may cause unexpected effects at an inlet contraction. • If the energy loss is substantial, a hydraulic jump may form at the inlet, causing excessive turbulence and potential erosion. • Hydraulic jumps may also be unstable and propagate upstream or downstream depending on hydraulic conditions and flow rates. • Hydraulic transitions of this nature should either be avoided or designed to occur at a suitable location that can be protected against erosion and prevent choking of the downstream culvert.
Inlet seepage	• Seepage of water around the outside of an inlet pipe barrel can wash out bedding material and erode material from around the pipe. • Cut-off walls, seepage-collars should be provided to prevent groundwater piping.

2.11.1.2 Reducing outlet erosion potential

Outlet and outfall design can reduce erosion potential by considering the outlet's energy and hydraulics.

Table 2-8: Outlet erosion issues

Issue	Considerations
Natural-channel erosion	• Consider the natural channel erosion already occurring in the downstream system. Over time, all natural watercourses will gradually erode towards a flatter less energetic system. • It is important to identify natural channel erosion and how it may progress and potentially affect any permanent structures over their design life. • New infrastructure should be designed not to exacerbate natural stream processes so that natural processes do not cause damage over the infrastructure's planned lifespan. • Understanding existing erosion requires site inspection surveys to be aware of any issues, risks and periodic lifetime inspection and maintenance requirements. • Stream stability can be assessed using HEC20 – Stream Stability at Highway Structures (Lagasse, et al, 2001).
Drops	• Avoid drops from outlet or aprons to the watercourse.
Grade	• Minimise pipe grade to the outlet.
Discharge jet alignment	• Align the outlet discharge jet with stream flow so that jetting or high-velocity flows against opposite stream banks are avoided.
Reduce velocity	• Reduce flow velocities and dissipate energy. • Specific energy dissipation structures can be provided to reduce velocity to appropriate levels but may also require consideration of additional bank or bed-protection schemes to a point where erosion is prevented.
Control hydraulic transitions	• Control the transitions (hydraulic jumps) of super-critical flow (high velocity) to sub-critical flow (low velocity) to occur at defined and protected locations.
Outlet seepage	• Seepage of water around the outside of an inlet pipe barrel can wash out bedding material and erode material from around the pipe. • Cut-off walls and seepage-collars should be considered to prevent groundwater piping where geotechnical conditions require.
Coastal erosion	• Determine the erosion and coastal processes to allow for either soft erosion of beaches and dunes or harder coastal cliffs. • Erosion may be seasonal or event driven, however there are likely long-term trends to consider, such as applying a shoreline analysis of historical imagery. • Sea-level rise may lead to increased erosion potential either through allowing more wave energy to reach the cliff/dune toe, or through natural weathering. More information is provided in *GD10 Coastal Hazard Assessment in the Auckland Region.* • Regional scale ASCIE lines are provided by Auckland Council through GeoMaps based on *Predicting Auckland's exposure to coastal instability and erosion,(Tonkin + Taylor, 2020).*

Issue	Considerations
Coastal outfall structures	• Consider location in first instance. • Protect the surrounding embankment where an outlet is located because the structure may induce increased scour on either side due to possible wave focussing, as well as existing/future shoreline recession trends. • Consider if scour protection is required, and if so, can natural features mitigate scour, e.g. shore platform, or dynamic beach recovery. • Consider structural support, such as piles or measured sub-base to avoid scour damage and undermining.
Streamlining	• Streamline flow to minimise turbulence and the formation of eddies.
Bank protection	• Protect banks where overland flow paths will re-join the natural watercourse.

2.11.1.3 Reducing overland flow path erosion potential

Where overland flow bypasses a stormwater network, there is potential for high-velocity flow to damage surface features, property and cause hazards and significant erosion where it passes over steep, natural surfaces, or easily erodible material, especially as it enters a downstream natural channel via a steep natural bank.

Figure 2-7: Example of a designated overland flow path

- Design the flow path (e.g. swales) to cater for the overland flow and direct it away from vulnerable areas, steep slopes or easily erodible material. Velocity within the swale may still need to be considered and controlled (depending upon lining/protection scheme used).
- Undertake 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. However, planting should be designed such that it does not cause flow to spread outside of the designed and protected flow, or trap debris that may block the overland flow and lead to flooding of property/habitable floors.
- Scour protection is needed for vulnerable structures/material.

- Consider whether materials used are suitable for high-velocity areas.
- Steep banks where the consequence, hazard or cost of repair is high, require specially designed energy dissipation structures, chutes, stepped channels and/or control of overland flow velocities.

2.11.1.4 Protecting structures and watercourses from erosion

In addition to the above fundamental approaches to reducing erosion potential, there are other strategies that can reduce the risk to structures:

- Consider transported sediment load inflows and abrasion from air entrainment or cavitation
- Pay careful attention to joints/discontinuities/bends/benching and other losses
- Structure foundations and support should be extended below the expected scour depth
- Locate structures to avoid erosion from the mainstream or other flows
- Consider groundwater flows (and increased groundwater flows during and after storm events) around structures that may washout fines or materials that lead to instability and potential failures
- Locate the edges of scour protection schemes away from high velocities and eddies.

2.11.2 Assessment of acceptable velocity

Erosion scour and the ability for a natural channel to sustain flow velocities is a complex subject with a number of empirical approaches being developed for different purposes and by different organisations. A simplified approach has been adopted for this guidance as an interim measure while further active research is undertaken by Auckland Council. It is expected that this document will be updated with further guidance in the near future.

The design process around assessing the suitability of stormwater inlet and outlet velocities is presented Figure 2-8 and elaborated on in Section 3.2:

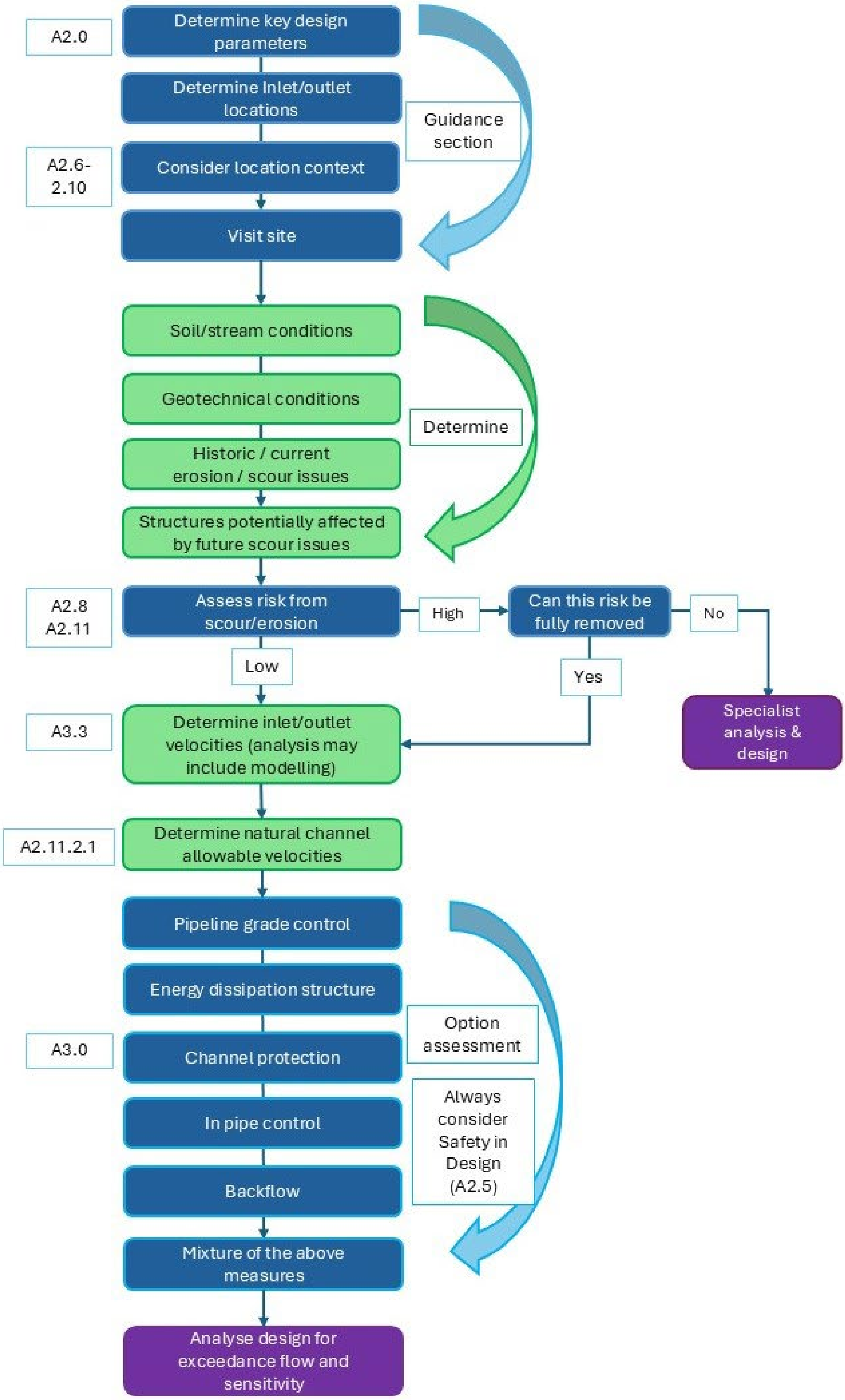


Figure 2-8: Design approach flow chart

2.11.2.1 Pipes, culverts and box sections

Table 2-9 provides minimum and maximum velocities which apply to within the stormwater pipe or culverted network (refer to the Auckland Council SW CoP).

Table 2-9: Stormwater pipe or culverted network minimum and maximum velocities

Self-cleansing velocity	• A desired minimum velocity of 1.0 m/s should be achieved for the 50% AEP event (2-year ARI). • This may be reduced to an absolute minimum of 0.6 m/s with agreement by Auckland Council. • Culverts have the same criteria as specified in the Auckland Stormwater CoP.
Maximum velocity	• An acceptable maximum velocity in all pipes for the 10% AEP design storm (10-year ARI) is 4.0 m/s.
Culvert maximum velocity	• Culverts should be designed such that the maximum velocity within the culvert generated by the 1% AEP (100-year ARI) event does not exceed 6.0 m/s. Higher velocities in culverts require approval from Auckland Council.

The maximum velocities required above will likely cause excessive erosion if discharged to natural channels, banks and surfaces. Velocities should therefore be reduced to ensure the natural environment is not damaged either by:

- Reducing pipe or hydraulic grade to reduce outlet velocity to an acceptable level, noting that beach sand will likely erode when velocities exceed approximately 0.3 m/s
- Dissipate energy (roughness rings, stilling basins, baffles, drop pools) such that the velocity reaching the natural environment is lower and acceptable
- Provide erosion protection methods to affected surfaces until the velocity has reduced to acceptable levels.

2.11.2.2 Erosion return period

Erosion due to flows entering stormwater inlets and discharging from outlets cannot be prevented in all instances. Extreme events are likely to cause some erosion but should be kept to a minimum to reduce risk, but are also on-going operational maintenance liabilities.

Streams and culverts	• Use 10% AEP (10-year ARI) design velocity for assessing erosion. • The 2% AEP (50-year ARI) and 1% AEP (100-year ARI) velocities should also be checked to determine erosion risk and consequence. • Analysis should be undertaken of the range of design velocities to determine whether potential mitigation or protection is desirable/cost-effective and should be agreed with Auckland Council.

Pipe and treatment device outlets	• Use 50% AEP (2-year ARI) design velocity for assessing erosion. • The 10% AEP (10-year ARI) and 2% AEP (50-year ARI) velocities should also be checked to determine erosion risk and consequence. • Analysis should be undertaken of the range of design velocities to determine whether potential mitigation or protection is desirable/cost-effective and should be agreed with Auckland Council.
Overland flow paths	• Use 10% AEP (10-year ARI) design velocity for erosion. • The 2% AEP (50-year ARI) and 1% AEP (100-year ARI) velocities should also be checked to determine erosion risk and consequence. • Analysis should be undertaken of the range of design velocities to determine whether potential mitigation or protection is desirable/cost-effective and should be agreed with Auckland Council.
Detention pond weirs / earth banks (non-certifiable)	• The consequence of failure of the banks needs to be determined to define the level of erosion protection required. • This is specialist analysis and design and should be undertaken by a competent hydraulic and geotechnical design consultant.

2.11.2.3 Natural channels

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

For discharge to natural streams or gullies, erosion potential can be evaluated by calculating the culvert exit velocity and comparing it to the velocities that cause erosion in different channel materials. 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.

Table 2-10 gives guideline velocities for the maximum velocity that natural channels and other materials can sustain before the onset of erosion. It is important to note that the following assume that the natural channels listed below are 'aged' or 'well-seasoned' and not recently constructed. The velocity presented are the mean velocity of the flow cross-section.

Table 2-10: Maximum velocities for erosion control

Material	Maximum velocities for erosion control in unlined channels (m s-1)	Source
Fine sand, colloidal	0.45	B
Sandy loam, noncolloidal	0.50	A
Silt loam and alluvial silt, noncolloidal	0.60	A

Material	Maximum velocities for erosion control in unlined channels (m s-1)	Source
Ordinary firm loam	0.76	B
Volcanic ash	0.76	B
Stiff clay and alluvial silt, colloidal	1.10	A
Shales and hardpans	1.80	A
Fine gravel	0.76	A
Graded loam to cobbles, noncolloidal	1.10	A
Graded silt to cobbles, colloidal	1.20	A
Coarse gravel	1.20	A
Cobbles and shingles	1.50	A
Tussock type grasses	0.5–1.3	C
Couch, carpet and sward-forming grasses	1.4–2.0	C
Boulders (250 mm minimum)	5.0	D
In-situ concrete or hand packed rock (300 mm minimum)	6.0	D
Precast concrete culverts	8.0	D
Precast concrete pipes to NZS 3107	8.0	D

A. From Stormwater Treatment Standard for State Highway Infrastructure (NZTA, 2010) and Brisbane City Council (2003). The original source of this data is Fortier and Scobey (1926) published in the Special Committee on Irrigation Research of the American Society of the Civil Engineers.

B. *Fortier and Scobey (1926) published in the Special Committee on Irrigation Research of the American Society of the Civil Engineers.* It should be noted that this is limited to the mean velocity of straight channels of small slope, after aging (e.g. not freshly constructed) with flow depths less than 0.9m deep. (Source: Open-Channel Hydraulics, Ven Te Chow, 1959).

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

D. *Compliance Document for the NZ Building Code – Clause E1 Surface Water (Section 7 – Table 5).*

As the allowable velocities (from sources A and B only) are mean velocities based on an assumed flow depth of 0.9 m (Fortier and Scobey), the velocity should be corrected for the real depth of flow and multiplied as shown in Table 2-11.

Table 2-11: Depth of flow correction factor

(The maximum permissible mean velocity in open channels (Hydrotechnical Construction, Moscow, 1936)

Depth (m)	Correction factor
0.3	0.80
0.6	0.90
0.9	1.00
1.5	1.10
2.0	1.17
3.0	1.25

2.11.3 Understand the existing system

Erosion is an ongoing time and flow varying process. It is important that wherever inlet and outlet structures interact with the natural environment that the existing system and erosion/sedimentation processes are understood well enough to make sound engineering decisions.

Figure 2-9: Examples of stream erosion in Auckland

In order to make decisions around structure locations and erosion prevention measures, the following are required to be defined and understood:

- Which natural watercourse, or coastal environments will be interfaced with.
- The geology, soils and sediment types upstream and downstream the stream passes through, or the natural environment encompasses.
- Known history of erosion/sedimentation processes in the stream reaches affected (including downstream). Auckland Council watercourse assessments, operations staff or local landowners will have knowledge around these issues as well as maintenance and interventions required to repair stream banks or affected structures.
- Site visits should be undertaken to confirm and document erosion/sedimentation processes and to identify and understand potential risks. This may also include

determining the depth of sand over shallow bedrock on a beach and possible long-term shoreline recession, which may be affected by projected sea-level rise.

- Is the channel stable or degrading? What are the causes of any degradation? How will the project likely affect these processes?
- Is the channel/shoreline migrating? Or does it have a history of migrating (In the Auckland region, historic aerial photography can be used to aid assessment of this process). Would climate change cause an acceleration of this?
- Will the coastline retreat in response to climate change?

2.11.4 Erosion failure examples

The following examples illustrate where erosion has been recently observed and has led to expensive failure or repairs.

2.11.4.1 Inland outlets

Figure 2-10 to Figure 2-13 provide examples of erosion failure.

Figure 2-10: Culvert overtopping (outlet erosion after event) and pond failure due to piping pond failure. Photo courtesy of Stantec

Figure 2-11: Left: Outlet erosion around structure (overland flow) Right: Erosion of riprap (excessive velocity and poor selection of Reno mattress fill rock)

Figure 2-12: Outlet erosion of protected spillway downstream of pond level spreader

The culvert at this site experienced an extreme wet weather event. The flows at the head of the culvert significantly exceeded its capacity and there was no formalised secondary flow path for flows exceeding the design capacity. This led to significant overtopping of the road embankment. The overland flow affected a number of buildings and re-entered the stream at the downstream end of the culvert. The flow down the steep embankment at the downstream end caused erosion of the bank face, undermining a building and causing the loss of the road edge, footpath and buried services. Figure 2-13 shows flows receding after the storm peak, but still overflowing the road.

Figure 2-13: Overtopping led to excessive downstream erosion (outlet to downstream watercourse)

2.11.4.1 Coastal outfalls

Figure 2-14: Left: Outfall suspended above beachhead, Right: Poor erosion control

Issues with piping an overland flow path in this case involved a coastal outfall pipe constructed without proper erosion consideration or scour matting, which resulted in erosion of the cliff face. Flow from the outfall pipe significantly exceeded the area's natural capacity to manage erosion, leading to substantial undermining of the erodible bank and exposure of the outfall structure. The uncontrolled discharge of water caused excessive erosion, endangering nearby structures and the stability of the surrounding area.

Figure 2-14 shows the extent of the erosion and the resulting damage to the cliff face after peak flow had receded, as well as inappropriate construction materials for the coastal environment.

This example shows an outfall which has been retrofitted and would need to be drilled to avoid discharge from saturating slope. This complication may have been avoided with greater design consideration for erosion control and structural support, public safety and visual amenity.

2.11.5 Erosion/scour velocity consideration examples

Below are some examples of where erosion, scour, velocity, and turbulence considerations are needed. In each case, the likelihood and consequences of potential erosion should be determined and understood to aid risk assessment of potential design modifications to remove, mitigate, or protect against those risks. This process should also identify in detail the agreement with Auckland Council about long-term inspection and maintenance issues resulting from the risk assessment and mitigation approaches to be adopted. Determining the ability of the various natural and designed features to endure the agreed design flow velocities is also critical to a durable design.

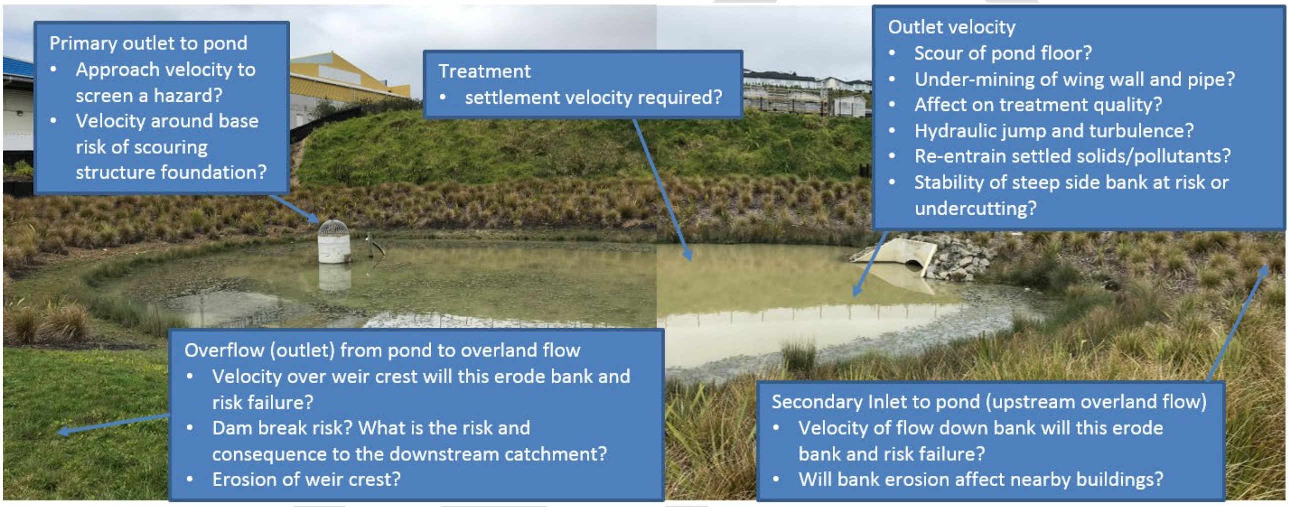


Figure 2-15: Velocity considerations for a pond

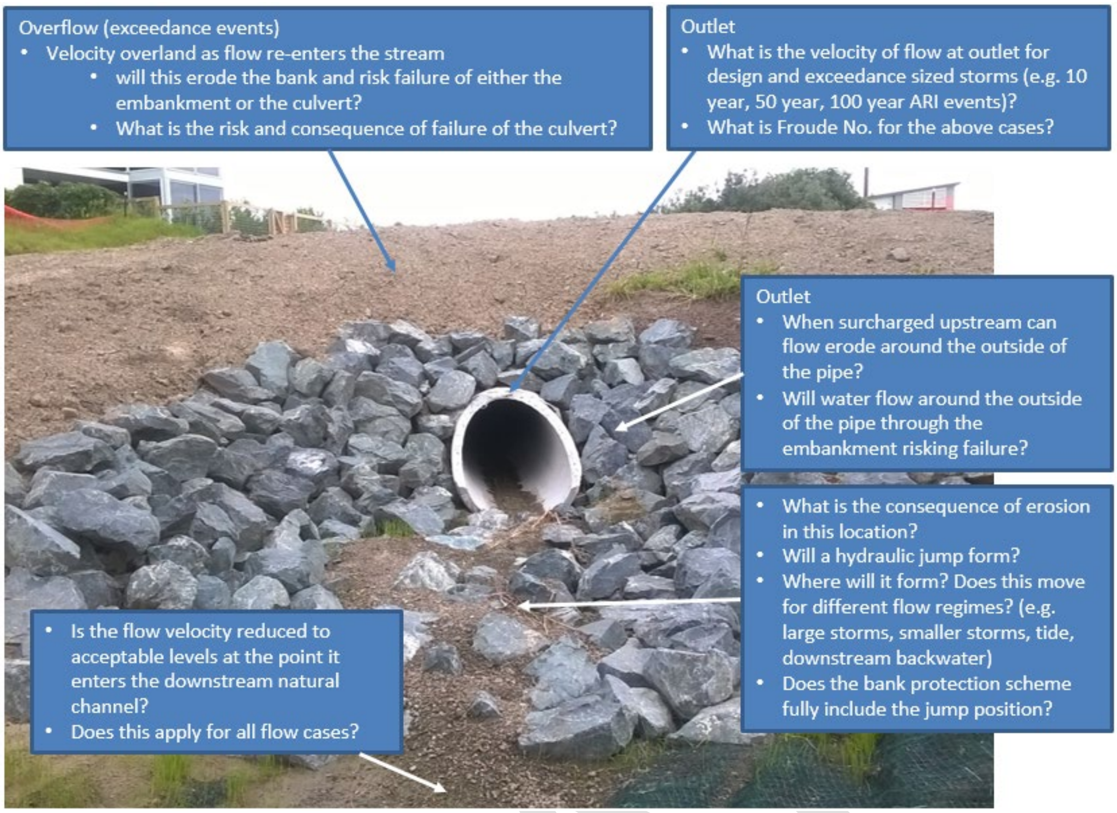


Figure 2-16: Velocity considerations for a culvert outlet

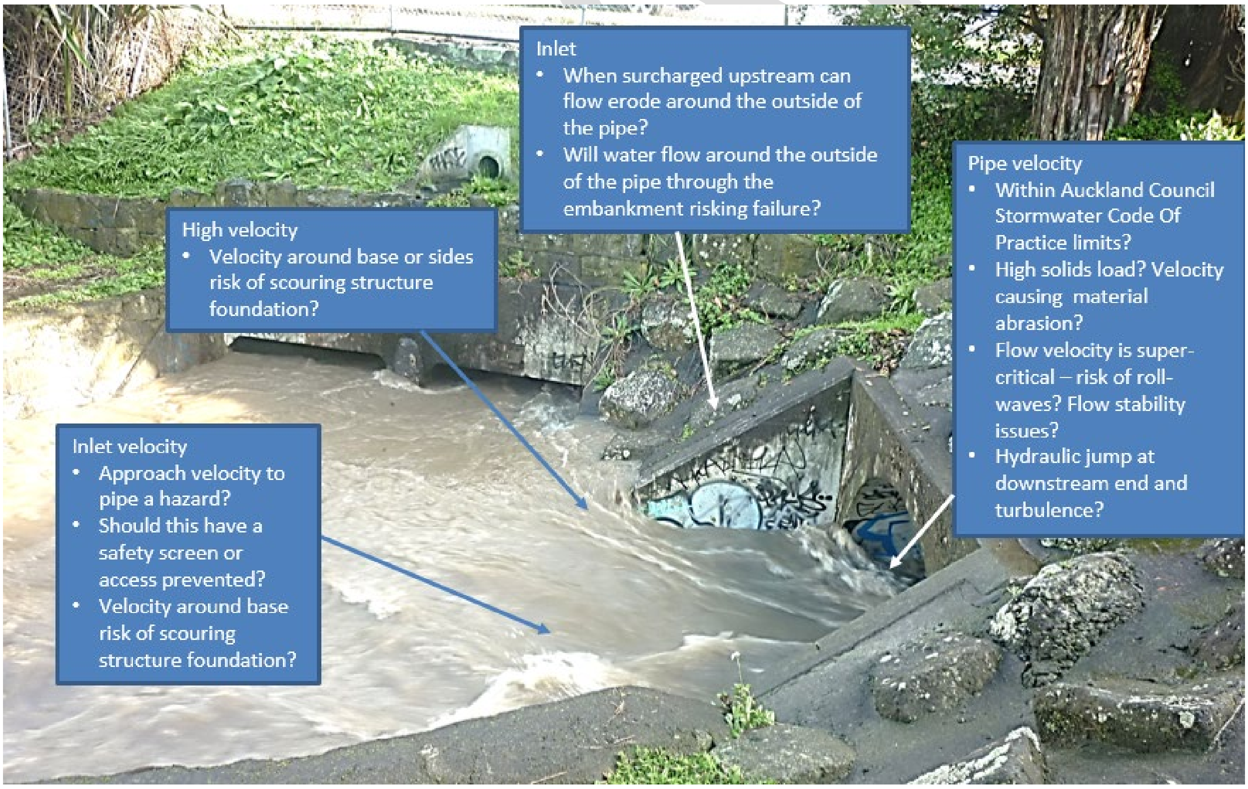


Figure 2-17: Velocity considerations for a pipe inlet from a watercourse

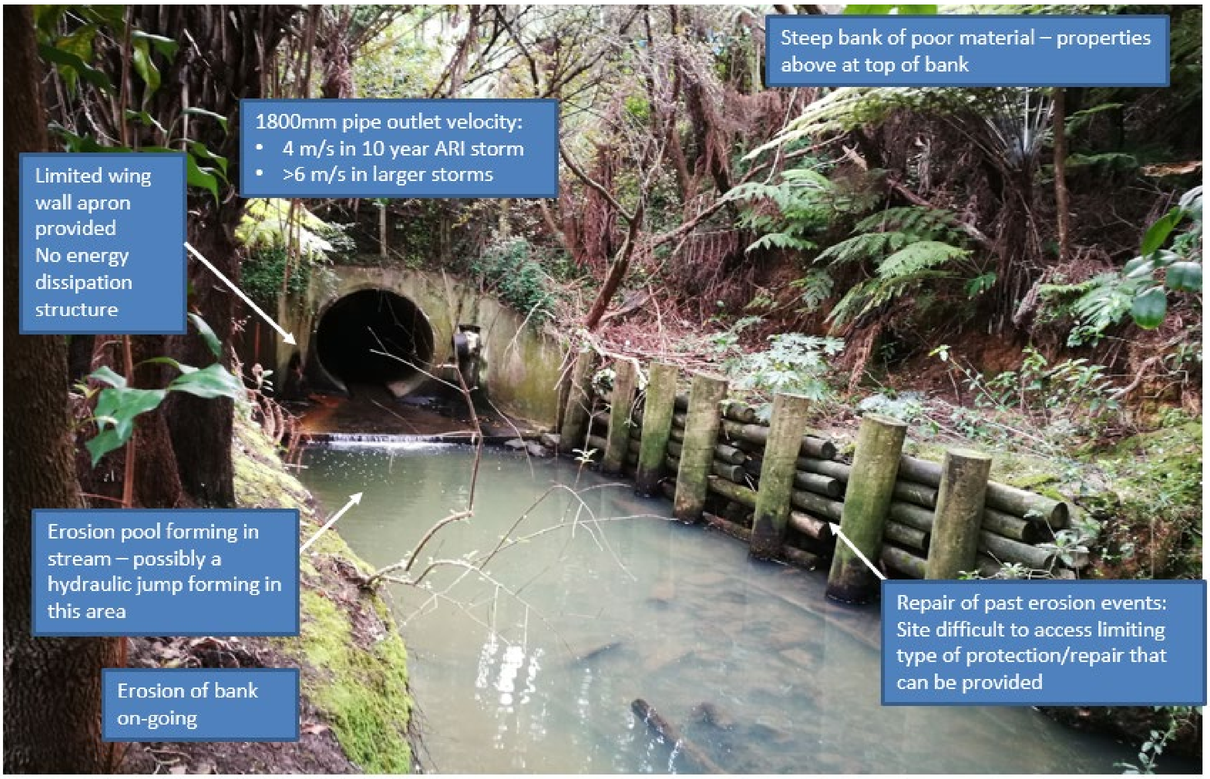


Figure 2-18: Velocity considerations for a culvert outlet

Figure 2-19: Velocity considerations for a culvert inlet

2.11.6 Coastal erosion / scour

Coastal erosion and scour are significant environmental concerns in New Zealand, particularly due to the country's rugged topography and coastal geology. Unlike stormwater flows described above, where the process is driven predominately by the velocity of the flowing water as it drains out to sea, waves could typically lead to the suspension and transport of sediment from around an outlet structure or erode engineered rock protection from the shoreline near an outlet. This is due to effects such as induced pressure and turbulent vortex flow caused by waves, which are further affected by seasonal variations; water depth/tide level; offshore wave height/period; and incoming incidence angle.

Of similar concern may be (intermittent) burying and resulting blockage of the outlet by shoreline sand and insufficient upstream head to force the outlet open. Monitoring these outlets, especially before expected heavy rainfall events, may be required to ensure that the drain will flow. Analysis of historical aerial photographs can provide some insight. Mitigation may be possible by extending the outlet seaward, but the pipeline may then act as a groyne. A coastal processes investigation is required to determine the most appropriate location for discharge point, i.e. directed towards headlands or to the end of beaches (away from the more dynamic central beach area or dune systems).

Over a long period, these processes may lead to a long-term trend of the coastline receding inland. This will be dependent on the type of shoreline such as a sandy beach, which may recover over time versus a coastal cliff which will continuously erode, the rate of which will depends on the local geology. Tonkin + Taylor undertook the study, *Predicting Auckland's Exposure to Coastal Instability and Erosion (2020)* to map the high-level risk for the Auckland region, which is available through the Auckland Council's GeoMaps platform (Figure 2-20). The regional scale assessment of the area susceptible to coastal instability and erosion (ASCIE) provides a conservative or 'first pass' appraisal of the natural hazard extent.

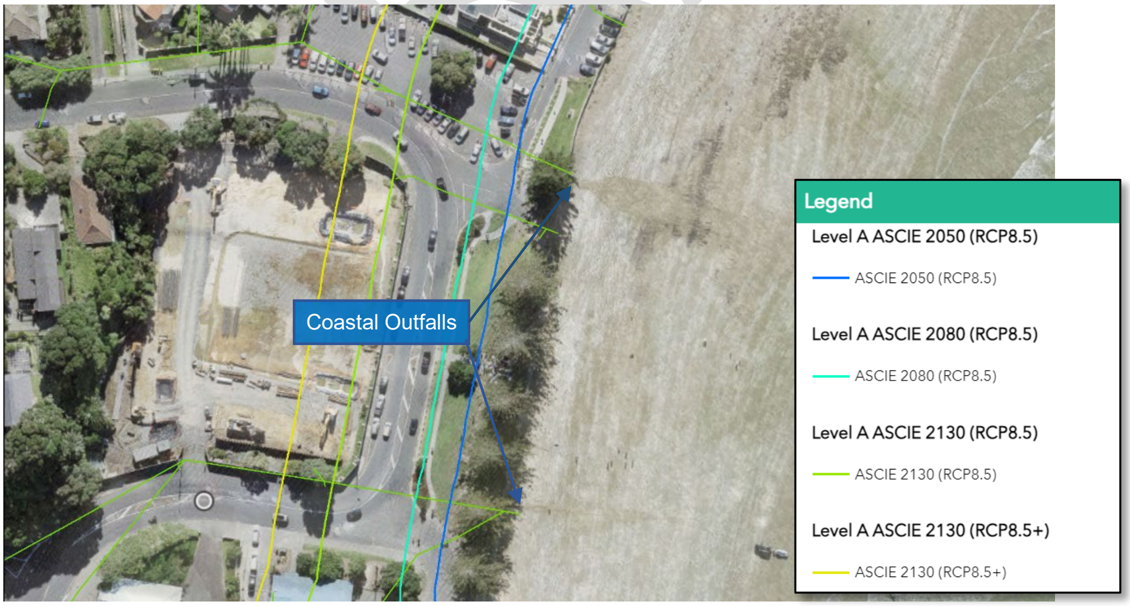


Figure 2-20: Example ASCIE lines in relation to coastal outfalls

In some cases, stormwater discharges across sandy beaches may transport sand away from the upper beach which could result in beach lowering and exposure, with structures being undermined and reduced beach amenity. The discharge point along a beach, therefore, should be the first consideration in terms of mitigating or reducing beach scour, along with consideration of a beach's natural dynamic recovery. If there is sufficient sand supply however, short-term erosion in the vicinity of the outlet may be considered acceptable to reduce the extent of scour protection structure that is needed. If resulting net beach scour is an issue, any structure required to provide protection would need to be designed by a suitably qualified and experienced person.

Where a stormwater drain is extended seaward from a low-lying flat hinterland, this may result in a small rise in the flood level.

Where shoreline reclamation occurs seaward of a low-lying area, there may be an increase in the mean water table level and consequences for existing development.

A thorough methodology to assess potential coastal and beach erosion should be established as part of an effective design philosophy, as described further in GD 2021/010 *Coastal Hazard Assessment in the Auckland Region*, Auckland Council (GD10).

2.12 Sedimentation

Figure 2-21: Sedimentation of a culvert inlet

Sedimentation occurs when particles are deposited at the bottom of a body of water. This usually happens when velocity is low and when there is enough 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 re-suspension 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 into account in the design or through maintenance planning.
- Outlets should be positioned, below elevated water levels near the surface of the ponding zone and above the base sediments to avoid sediment resuspension.

2.13 Debris loading and blockage risks

Blockage of hydraulic structures due to debris reduces capacity and therefore the structure's ability to perform its function.

Overland flow caused by blockages that have not been considered, assessed, and designed for, can lead to erosion, followed by collapse and failure of surrounding structures (e.g. buildings) or the hydraulic structure. These overtopping/overland flow events can also result in risks to life.

Blockages within outlet structures pose significant operational challenges. Debris blockages in structures such as coastal outfalls and screens can lead to reduced hydraulic capacity, increased flood risk, environmental degradation, and public health hazards. Often outlet screens would be hinged at the top to provide a barrier to entry from debris (and persons/ wildlife) however attention needs to be paid to the operation and maintenance of this system with aspects such as sand buildup, and corrosion impacting its effectiveness.

Type of debris (e.g. trees, bushes, leaves, branches, grass clippings, gravel, river stone, boulders, etc. as seen in Table 2-12) and potential loading the structure may encounter will have a significant impact on the design and is determined by the following:

- Upstream land use (e.g. forests, parks, construction sites, gravel pits, spoil tips, industrial yards and storage facilities, etc.)
- Availability of debris within that land use (forest harvesting debris, fallen limbs, loose soils, stored material, etc.)
- Debris mobility (can the debris be easily moved?)
- Transportability of the debris (the depth, velocity and flow required to transport it from source to receptor).

Acceptable guidance for debris loading, blockage risks, and screen design include:

- Chapter 6 - Blockage of Hydraulic Structures (Australian Rainfall and Runoff) provides guidance on how to assess the debris potential of an upstream watershed or system
- Practice Note 2017/002 – Trash and security screens for culverts (Auckland Council)
- Trash Screens and Safety Screen Guide 2009 (Graham et al, Environment Agency, UK)
- Culvert Manual, Ministry of Works and Development (CDP 706)
- Culvert Design and Operation Guide (CIRIA C689, 2010).

Additional issues to be considered during the design are:

- Is the inlet critical? It's important to understand the consequences of blockage from large storms
- Gross debris traps/basins, debris fins/deflectors
- Low flow or normal dry weather blinding of the screen can lead to excessive inlet maintenance or blockage
- Safe screen bypass so that the inlet can continue to function even when the main portion of the screen is largely blinded
- Access and working space/platforms to allow easy screen maintenance. Safe access to clean/unblock the screen during storm events may not always be practical or possible and requires careful discussion with the future owner/operator. This may require additional bypass/overflow facilities and careful protection/lockout or warning signs
- Space should be allowed for temporary stockpiling of screenings while working
- The screen size should be significantly oversized for the pipe capacity.

Table 2-12: NZ examples of debris loads at inlets/outlets and comments

Debris/screen	Comments
	• Forestry debris washed against a road bridge following a large storm. • Large-scale debris may require a high-level bypass design or additional culvert barrel redundancy. • Additionally, gross debris deflectors or fins can be installed upstream.

Debris/screen	Comments
	• Urban stormwater debris collected on trash screen at culvert inlet. • The screen has been completely blinded by relatively small material. • There is no allowance for bypass flows once the screen is blinded. • No easy access to clean the screen (maintenance platform or working area) or locations to put/place raked debris.
	• Grass clippings/leaves from large upstream reserve wrap around vertical bars of the screen and blind the screen. • Horizontal bars at lower levels may have prevented this blinding.
	• This screen has no low-flow slot and so it collects debris in dry weather. • The screen area is increased to allow for blinding and higher flows but the bar spacing tapers at the top of screen, increasing the risk of blinding.

Debris/screen	Comments
	• Typical Auckland urban stormwater debris collected on trash screen at the culvert inlet, where there was some upstream open parkland. • The screen has been largely blinded by relatively small material. • The screen has a low-flow slot to avoid collecting floating material/debris during normal dry weather flows. This allows some bypass but does not allow for major bypass flows once the screen is fully blinded. • There is no easy access to clean the screen (maintenance platform or working area) or location to put/place raked debris.
	• Pond outlet structure with mesh screen on the low-flow orifice and a scruffy dome for bypass flows. • The low-flow screen is blinded with pond weed and is difficult to clean as it is located within the pond, making access potentially hazardous. • Mesh screens are difficult to clean as they cannot be raked. Once the screen is fully blinded and the pond has risen to the scruffy dome level; access is more difficult, and the screen would be deeper than arms-length. • The scruffy dome is very difficult to access and would require specialist equipment to do so.
	• Pipe inlet structure and screen. Upstream is a steep natural bush catchment. • The channel is lined with stone to cater for high velocities and safety fencing is provided to prevent access. • The long-raked screen has a flat overtopping section. • The screen has allowed flow to enter the downstream pipe system while preventing access. • As the screen has no low-flow slot, debris and sedimentation has collected but the multi-stage screen (raked front and flat top) has allowed the inlet to continue to function. • There is no safe working platform from where to rake the screen of debris and no area for temporary stockpiling of screenings. Access is only by climbing over a safety fence and there is no vehicle access.

Debris/screen	Comments
	• Bottom of hinged coastal outfall screen blocked by revetment rocks which have shifted from wave movement hence cannot swing open if the screen is blocked. • The screen and hinge have also corroded possibly preventing movement.

2.14 Basis of design definition

Once all the critical information and key issues are adequately defined, the designer should determine:

- Project objective (agreed with key stakeholders)
- Planned levels of service and or levels of protection:
    - Inlet/outlet capacity, velocity limits (maximum and self-cleansing from the Auckland Council SW CoP)
    - Pipe or structure capacity (10% AEP [10-year ARI] or larger capacity). Note that the Auckland Council SW CoP requires culverts to cater for the flows and water levels generated by the 1% AEP event (100-year ARI) adjusted for climate change
    - Level of protection required for the downstream environment, ecology, and habitats. This may result in water quality, turbidity, turbulence, sediment, and discharge treatment requirements
    - Level of stormwater treatment required at each device (required settling/treatment velocities, inlet velocity to the device and outlet velocity from the device)
    - Detention volumes or levels of service required
    - Extreme event overtopping/bypass/overland flow provisions and requirements
    - Velocity limits that the downstream system can sustain without project-induced erosion
    - Retention systems in place to capture and infiltrate stormwater on site to mimic the existing site hydrology
    - Level of detention facilities to store and release at a controlled rate
    - Level of fish passage maintained to restore natural fish passage in all watercourses and as part of general environmental protection
    - 90 and 95th percentile water quality flows (‘first flush’) to remove accumulated contaminants

- Hazards/risks (existing and future) and their potential consequences. The hazards should have been assessed and addressed either by removal, control and/or mitigation
- Upstream and downstream hydraulic and environmental impact.

2.15 Consideration of the entire system

Stormwater networks consist of connected parts each of which can influence the performance of upstream and downstream elements, depending upon the prevailing hydraulics.

Any hydraulic system should be considered and analysed as a single interconnected system to fully understand how the design will behave. Energy management and the consideration of high velocities are required throughout the design to ensure that the structure will meet its performance objectives, and expected lifespan and will not cause undesirable effects.

The overall approach and considerations for designing wholistic hydraulic systems include:

- Assessment of the complexity of the system and the corresponding required design
- Assessment of which elements can affect and influence others (e.g. blockage downstream causing upstream depth increase, surcharge and overland flow)
- Identification of unstable hydraulics and how they may affect upstream and downstream conditions (e.g. roll waves, air entrainment, air release, migrating hydraulic jumps)
- Energy (velocity and velocity head) should be considered throughout the designed system to address:
  - Safety
  - Maintenance and safety
  - Air entrainment and flow bulking (and two-phase flow potential) (above 4 m/s)
  - Roll-wave formation and unstable hydraulics. (normally a risk above a Froude of 1.5)
  - Local losses and benching detail
  - Local losses at bends and junctions (prevent corkscrewing/helical flow at bends, or flow blocking at junctions)
  - Limitations on scour/erosion and the inlet and outlet
  - Cavitation risk (very high velocities > 6-10 m/s and rougher pipe materials, such as concrete)
  - Super-critical flows require careful consideration and sensitivity testing (around pipe material, joints, junctions, and bends to ensure hydraulic jumps do not form unexpectedly potentially causing flow blocking/air issues/material erosion/unstable hydraulics). Very high-velocity flows can force flow through pipe or slab joints/cracks leading to under drainage issues, bedding scour, potential leading to collapse.
- As part of the design process, hydraulic long sections of pipelines and structures should be provided showing:
  - 10-year, 50-year and 100-year hydraulic grade lines and water surface profiles

- Velocities in the system at key locations (e.g. steeper sections, inlets and outlets, and downstream natural channels)
- Clearly marking pipelines and river/stream reaches of super and sub-critical flows and transitions (e.g. hydraulic jumps, backwater curves).

Auckland Council considers situations where the flow velocities above 4 m/s at either the outlet or inlet of a structure as well as where Froude numbers are higher than 1.7 to require specialist engineering design by an experienced and competent hydraulics specialist, including coastal engineering at the shoreline. Large, critical and complex systems may require detailed analysis using modelling techniques such as:

- Steady flow modelling (HY8, HEC-RAS, ICM, Mike 11, Mike Urban) – (steady flow means static, non-time varying, flow calculations). Can be conservative for larger pipe networks and systems.
- Unsteady flow modelling (ICM, Mike Urban, Mike 11, Mike 21, Mike Flood, HEC-RAS,) – (unsteady flow means time-varying dynamic flow calculations). Required where understanding time-varying performance is important such as attenuation, time of concentration, culverts where performance changes between inlet and outlet control, migrating hydraulic jumps and transitions between flow states (sub to super critical).
- CFD (computational fluid dynamics) modelling where analysis of discrete but complex structures is required to understand and evaluate three-dimension hydraulic performance and velocity distributions. Often used for structures such as spillways, intakes, fish passages, gates, outlet structures and natural channels, where the free surface profile, velocity distribution or air flow and bubble movement are critical to the performance.
- Physical models are the construction of small-scale prototypes to validate the expected performance of hydraulic structures where there is limited empirical evidence or guidance or there is concern over assumptions or potential for unstable flow regimes and large air movements. Typically undertaken only for large, expensive and critical infrastructure where the risk from unexpected performance is high.

It is important that the risks of any hydraulic design are clearly understood, and that the analysis approach is agreed with Auckland Council, before the detailed design process is commenced.

2.15.1 Whole-of-life

A life-cycle cost is a means of comparing multiple stormwater management options, as well as providing a framework for future expenses associated with the preferred option. For sites where a number of devices are feasible, the Net Present Value (NPV) of each option should be calculated using standard Auckland Council interest and 100-year life factor for capital and maintenance costs. This will determine which are the most economical with regard to all benefits (some generic guidance on costs associated with individual devices is provided). Sound reasons are required for proposing options which will have higher operational costs over their life.

A life-cycle cost:

- Allows for an improved understanding of long-term investment requirements
- Helps decision-makers make more cost-effective choices at the project scoping phase
- Provides for an explicit assessment of long-term risk[6]
- Reduces uncertainties and helps councils determine appropriate development contributions
- Assists councils in their budgeting, reporting, and auditing processes.

Decision-making on the use of stormwater treatment devices needs quality data on the technical and financial performance of these devices. The financial performance of the device will depend on the sum of costs associated with design, construction, use, maintenance, and disposal. Life-cycle costing can be used for structuring and analysing this financial information.

In its simplest form, a life-cycle cost follows the following steps (1 – 11):

1	Specify device parameters	• The device needs to be sized appropriately for the contributing catchment area, including: ○ Device design and expected contaminant removal ○ Landscaping requirements. • Sizing and design parameters should be specified within the life-cycle cost analysis.
2	Specify the lifespan	• The lifespan is the functional life of the asset in years.
3	Specify the life-cycle analysis period	• This is the period of time (in years) over which the model will analyse the costs. • The lifespan may differ depending on the type of device but ensure that the life-cycle analysis period is consistent so that the life-cycle cost results are comparable. • TR 2013/043[7] recommends that the total life-cycle analysis period should not exceed 60 years. • The Auckland Council Cost Benefit Analysis Primer[8] also provides recommendations on the life-cycle analysis period. • Life-cycle analysis periods should take account of fabricated elements containing a treatment device that is generally required to have a design life of 100 years, where the device might require restorative renewal within that lifetime.
4	Specify the base date for life-cycle cost analysis	• Ensure that all costs used in the life-cycle cost analysis have the same base date.

6 Risk in this context can be understood as the quantum of maintenance cost liability that councils may face once assets are vested.

7 Auckland Council TR 2013/043 *Auckland Unitary Plan Stormwater Management Provisions: Cost and Benefit Assessment*

8 Auckland Council TR 2016/018 *Understanding the Costs and Benefits of Planning Regulations: A Guide for the Perplexed*

5	If necessary, specify the inflation rate	• Life-cycle cost analyses do not include an inflation component. However, depending on where the cost data is sourced from, costs may need to be inflated or deflated to ensure all the costs in the model have the same base date. • It is recommended that the inflation index provided by Statistics New Zealand (the Producer Index for “Other Construction Activity” rates) is used.
6	Decide on a discount rate in order to inform the final NPV	• Using a 4% discount rate, in line with Auckland Council recommendations, allows for a cautionary assessment and understanding of long-term maintenance costs.

7	Determine the total acquisition costs	• Total acquisition costs relate to the design, planning, consenting and construction costs of a device. It can include, amongst other things:
		  • Site establishment
		  • Materials
		  • Equipment hires
		  • Locating existing services
		  • Traffic management
		  • Site clearance
		  • Earthworks/excavation
		  • Erosion protection Consent compliance and inspections
		  • Planting/landscaping
		  • Transportation
		  • Labour
		  • Clean-up
		  • Costs of any associated features (e.g. signage, fencing, etc.)
		  • Land costs
		• All total acquisition costs should be documented in the form of a ‘schedule of quantities’ with costs assigned to each element.
		• Unit costs, units and quantities should be clearly specified.

8	Determine the routine maintenance costs	• These are annual costs which relate to routine maintenance events such as mowing grassed areas, weeding, general inspections, debris removal, etc. They include costs associated with relevant administration, inspections, staff training and waste disposal. • In some instances, such as within the Coastal Marine Area (CMA), maintenance works may require consent. Resource consents need to be provided for future routine maintenance. • COSTnz and TR 2013/043[7] provide guidance on the different types of routine maintenance activities for devices. • Maintenance costs need to be specified for each identified item of maintenance, along with unit costs, units and frequencies of maintenance.

9	Determine the corrective maintenance costs	• These are costs associated with significant corrective interventions for the treatment device. • They occur infrequently and can be incurred as a result of large storm events. They include repairing parts, cleaning out sediments and their disposal, replacing filter media, etc. • Any special or irregular maintenance activities should also be included. • COSTnz and TR 2013/045[9] provide guidance on the different types of corrective maintenance activities for devices. • Maintenance costs need to be specified for each identified item of maintenance, along with unit costs, units and frequencies of maintenance.
10	Decommissioning costs	• If it is envisaged that the device will be decommissioned at the end of the life-cycle analysis period, these costs should be included. • If the device will continue to operate, then corrective maintenance needs to be scheduled for the final year of the life-cycle analysis period and decommissioning costs can be excluded.
11	Total discounted life-cycle costs - NPV	• Run your model to determine the total discounted life-cycle costs, i.e. the NPV. • The NPV can be compared for different devices. The lowest NPV equates to the cheapest option.

Taking these steps into account, strategic life-cycle management provides an opportunity to explore various options to extend the longevity of outlet infrastructure. Dynamic adaptation pathways are a risk-based approach which offer councils and key infrastructure stakeholders opportunities for adapting life cycles of their assets to address the uncertainty in climate change and population growth without investing in a possibly costly measure early on. Figure 2-22 highlights a design pathway exemplar of proactive consideration of policy and physical action. By considering numerous triggers and thresholds, the life cycle of an asset can be managed more effectively over time, while allowing for adjustment to limit the possibility of maladaptation.

[9] Auckland Council TR 2013/045 *Living Roof Review and Design Recommendations for Stormwater Management*

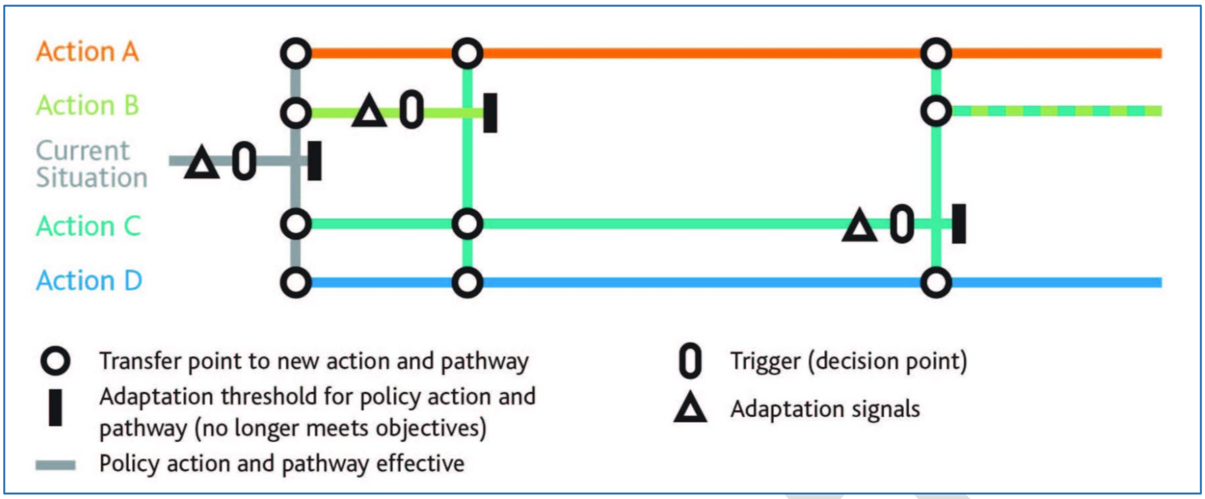


Figure 2-22: Example of adaptive policy planning for an Auckland Council Asset. Source: Lawrence et al 2020. Adopted from Haasnoot et al (2013).

Further information can be found in:

- TR 2013/043: *Auckland Unitary Plan Stormwater Management Provisions*: *Cost and Benefit Assessment*, Auckland Council
- TR 2016/018: *Understanding the Costs and Benefits of Planning Regulations: A Guide for the Perplexed,* Auckland Council
- Standards Australia/New Zealand. (2001). *Life cycle costing – An application guide* (AS/NZ4536:1999). Standards Australia, Homebush, NSW, 2001
- *Dynamic Adaptive Pathways Planning: A Guide,* Auckland Council (to be issued).

3.0 Design guidance

3.1 References

Open channel flow and hydraulics overall is a very broad and specialist subject that is required to be applied when designing transitions between surface, open-channel and pipe hydraulic systems. It is not intended that this guidance replicate the full depth of this subject matter. The following textbooks and sources are considered industry standard:

- Chow V.T. 1959: *Open-Channel Hydraulics*. New York: McGraw-Hill
- Chaudhry, M.Hanif. (2008): *Open Channel Flow,* Springer Publishing Company
- Elger D.F. Williams B.C. Clayton T. Crowe C.T. and Roberson J.A. (2014), *Engineering Fluid Mechanics*, 10th Edition
- Various, *Australian Rainfall and Runoff Guidelines 2019*, Australian Government, Geoscience Australia
- Warner J.C. et al, (2009): *HEC22 – Urban Drainage Design Manual*, 3rd Edition, US Federal Highway Administration
- Thompson P.L, Kilgore, R.T: (2006): *HEC14 – Hydraulic Design of Energy Dissipators for Culverts and Channels,* 3rd Edition, US Federal Highway Administration
- Witheridge, G.M. 2023, *Background to Rock Sizing and Rock Roughness Equations*. Catchments and Creeks, Bargara, Queensland.

3.2 Design processes

3.2.1 Feasibility design

During design, engineers should consider site feasibility, and the implication of development on a proposed section of land. In doing so, and in scoping a project, they should consider the following aspects:

- Agree overarching place outcomes with asset owners including Auckland Council, Auckland Transport, NZ Transport Agency Waka Kotahi, KiwiRail and mana whenua.
- Understand the project budget and the consenting and approvals process.
- Foster early involvement by relevant experts to incorporate an understanding of the values associated with place, for example (but not limited to):
    - Landscape character and values (including Outstanding Natural Features and Landscapes).
    - Social-economic and ecological values.
    - Historic and cultural narratives.
    - Land and water investigations.

  - Resilience (resilience of the infrastructure from an intergenerational perspective and resilience of the land we are trying to protect – meaning that the land which can be used, e.g. residential land, productive land and features and landscapes that are of particular character and relevance can support, and is protected from the effects of erosion, flooding and inundation).
  - Recreation values, and
  - Liveability for communities.
- Understand the site, engineering constraints and who needs to be involved:
  - The necessity of the asset should be evaluated, and its intended purpose (including the purpose relative to its proposed location).
  - Assets should be monitored, maintained and accessed relatively easily throughout its operational life.
  - Note the current and future land use(s), land cover and landform. Assess how the asset will be sustainable, (in coastal environments through the integration of coastal resilience), response to land use, response to scour and erosion, ecological and cultural significance.
  - Identify opportunities for design of multifunctional places and interaction with the environment.
  - Is the outlet going to be in an area where the community has a relationship with the landscape and water? What is the extent of the relationship, and who are the stakeholders (including mana whenua, asset owners, community, and environmental groups)?
- Consider a nature-based solution that uses the natural landscape to catch, store and improve the quality of water, and protect adjacent land, resources, and assets:
  - Natural land and / or water-based treatments or innovations, such as water sensitive design, green outfalls, eco-reefs, wetlands, creating room for rivers or living seawalls.
  - Design to accommodate floodwaters.
  - Integrate with the natural environment, heritage, culture, and recreational values, in balance with meeting engineering needs, and providing the optimal commercial, educational, and economic uses consistent with environmental and social concerns.
- Identify opportunities to enhance connectivity, for both people and aquatic life (animals and plants):
  - Links to other places and / or features
  - Construction, maintenance, and decommissioning access
  - Accessibility and access for all
  - Personal safety and Crime Prevention Through Environmental Design (CPTED), including wayfinding
  - Ecology and habitat connectivity.
- Consider aesthetics, and how the asset might look in the short and long term.

3.2.2 Option assessment and concept design

Upon completion of the feasibility study, option assessment and conceptualisation should further evaluate the suitability of an asset's design.

Options are to be integrated across engineering and design disciplines and are to be developed in meaningful and ongoing relationships with asset owners, stakeholders, mana whenua, community, and environmental groups, also in conjunction with relevant experts. Key considerations during conceptual design of infrastructure include:

- Does the preferred option fit into the landscape in terms of scale and agreed overarching outcomes for place?
- Consideration of a risk-based approach to design requirements allowing for adaptation planning.
- Consideration of multifunctionality and futureproofing.
- Buildability and how the design meets local and national design guidance, building codes and standards. The correct experts should also be consulted as appropriate.
- Is there buy-in from end users - mana whenua, the community, and stakeholders?
- Are there any plans by third parties with the proposed land which cause a conflict?
- Does the concept:
    - Respond to recommendations and design objectives in relevant expert studies?
    - Respond to hazards – such as flooding, storm surge and shoreline scour impacts?
    - Improve the surrounding environment through re-vegetation with native / indigenous species?
    - Use vegetation and rocks increasing energy dissipation and wave attenuation resiliency?
    - Manage effects of stormwater, sediment and sand movement / retention and pollutants?
    - Promote and provide suitable habitat for nesting animals and aquatic animals?
    - Use resilient, enduring and, wherever possible, local materials?
    - Where proprietary or bespoke systems are used, are they designed for durability and self-sufficiency?

3.2.3 Preliminary and detailed design

Providing sufficient detail at inlets and outlets is an integral process to achieve the agreed project outcomes and objectives, bring to life narratives from engagement and concept design, and translate them into on-the-ground experiences through design details that embody:

- Landscape / urban / architectural design in conjunction with engineering design and ongoing stakeholder and mana whenua engagement.

- Partnering with experts and asset owners to achieve overarching outcomes through the design process, considering risk-based design conditions which allow for future resilience and trigger-based adaptation interventions. See Figure 2-22 above.
- Use of land and features (nature-based solutions) wherever possible.
- Response to approval conditions, e.g. Resource Consent.
- Embodiment of mana whenua values in detailing of features, artwork, etc. follows a co-design process in genuine partnership with mana whenua, and involves the right people.
- Existing material reuse, recycling, or use of lower carbon materials wherever possible to save energy and reduce carbon emissions.
- Consider how new materials may be able to be reused or recycled through operation and at decommissioning.
- Consider material tolerances to conditions, e.g. to salt, and the design life required.
- Ideally, a coastal outfall should be situated at the back of the beach through either the seawall or coastal cliff.
- Consider combining outfalls, such as redirecting discharge points to headlands and away from central beach areas.
- Carefully consider erosion around the structure caused by waves and discharge velocity scour.
- Where possible, incorporate the intake/outfall into a suitable structure or environment, such as:
    - The rock toe of a revetment
    - The bedrock foundations of a sea wall
    - Ancillary structures, such as viewing platforms or jetties
    - Local landscaping.
- Consider the discharge may form a channel along/across the beach, posing a hazard. Therefore, limit the discharge velocity to the beach material's maximum velocity for erosion control.
- Structures could include energy dissipators to manage high-velocity flows effectively (see Table 3-9 below).
- Integration with the landscape: use of local materials, colour and appearance of structures, and features to meet project outcomes and objectives.
- Getting the right plant in the right place – using correct planting palettes for the place, cross-checking with planting guides and ecology. Working in partnership with relevant experts to provide clear direction to contractors and maintenance teams about where to locate plant species on site to maximise hydraulic performance, provide or enhance habitat and achieve water quality outcomes.
- Opportunities for mana whenua and community involvement in implementation where appropriate.

3.3 Hydraulic assessment

When undertaking a hydraulic assessment of any intake/outlet system, a number of aspects need to be considered, e.g.:

- Is the inlet/outlet entering/discharging a channel, or a culver or a pipe? If a pipe, will it be completely full?
- Is the outlet submerged, or partially submerged?
- Is the outlet unsubmerged (brink depth)?
- The slope of the outlet?
- Is the outlet discharging as a jet which will abruptly expand?
- How will the hydraulic jump be managed?
- Are there any local head losses due to components such as screens or backflow devices?

HEC14 – Hydraulic Design of Energy Dissipators for Culverts and Channels provides calculations and examples of cases including these aspects.

3.3.1 Flow conditions

In hydraulic assessments of inlets and outfalls, managing energy levels within the flow is crucial for ensuring system stability and minimizing potential erosion. A key strategy to achieve this is by increasing the cross-sectional flow area, which directly reduces the energy by lowering the velocity head and increasing frictional losses. However, the effectiveness of this approach is highly dependent on the flow regime at the outlet. Understanding the characteristics of sub-critical, critical, and super-critical flows, as well as the formation of hydraulic jumps, is essential for designing systems that control energy dissipation and manage the associated environmental impacts effectively.

It is critical to note that this is dependent upon the flow regime at the outlet.

Table 3-1: Flow condition characteristics

Sub-critical flow	• Defined as having a Froude number < 1. • It is described as slow and deep. It is deeper than the critical depth for that section and is dominated by gravitational forces and behaves in a stable way. • Sub-critical flow is considered downstream controlled and increases with depth upstream to overcome losses such as friction.
Critical flow	• Defined as having a Froude number of one. • It flows at critical depth and has the minimum possible energy level for the flow rate. • It is considered unstable as slight changes in energy will cause it to jump to either sub-critical or super-critical regimes.
Super-critical flow	• Defined as having a Froude number > 1. • It is described as fast and shallow and is dominated by inertial forces and behaves in an unstable way.

	• Super-critical flow is considered upstream controlled, transfers disturbances downstream and increases in depth downstream with losses. • Expanding the channel section to decrease velocity, as noted above, will potentially cause a hydraulic jump to form as the flow reverts to sub-critical flow.
Hydraulic jumps	• Standing waves that form where super-critical flow transitions to sub-critical flow. • Hydraulic jumps are turbulent, dissipate energy and can erode unprotected banks. • It is usually desirable to control where hydraulic jumps form so that erosion protection can provided. • If it is within the pipe, it can be controlled more effectively, however, it may add to increased pressure, surging. • Outside of the pipe can allow for energy to be dissipated over a wider area but may lead to less controlled flow patterns making downstream management more complex. • The air entrainment that may take place at a hydraulic jump can impact water quality, particularly in sensitive ecological areas. Designers should consider the potential environmental impacts of the jump, including the introduction of oxygen, mixing of sediments, and effects on aquatic life. • The type of hydraulic jump that will form can be assessed by the Froude number of the flow, with higher Froude numbers resulting in stronger jumps that dissipate more energy. The next section describes different types of hydraulic jump based upon their defining characteristics.

3.3.2 Froude number

Froude number (Fr) is a dimensionless number used in hydrodynamics to describe different flow regimes (e.g. sub-critical flow (slow and deep) and super-critical flow (fast and shallow) of open channel flow. The Froude number is critical for assessing energy dissipation and hydraulic jumps at or near outlet structures.

Froude number relationship for all cross-section shapes: $$Fr = V/(gD)^{0.5}$$ *Equation 2*

Where:

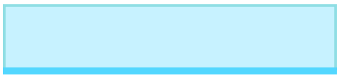
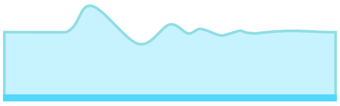
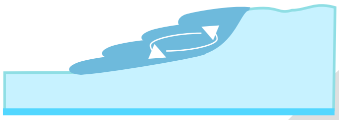
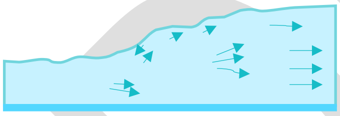
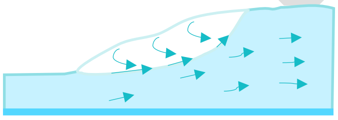
$V =$ Velocity, m/s

$D =$ Hydraulic mean depth, m (cross-sectional flow area / width of the free water surface)

$g =$ Gravitational acceleration, m/s^2

The following guide outlines how different Froude numbers affect flow conditions at outlets, focusing on their implications for erosion risks and the need for energy dissipation measures. This information is particularly relevant for rectangular open channels and partially full pipes:

Table 3-2: Outlet erosion issues (after HEC14, Ven Te Chow, 1973 and US Bureau of Reclamation)

Froude No. at outlet	Considerations
<1	• Flow is sub-critical (described as slow and deep), and no hydraulic jump can occur.
1.0 	• Flow is critical, and no hydraulic jump can occur. • However, the flow is unstable and slight changes in energy, e.g. friction, flow, hydraulics or condition can cause the hydraulic regime to flick to super-critical (>1) or sub-critical (<1). • Designers should consider the sensitivity of the design to change in conditions and how that may affect the outlet velocity and energy dissipation requirements.
- 1.7 	• Flow is super-critical (described as fast and shallow). • Any hydraulic jump will show surface undulations and is therefore called an undular jump. It is a weak jump that will dissipate little energy. • Outlets 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 should be roughly twice the incoming depth and the exit velocity is about half of the upstream velocity.
1.7 – 2.5 	• Flow is super-critical (described as fast and shallow). • Any hydraulic jump will show surface rollers, but the downstream water surface remains smooth. • This is termed a weak jump and the energy loss due to the jump is relatively low. • Outlets are likely to need a riprap or concrete baffle block arrangement.
2.5 – 3.0 	• Flow is super-critical (described as fast and shallow). • Any hydraulic jump will be characterised by an oscillating jet that fluctuates from the bottom of the channel to the top, resulting in turbulence. • The jet oscillations can cause large waves to travel downstream which can cause erosion of earth banks. • Outlets and downstream banks are likely to need riprap protection, or the outlet may be provided with a concrete baffle block arrangement.
>3 with high velocity flows or large vertical drops 	• Flow is super-critical (described as fast and shallow). • 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 the information in this section is sourced.

3.4 Importance of hydraulic jumps at outlet structures

Hydraulic jumps occur when super-critical flow (fast and shallow, with a Froude number > 1) transitions to sub-critical flow (slow and deep, with a Froude number < 1). This transition results in a sudden rise in the water surface and a significant reduction in flow velocity, effectively dissipating kinetic energy. Hydraulic jumps are critical in managing energy dissipation at outlet structures, whether they occur inside or outside the pipe.

Hydraulic jumps can be both beneficial as well as detrimental simultaneously. When properly managed, they efficiently dissipate energy, reducing the risk of downstream erosion. However, if uncontrolled, they can create undue erosion, particularly where flow patterns become less predictable.

Inside a pipe, controlling the location of a hydraulic jump can help manage internal pressures and minimise surging, but it may also increase the risk of localised high-pressure zones. Outside the pipe, hydraulic jumps allow energy to be dissipated over a broader area, reducing the intensity of the flow and its erosive potential. However, this can lead to less controlled flow patterns, making downstream management more complex.

Understanding and controlling hydraulic jumps are essential for ensuring the stability and longevity of outlet structures, as well as for protecting downstream environments from erosion and other forms of damage. The *Hydraulic Design of Energy Dissipaters for Culverts and Channels* (HEC 14) provides detailed guidance on designing energy dissipation measures to effectively manage the impacts of hydraulic jumps, whether they occur inside pipes or in open channels.

3.5 Inlets

At inlet structures which capture upstream flow to be directed into a different part of the network, scour, erosion and resuspension of sediments can be reduced by controlling energy and flow velocities at the inlet device. Methods to manage in-flow velocities, include manipulating inlet grades, dispersing inflows, having submerged outlets discharging into permanent water and energy dissipation.

3.5.1 Flows

Flows can enter devices as distributed flows (i.e. from an overland flow) or as concentrated flows (i.e. from pipes). This section provides design considerations for flows from a piped network as well as overland flows (Figure 3-1).

3.5.1.1 Inlet from channelised flow

For all concentrated inflows, energy dissipation at the inflow location is important to minimise any erosion potential. For small devices, this can be achieved with:

- Rock benching and/or dense vegetation
- Rain gardens where concentrated flows are received
- A flow distribution weir or small forebay may be required.

Additional designs might include:

- **Riprap:** The design of rock riprap for energy dissipation is covered in Section 3.8.1.3.
- **Submerged inlet:** An inlet pipe which discharges below the permanent water level can also reduce flow velocities and provide sufficient energy dissipation. However, re-suspension of sediments as a result of turbulence should be avoided when designing a submerged inlet by providing a large pipe size with sufficient water depth and space between the inlet pipe and opposite bank.

3.5.1.2 Inlet from overland flow

An advantage of flows entering a device in a distributed manner (i.e. entering perpendicular to the direction of the device) is that stormwater enters as shallow sheet flow, which maximises contact with vegetation, particularly on the batter receiving the distributed inflows.

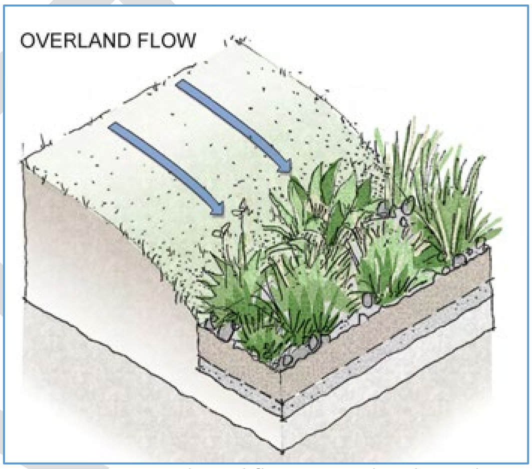


Figure 3-1: Distributed flow examples through overland flow inlet.

Source: North Shore City Council "Bioretention Guidelines", 2008

Inlets should :

- Disperse flow evenly across the treatment device at the lowest possible velocity
- Be positioned to maximise residence time and not allow short-circuiting through the device
- Be elevated enough to avoid elevated water levels (temporary or permanent) in the device, as this can cause issues such as blockage and re-suspension of sediment. 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.

<u>Inlet velocity control</u>

Energy and flow velocities from sheet flow can be controlled by:

- Dispersing low velocity flow across a landscaped area or through a grassed filter strip
- Dispersing flow through kerb cuts and across pavements and/or past wheel stops for parking areas
- Dispersing flow through a spreading trench around the perimeter of a bioretention area.

It should be noted that in some cases, overland flow is intended to be captured by a channel, stream or pipe and in these cases, the inlet would be designed to capture as much flow as possible at a control point rather than disperse the flow.

3.5.1.3 Vegetation strips and planting

A batter slope is often referred to as a filter strip - to function most efficiently it requires dense vegetation and shallow flow depths below the vegetation height. Planting of inlet (and outlet) structures should be considered carefully and should not obstruct flows or cause maintenance issues.

The filter strip provides good pre-treatment (i.e. significant coarse sediment removal). Filter strips provide excellent pre-treatment, filtering stormwater as a first step in a treatment train.

3.5.1.4 Kerb cuts

Where kerbing is required for vehicle containment or path-user safety, and drainage is to a stormwater treatment device such as a swale or rain garden, the kerbing may be interrupted at intervals to create inlets into the stormwater device. The cuts allow for even distribution of road run-off into the treatment device.

Kerb size: Kerb cuts should normally not exceed 300 mm in length and be at least 600 mm apart, with inlet capacity designed as a weir (Auckland Transport Design Manual: Section 1). In a car park, these inlets can also be combined with wheel stops.

Kerb shape: Kerb inlets aligned perpendicular to the flow path should be designed using the broad-crested weir approach. However, where the inlet is orientated parallel to the flow path, the opening length should be increased (or multiple inlets used) to minimise the potential for flow bypass. The shape of the inlet can also greatly affect the behaviour of both low and high flows.

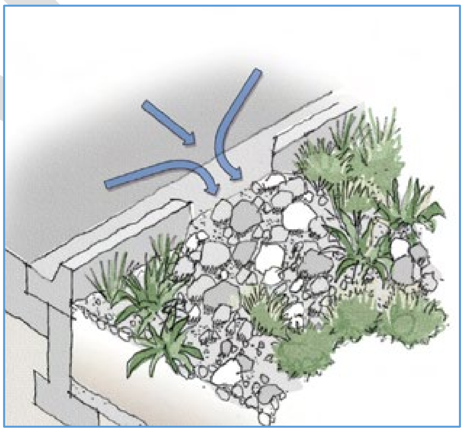


Figure 3-2: Concentrated flow examples through a kerb break

Source: North Shore City Council "Bioretention Guidelines", 2008

Desirable attributes of a kerb inlet are:

- Rounded or tapered kerb edges (with sufficiently large radius for the design flow rate)
- Concrete apron with a grade of approximately 10% to prevent localised ponding and sediment build-up on the road
- Energy dissipation at the apron toe using grouted and/or wire mesh encased rock (spacing of rock should not create channelled flow).

Flow diversion using raised structures within the kerb and channel should not be used as this poses a potential hazard to bicycles and motor vehicles.

Set-down: Where flush kerbs are used, a set-down from the pavement surface to the vegetation is needed. This provides a space for sediments to accumulate off the pavement surface. Generally, a set-down from kerb of 60 mm to the top of vegetation (if turf) is adequate; total set-down to the base soil is therefore approximately 100 mm (with turf on top of base soil). This can be part of the set-down required for the provision of detention storage above the surface of the device.

3.5.1.5 Level spreaders

Level spreaders disperse flows and promote low velocity sheet flow. They are commonly installed in the following inlet situations:

- Upstream of filter strips or riparian buffer areas to help prevent rill erosion or preferential flow paths
- As inlets to rain gardens, swales, ponds and wetlands (Figure 3-3).

Figure 3-3: Level spreader outlet with energy dissipation onto grassed filter strip

Level spreaders can also be used when a stormwater management device discharges onto land and dispersion is required to avoid scouring and erosion of an overland flow path (e.g. discharge from a rain tank into an overland flow path). This is not recommended at the top of coastal cliffs/banks where saturated soils from infiltration can exacerbate slope instability (see Table 3-7).

Level spreaders can have several forms including wood or concrete beams parallel with the ground contours, subsoil drainpipes or gravel filled trenches. Their purpose is to spread discharges from a system at low velocities over a sufficiently large area to avoid concentrated flow.

Erosion protection may still be needed:

- Downstream, especially where there is a drop from the outlets
- Upstream, to avoid undercutting.

Flow / level spreaders should be level to achieve even discharge across their length. The design should consider the construction of the flow spreader such that level construction can be achieved with only moderate work and is not liable to settlement over time.

3.5.2 Bypass design

Some stormwater devices require a high-flow bypass to divert flows in excess of the design storm in a safe and controlled manner, away from the treatment device to avoid erosion and re-suspension of sediment. Bypasses are generally designed as part of an inlet structure by including a diversion weir, e.g. the weir can be placed in an open channel to divert flows around a wetland and into the stream.

Generally, the bypass is required to convey the 10% AEP event, in order to comply with Section E1.3.1 of the New Zealand Building Code. Consideration also needs to be given to exceedance flows, risks and hazards to determine whether these bypass flows should be increased to a higher standard (e.g. 1% AEP) or whether a separate overland flow path should be designed for.

The high-flow bypass inlet may be configured in following ways:

- A grated riser within the detention zone, to convey flows in excess of the first flush into the public stormwater system
- An inlet designed to enable flows in excess of the first flush to bypass the device and be conveyed into the public stormwater system. Where possible, this is the preferred option because it reduces potential damage to devices in large storm events.

All bypass designs are required to be non-blocking to minimise the risk of flooding. Safe overland flow paths should also be provided for all flows in excess of the bypass capacity.

3.5.2.1 Off-line bypass design

An off-line bypass routes high flows around the device once the ponding area is full and reduces the risk of re-suspension of captured pollutants and mulch during high flow events. Off-line configuration is recommended where high contaminant loads are likely, or where high velocities are expected during high flow events.

An off-line bypass for bioretention treating road runoff is shown in Figure 3-4. Initially, runoff enters the bioretention device through the kerb cut. Once the ponding area of the cell is full, any additional flows bypass down the channel to the high flow inlet (e.g. kerb inlet or grated catchpit).

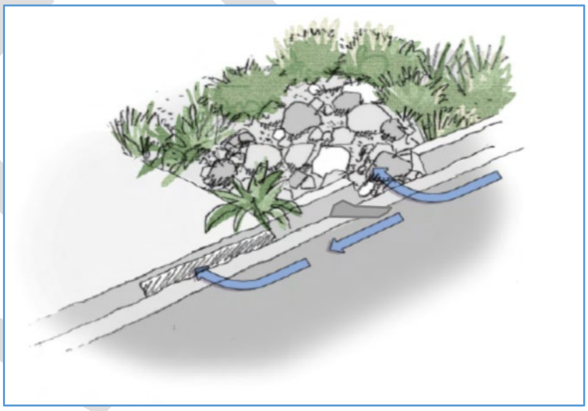


Figure 3-4: Example of an off-line high flow bypass

3.5.2.2 On-line bypass design

An online bypass consists of an overflow riser within the bioretention ponding area. Figure 3-5 shows two possible configurations:

- The downturned elbow overflow is suitable for small (e.g. domestic) devices. It retains floatables, such as mulch, within the device, and minimises the likelihood of blockage.
- The manhole with a scruffy dome overflow riser is suitable for large (e.g. commercial) devices. The scruffy dome is resistant to blockage; however, there may be some loss of mulch and floatables during bypass. Using non-floating mulch in the device is important in this instance.

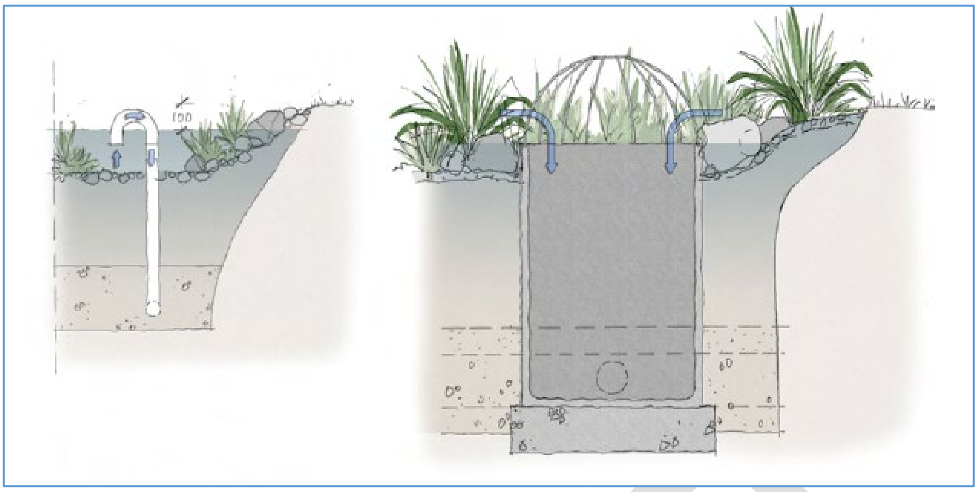


Figure 3-5: Examples of online bypasses for bioretention devices
Riser with downturned elbow suitable for small rain gardens (Left) and manhole with scruffy dome for large rain gardens (Right).

3.5.2.3 Flow splitters

Flow splitters can be incorporated into inlet manholes to divert large event, high-velocity flows away from a treatment device to avoid scour and sediment re-suspension. The water quality volume is passed through the device with excess flows being diverted. This is not possible where the treatment device also provides detention.

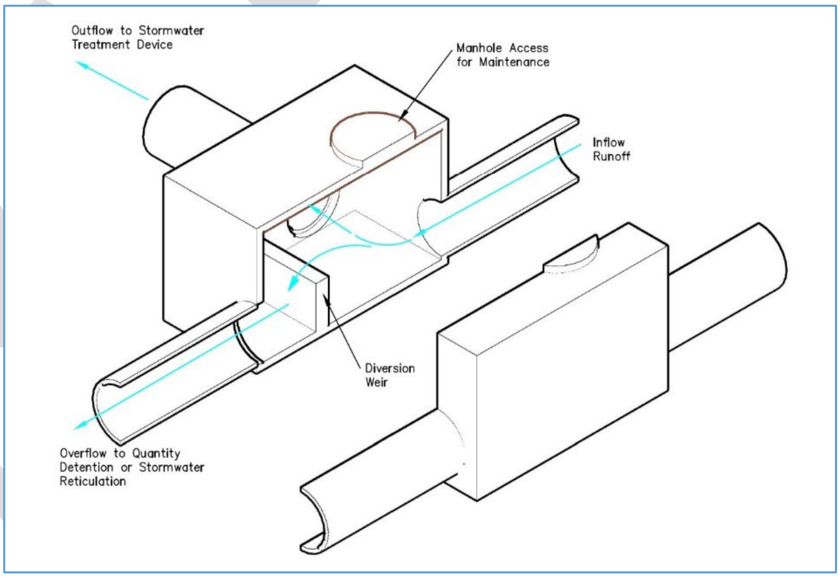


Figure 3-6: Weir splitter in manhole

Flow splitters should be specifically designed depending on the situation but are often achieved using a weir formed inside a manhole (Figure 3-6). Runoff enters the manhole with normal flows (water quality volume) discharging to the device and larger flows overtopping the weir and discharging through a second outlet.

Smooth benching and concrete finishing are important so that turbulence is minimised, and erosion is avoided. The flow splitter should allow for maintenance access and be designed to prevent debris being trapped.

3.6 Outlets

Outlets should be designed to address all flow conditions (including above-maximum design flows), to be safe and protect the receiving environment. Low-energy discharges can be promoted by lower pipe grades; large-sized outlet pipes if the outlet is submerged; and reducing head through drop outlets. Providing downstream energy dissipation will be required to compensate for higher velocities and allow flow transitions from engineering structures to more natural flow regimes.

Except for within the treatment device itself where sedimentation may be required, the design should prevent sedimentation from occurring by positioning the outlets near the surface of the ponding zone and above the base sediments to avoid sediment re-suspension.

The system must be designed such that minimum velocities comply with the stormwater section in the Auckland Council *Code of Practice for Land Development and Subdivision*.

Potential consequences of flows in excess of maximum design flows should be considered and mitigated by the design. Causing a hazard (flooding) or any erosion with the potential to damage buildings, highways or other infrastructure should be prevented. Outlet design can reduce erosion potential by:

- Mimicking natural hydraulic features where possible
- Avoiding drops from the device outlet to the watercourse
- Minimising grade to the outlet
- Aligning outfall discharge with stream flow so that jetting or high velocity flows against opposite stream banks are avoided
- Armouring erosion-prone surfaces by suitable measures such as riprap and vegetation
- Reducing flow velocities and dissipating energy.

It is common for outlet discharge locations to have steep outlet pipe grades and the potential for downstream erosion. Key design practices therefore should include:

- Obtain as much energy dissipation as possible within the service outlet manhole. 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 to avoid erosive turbulence, or 'water-blasting' 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.
- Outlets entering natural streams should be set back from the main channel to minimise energy dissipation within the stream. Ephemeral stream tributaries or gullies are ideal for providing setbacks and positions for energy dissipation while also retaining the overland flow path function.

- Penetrations through pond bases and walls such as manhole risers and outlet pipes should be suitably sealed and protected against water seepage, internal erosion and piping. As a minimum, measures such as waterproofing with bentonite paste/liners or similar, puddle flanges, toe drains, and filter diaphragms should be considered,. A suitably qualified geotechnical engineer should be involved in the design.
- Manholes and risers used as outlets should be equipped with scruffy dome-type grilled covers, hinged with a padlock ring for maintenance. For devices located in urban areas, more aesthetic alternatives may be submitted for approval by Auckland Council, subject to an assessment of the risks and consequences of blockages.

Coastal outlets are elaborated on in Section 3.7.

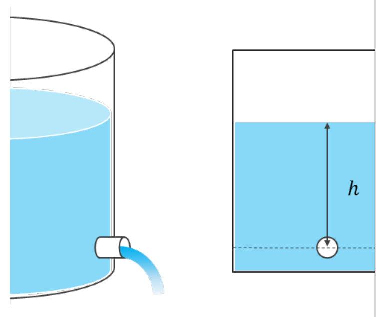
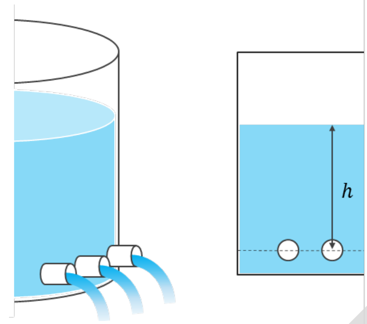
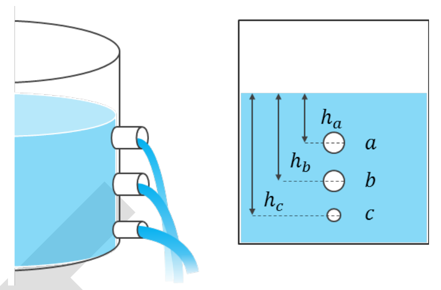
3.6.1 Orifice and low-flow outlets

Orifices are a specific type of outlet where potential energy (e.g. elevation head) is converted to kinetic energy (velocity) and generally convey low flows. Considerations include:

- Generally, service outlets should have orifices no smaller than 50 mm in diameter to avoid blockage. This requirement can be relaxed for orifices for multiple orifice outlets (e.g. multi-stage outlets or low-flow control on rain tanks) but still requires a minimum 30 mm diameter.
- Orifices or low-flow outlets should be located a minimum of 150 mm from the base of a device (excluding rainwater tanks where in some instances, the minimum is 50 mm) to prevent re-suspension of sediment.
- Low-flow outlets or orifices are prone to blockage. If the design includes a reverse sloping pipe or a siphon, then water will be withdrawn below the water surface and the outlet will be less prone to blockage by floating debris.
- Low-flow outlets or orifices should be designed to mitigate any adverse temperature effects (usually associated with ponds or unshaded channels). The outlet can collect the cooler, lower water by including a siphon, baffle plate, or reverse-sloping pipe.

A variety of design options for orifice outlets with corresponding equations is presented in Table 3-3.

Table 3-3: Orifice outlets

Type	Single orifice	Multi-orifice at same level	Vertically spaced orifices
Diagram			
Equation	$Q = C_d A(2gh)^{0.5}$	$Q = \mathrm{n} \times C_d A(2gh)^{0.5}$	$Q = C_d A(2gh_a)^{0.5} + C_d A(2gh_b)^{0.5} + C_d A(2gh_c)^{0.5}$
Comments	Generally used to control low flows Q = Discharge through the outlet, m/s A = Area of orifice, m^2 g = Gravitational acceleration, 9.81 m/s^2 h = Elevated head acting on orifice centreline	Generally used to control low to medium flows. n = Number of orifices C_d = coefficient of discharge for the orifice: C_d = 0.61 – sharp-edged C_d = 0.98 – rounded C_d = 0.80 – short tube C_d = 0.51 - Borda	To control flows from different design storms, i.e. WQV, SMAF, 10% AEP

3.6.2 Outlet structure: inlet control and outlet control

Typical design considerations for an outlet structure include whether a system is inlet or outlet-controlled. In this context, the inlet is defined as the inlet into the outlet structure. The outlet is the final outlet into the receiving environment.

Inlet control is when flow through the outlet structure is controlled by how much flow can get into the inlet, and outlet control is when the flow through the outlet structure is controlled by how much flow can exit the outlet.

For moderate flows (Flow Condition 1 in Figure 3-7), the top of the drop shaft acts as a sharp-crested weir. When the water level above the riser reaches a certain level (Flow Condition 2 in Figure 3-7), the riser is submerged and will act as an orifice and its inflow should be calculated using the orifice equation.

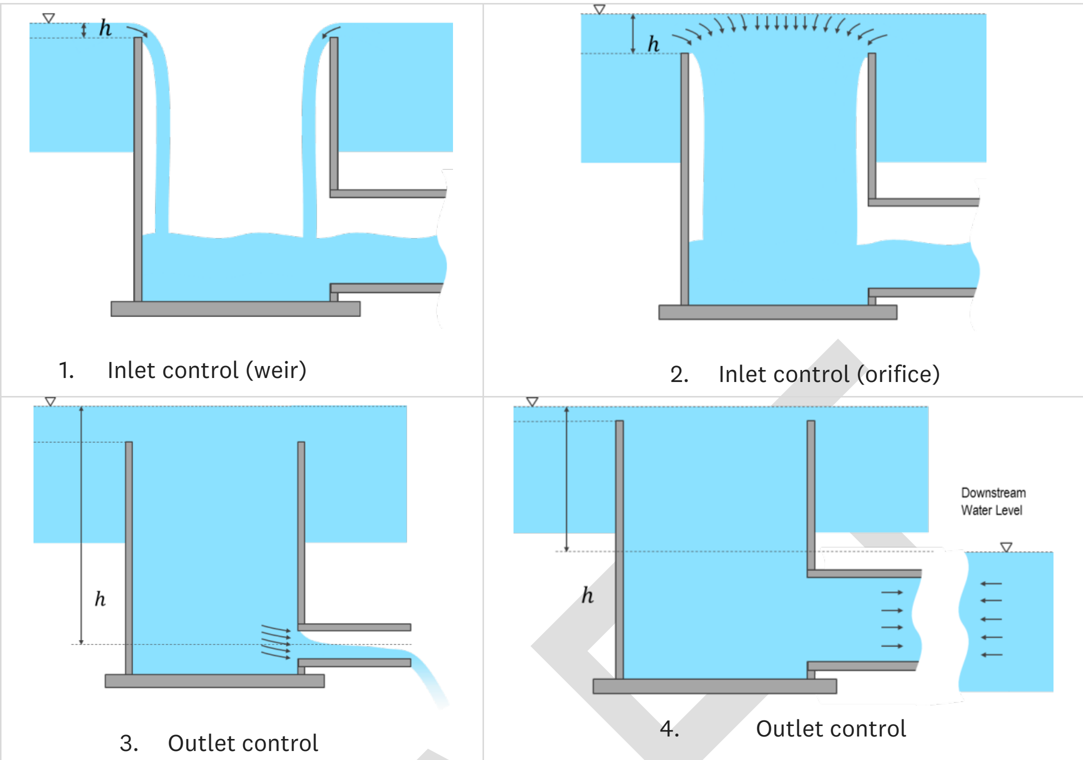


Figure 3-7: Flow conditions for inlet and outlet flow control

The outlet pipe can also control the amount of flow through the outlet structure, with either Flow Condition 3 or 4 (Figure 3-7). These two cases can be calculated in the same way as a typical culvert.

Important design factors associated with inlet control are headwater depth, cross-sectional area and entrance conditions (roughness, length and outlet conditions are hydraulically unimportant when calculating flow rates and velocities in a device that is controlled by its inlet).

Outlet control is dependent on all hydraulic factors upstream of the outlet tailwater, such as friction through the outlet, the difference between headwater and tailwater depth, inlet condition, and pipe slope. Under outlet control, flow is typically subcritical. Outlet control allows the designer to utilise friction losses and tailwater depth to help reduce velocity.

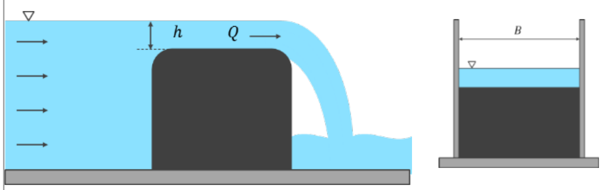
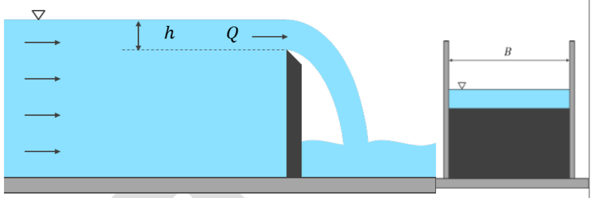
3.6.3 Outlet weirs

3.6.3.1 Broad-crested weir (emergency spillway)

Emergency spillways from wetlands and ponds should be designed as a broad-crested weir. The emergency spillway should be sized to convey the maximum flow which can enter the device. The spillway will work when the service outlet is partially or totally blocked or when its maximum design capacity is reached. The minimum freeboard above the maximum water level discharged by the spillway should be 500 mm. This will be the minimum top level of the embankment of the device. The emergency spillway should be armoured when the discharge velocity is greater than 2 m/s for more than one-hour duration.

The emergency spillway section is normally designed as a trapezoidal broad-crested weir as specified in Table 3-4.

Table 3-4: Weir structures

Type	Broad-crested weir (rectangular)	Sharp-crested weir (rectangular)
Diagram		
Equation	$Q = 1.7Bh^{\frac{3}{2}}$	$Q = 1.8Bh^{\frac{3}{2}}$
Comments	Used to design emergency spillways from ponds and wetlands Q = Discharge through the outlet, m^3/s B = Length of the weir, m h = Hydraulic head, m	Used to design internal overflow weirs inside manholes, flow splitters, etc.

3.6.3.2 Sharp-crested weir

A sharp-crested weir consists of a vertical flat plate with a sharp edge at the top as specified in Table 3-4 and illustrated in Figure 3-8. Common weir constructions are the rectangular weir and V-notch weir. The V-notch weir is often used for flow monitoring purposes.

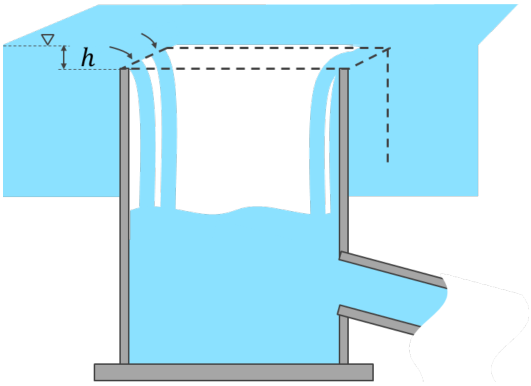
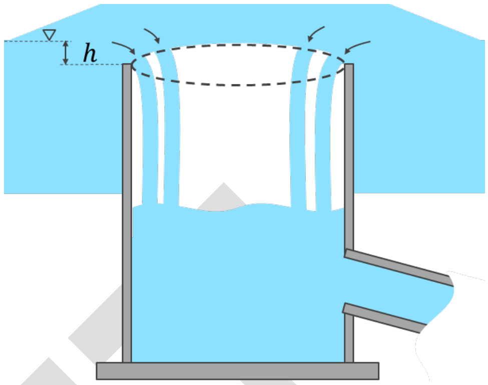
Sharp-crested weirs can be used in different combinations as part of an outlet manhole riser. The top of the drop inlet of a manhole riser will also act like a sharp-crested weir.

Figure 3-8: Sharp-crested V-notch weir

3.6.3.3 Drop inlets and manhole risers

A large category of outlets from stormwater management devices are manhole riser outlets, i.e. circular drop inlet and box weirs as per Table 3-5. The manhole riser often includes low-flow orifices and multi-stage weirs with high flows entering across the entire rim of the manhole (Figure 3-9). Key design issues include debris control, access (for maintenance and preventing unauthorised access), fish passage and safety.

Table 3-5: Drop inlet structures

Type	Box weir	Circular weir
Diagram		
Equation	$Q = 7wh^{\frac{3}{2}}$	$Q = 1.8Dh^{\frac{3}{2}}$
Comments	Used for the design of square manhole risers/drop-inlets Q = Discharge through the outlet, m/s h = Hydraulic head, m w = Length of the side, m	Used for the design of circular manhole risers/drop-inlets D = Diameter of inlet, m

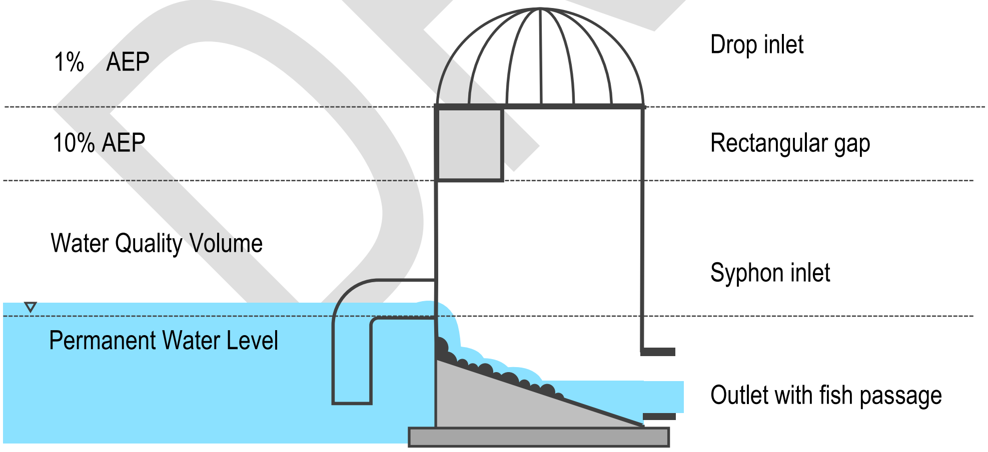


Figure 3-9: Cross-section of the typical vertical outlet structure

3.7 Coastal outfalls

Coastal environments are inherently dynamic, as seen in Figure 3-10, being subject to constant change. In most cases, a coastal outfall will be sized with the same requirements as other outlets, as described in Section 3.6. A coastal outfall will likely require the consideration of the additional design conditions, e.g.:

- Varying beach levels and coastal erosion, as noted in Section 2.11. In addition, the coastline may be subject to accretion and the outfall may be at risk of being buried; or receding, in which case potential future shoreline recession will need to be estimated. See *Predicting Auckland's Exposure to Coastal Instability and Erosion*[10], which provides more detail into the ASCIE maps, seen in Figure 2-20 above, and provides a basis for erosion considerations in the Auckland region.
- The lowest tide needs to be considered for the minimum tailwater depth definition as well as for construction to assess the requirement to construct in the wet. This is often defined as mean low-water spring (MLWS) tide which is a measure of low tide based on a statistical exceedance of low tides in a month but may also need to consider mean low-water neap (MLWN) tide which is when the difference between high tide and low tide is minimal and hence the lowest water level at the site will be higher than MLWS. The lowest astronomical tide (LAT) would be lower than this, as it is the lowest tide that can occur under average meteorological conditions over 18 years. The maximum velocity from the outfall may need to consider MLWS tide as the tail water condition, however the likelihood (joint probability) of that tide occurring at the same time as the storm event would need to be assessed.
- Mean High Water Springs (MHWS-10), which is the water height exceeded by 10% of all high tides at the site, is also available via the LINZ website.
- To determine the maximum tailwater depth above the coastal outfall, Extreme Sea Level is to be defined for system hydraulic performance calculations. Extreme Sea Level is a result of coastal storm tide and surge at a 1% AEP, or 100-year ARI in line with the AUP and can be found in the report *Auckland's Exposure to Coastal Inundation by Storm-tides and Waves*[11], but may require a site-specific study if the tailwater level is crucial to the function of the stormwater system. In addition, a sea-level rise component may be added, typically 1 m at the time of the Unitary Plan for a 100-year allowance, however, updated projections are provided in the *Coastal Hazards and Climate Change Guidance*[12] but other timelines and projections may be considered from resources such as the NZ SeaRise Programme's online tool.
- Wave action will induce forces on the outlet which will need to be considered in the structural design. In addition, currents may also cause drag forces and these may be due to waves, tides or natural circulation. Pipeline stability calculations would be required if the

10 Tonkin + Taylor TR2020/021 prepared for Auckland Council

11 Carpenter et al (2020)

12 MfE, 2021

structure will be experiencing these forces and additional weight, or piling would be required to counteract these load conditions. Further guidance on the above aspects is outlined in the *Coastal Engineers Manual*[13] notably hydrodynamics, sediment processes and design of coastal project elements.

- When designing outlets, particularly when including devices such as flap gates, duckbill valves, or inline check valves, it is crucial to account for the hydraulic losses introduced by these structures to prevent unnecessary high hydraulic head upstream. Each device has its own specific loss characteristics, typically quantified as a head loss coefficient (K). To ensure accurate accounting of outlet losses, the stormwater manufacturer's specifications for the loss coefficients of the specific device needs to be consulted and the coefficients incorporated into the hydraulic calculations to determine the total head loss through the system. Additionally, conduct detailed hydraulic modelling to simulate peak flows without causing excessive upstream head. This comprehensive approach will help maintain efficient operation and prevent flooding or system backflow.
- Fish passage, as noted in Section 2.7.4 above, is a key consideration as the coast is a habitat for key species during certain parts of their life cycle. Whilst consideration of fish passage can be minimal if there is no upstream habitat or other factors make it unnecessary, it should never be ruled out entirely and should be guided by a suitably qualified and experienced ecologist. A site-specific assessment will be required.
- Consideration should be given to connecting to existing nearby outfalls where possible and ideally redirecting discharge points to headlands and away from central beach areas if sufficient system driving head is available. Extensive redirection of flow should also be avoided, especially in cases of combining outfalls.
- Stormwater pipelines up to coastal outfalls are often constructed using trenchless methods and this would need to be considered in the design even if the outfall itself is not drilled.
- Wingwalls and headwalls may be required to provide a structured transition between a bank or revetment allowing for a robust termination of the pipeline structure. They may hold back sand and rock from shifting in front of the outfall or provide stabilisation of a bank slope above while providing a more resilient structure to turbulence at the outlet which would cause erosion. When designing structures such as concrete wingwalls, emphasis on coastal values and considerations should be made, and alternatives should be explored that may mitigate visual impact. If possible, incorporating coastal outfalls into existing structures to avoid new construction should be explored.
- Site-specific geotechnical considerations and investigations will be required by a suitably qualified and experienced geotechnical professional. Geotechnical investigations will be imperative for outfalls situated by cliffs and in areas of ground instability, whilst also being important as part of general design considerations which should be carried out in all cases to establish long-term risk.

[13] CEM (USACE, 2006)

- Anchoring may be required to negate buoyancy and uplift of submerged pipelines, especially with longer outfalls extending beyond the foreshore subject to wave loading, as shown in Section 3.7.1.3. This would need to be evaluated under design conditions and include stakeholder engagement.
- Works would likely require a resource consent.
- These structures could include the addition of energy dissipators, as recommended, to manage high-velocity flows effectively (see Table 3-7 and Table 3-9).

Further guidance in design resilience to long-term condition changes can be found in *Freeboard for the Auckland Region* (GD13).

Figure 3-10: Coastal outfall example (Urban Solutions Project Limited, 2018)

3.7.1 Coastal outfall options

Several options are available for discharging stormwater along a coastline include (but are not limited to) those listed in Table 3-6, denoting typical applicability of various outfall systems based on the discharge environment.

Table 3-6: Coastal outfall options summary with coastal location applicability

Section	Option	Cliff toe	Dune field	Beach	Shallow reef
3.7.1.1	Coastal outfall at the rear of the intertidal zone	Yes	Yes	Yes	Yes
3.7.1.2	Extended coastal outfalls through the foreshore	Yes	Yes	Possibly	Yes
3.7.1.3	Extended coastal outfalls beyond the foreshore	Yes	Yes	Yes	Yes
3.7.1.4	Naturalised coastal outfall solutions	No	No	Yes	Yes
3.7.1.5	Surge chamber / Bubble up pits	Yes	Unlikely	Unlikely	Yes

The suitability for each of these systems should be evaluated on a case-by-case basis, including (but are not limited to) a full geotechnical and structural appraisal, as well as serviceability and maintenance. Further details on these options are provided in the following sections.

3.7.1.1 Coastal outfall at the rear of the foreshore

The simplest coastal outfall is one which discharges above MHWS such as the rear of a beach (seen in Figure 3-11) where the stormwater forms a scour channel, or against a cliff face running over the wave-cut platform. This is preferable to other options as the outfall is easily accessible, away from the dynamic intertidal zone and can be protected but may not always be possible as the flows may prove a hazard and cause unacceptable scour. The outfall needs to be designed to manage high energy and volume stormwater discharge whilst mitigating erosion and protecting the surrounding coastal environment. Stakeholder impact should be considered with this solution sitting at the rear of the foreshore. Risk of public exposure to discharges such as combined overflows should be accounted for. Typically, these would be located at the toe of a coastal or reserve edge bank, or through the coastal erosion protection structure such as the revetment shown in Figure 3-11 and Figure 3-12.

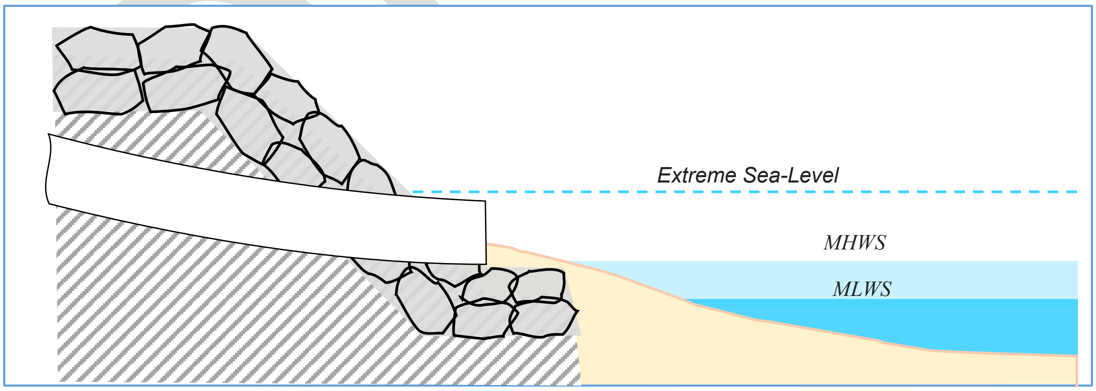


Figure 3-11: Schematic coastal outfall at the rear of the beach

Figure 3-12 shows a good example of a coastal outfall located within the coastal protection rock revetment, where the toe of the revetment structure is designed to incorporate the energy dissipation measures in the scour toe structure to provide long-term resilience whilst attempting to not exacerbate the built structures along the coastline with large concrete wingwalls.

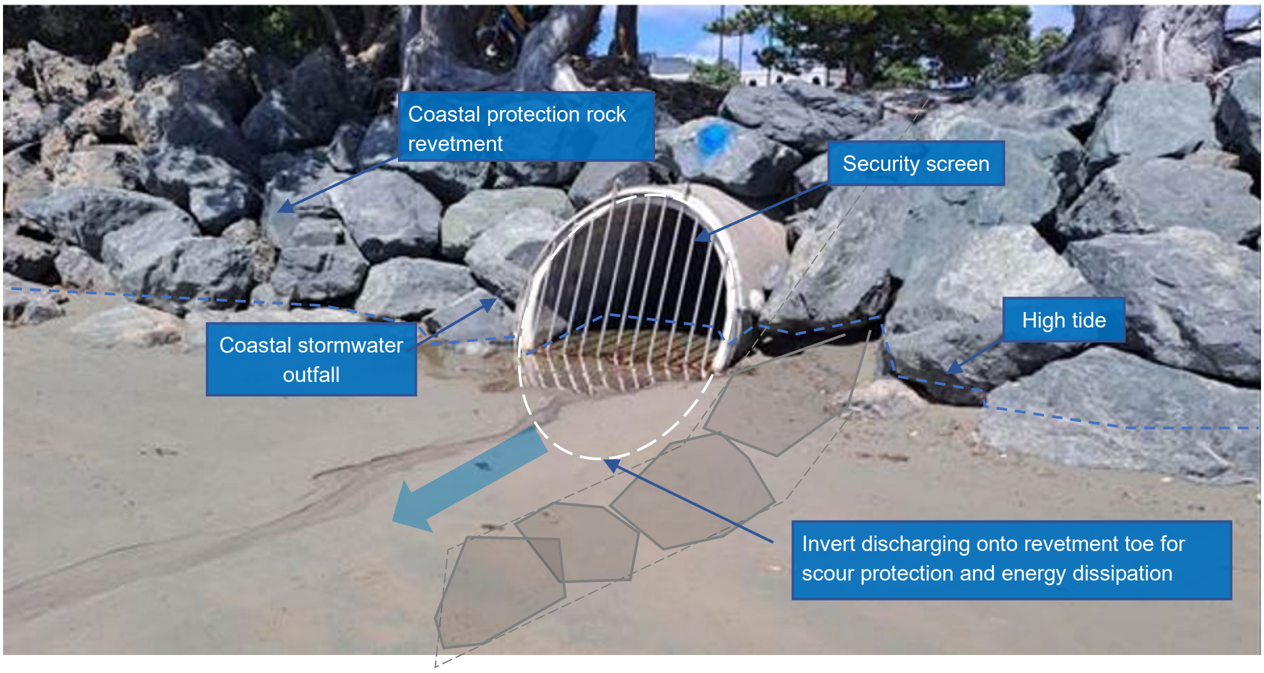


Figure 3-12: Example coastal outfall on the rear of a beach through rock revetment

Figure 3-12 also highlights the need for a security screen to prevent access to the outfall as well as debris which may wash up on the beach entering the stormwater pipe.

3.7.1.2 Extended coastal outfalls through the foreshore

On a wide beach, the scour channel from the outfall may pose a hazard to the public and it may be better to either extend the outfall to the lower beach or intertidal area if there is sufficient driving head available. This pipeline would need to be secured either to bedrock using piles (i.e. timber, steel) or weighted down with concrete, and wave scour should be allowed for as the beach profile will change to form a scarp and a bar due to storm conditions. The pipe will be exposed along the beach in these conditions which may form a hazard, and potentially act as a groyne. Consideration should also be given to visually mitigating the outfall pipe by encasing it in shaped or coloured shotcrete, to reduce its adverse visual impact across the beach face or possibly incorporating it into an amenity such as a fishing pier, viewing platform, groyne or other coastal structure.

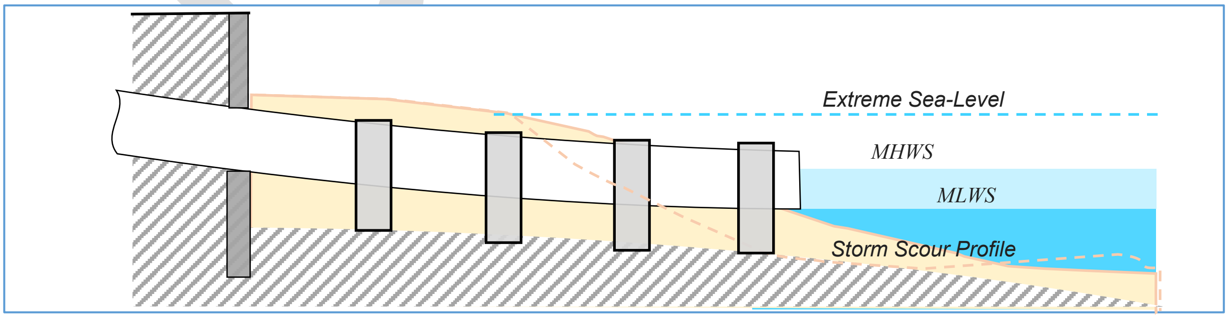


Figure 3-13: Schematic extended coastal outfall section

3.7.1.3 Extended coastal outfalls beyond the foreshore

In some cases, the outfall could run below the beach out to sea, which would be below any scour depth and hence would not be visible on the beach. This could be incorporated into structures such as jetties/groynes, installed via an open trench with a coffer dam or possibly trenchless using a method such as Horizontal Directional Drilling (HDD). This outfall would also require some sort of discharge chamber or diffuser manifold to provide adequate mixing and may require a course screen to limit the ingress of swimmers/wildlife. Sedimentation within the pipeline should be a consideration during the design process where flushing and/or maintenance access should be considered.

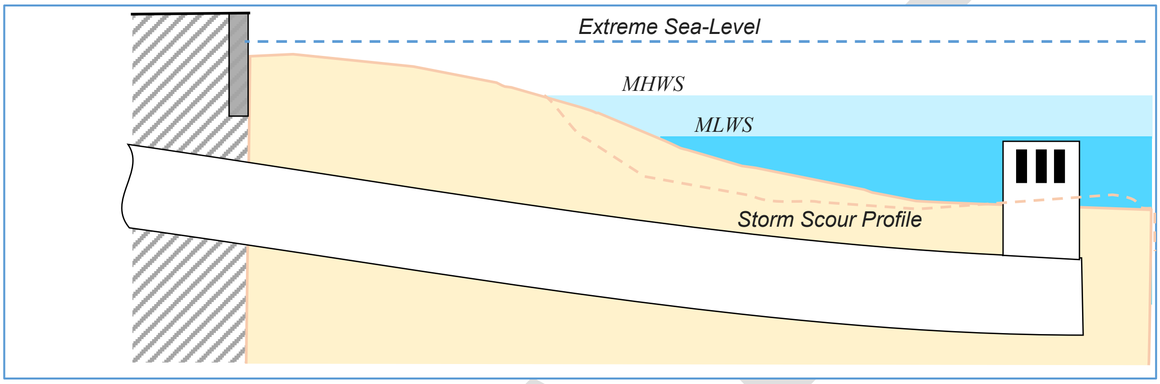


Figure 3-14: Schematic coastal diffuser outfall section

3.7.1.4 Naturalised coastal outfall solutions

To improve the natural amenity of the outlet on the coastline (Figure 3-15), the outfall could be set back from the coastal edge with a planted channel to the beach to stabilise the channel and allow for some infiltration prior to the beach. Special consideration would be required to outlet velocities to ensure that the swale remains in place under normal operation. Some maintenance would be required to maintain the planting of the channel post-storm conditions where erosion and scour would take place. Planting of salt-marsh grasses and dune plants, such as spinifex sericeus, downstream can provide erosion resilience and assist with aesthetic value. Auckland Council's *Coastal planting guide* provides further information around the different coastal zones and subsequent guides are available for specific coastal areas such as dunes, coastal wetlands, salt marshes and estuaries, etc.

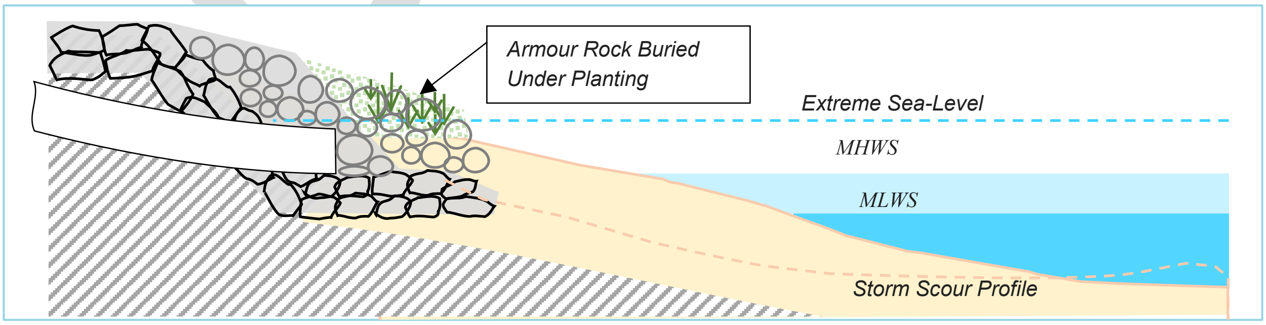


Figure 3-15: Schematic coastal nature-based solution

Figure 3-16 is an example of a naturalised coastal outfall which significantly improved natural amenity by implementing or adapting to natural processes.

Figure 3-16: Example of a naturalised coastal outfall

This naturalisation was carried out due to significant erosion around the previous outfall structure. The pipe settled and failed at a joint, resulting in erosion of the back-dune area from the outfall. The end section of pipe was removed, setting the outlet position landward. As shown in Figure 3-17, a planted channel was then constructed, providing a sustainable long-term solution as well as increasing aesthetic value.

Figure 3-17: Left: Eroded coastal outfall structure *Right: Naturalised outfall remediation*

3.7.1.5 Surge chamber / Bubble up pits

Another common discharge location within the Auckland region is at the bottom of a coastal cliff or earth bank. Here, there is a large hydraulic head to the discharge, and this will need to be carefully considered. In addition, recent experience has shown that these cliffs are unstable and hence allowance should be made for on-site selection for debris eroding from the cliff, while opportunities are also explored for the outlet to blend in with its surroundings. Figure 3-18 shows a surge chamber outlet manhole at the base of a cliff. The velocity and turbulence of discharge should be monitored and limited to protect marine flora and fauna from high-energy discharge scenarios. Additional measures such as impact baffles may be of use in these circumstances. Whilst flattening of the upstream pipe from the outlet will alleviate high velocity risks, there may still be a risk of hydraulic jumps which should be considered.

Bubble-up pits (surge chambers) should be designed on a case-by-case basis for the designed intake and peak-velocity flow scenarios (further details are provided in Section 3.8.2).

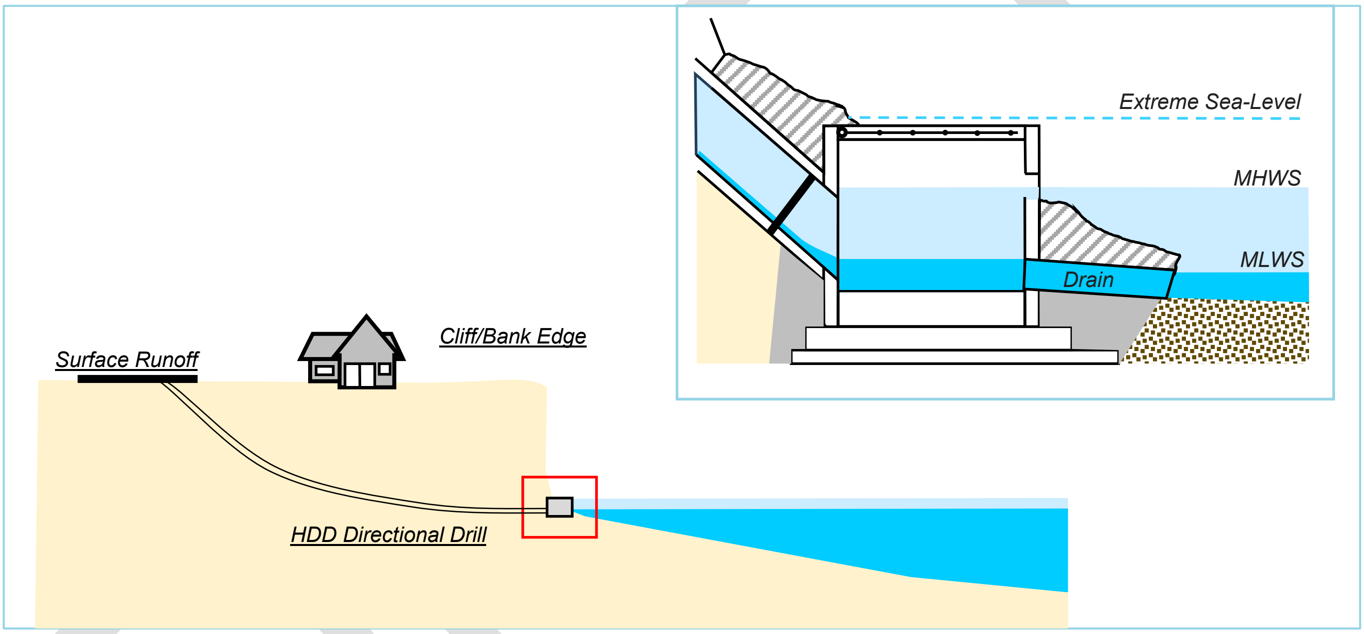


Figure 3-18: Schematic surge chamber-outlet manhole section sketch

A surge chamber/ bubble up pit may take the form of a single structure as is seen on the right of Figure 3-18 above. However, Figure 3-19 illustrates an example of the surge chamber overflow located at the rear of a coastal walkway located at the bottom of a cliff for high flow conditions (left image) with a smaller coastal outfall built into the coastal protection revetment for typical conditions.

It is common to install grilles on surge chambers, which as noted in Section 2.5.4, would only be considered in special cases as potential issues such as entrapment and debris accumulation may occur. Therefore, the design should consider the conditions described in Section 2.5.4 and would require extensive input from Auckland Council.

Figure 3-19: Surge chamber (at the rear of a coastal walkway), with low flow outfall in revetment below

3.7.2 Coastal backflow prevention

Coastal outfalls may require a backflow device to be installed to prevent water ingress into the stormwater system due to storm surge events, or possibly even to prevent tidal fluctuations. This will become more prevalent as climate change leads to sea-level rise. Design should consider at least 1 m of additional sea level as per the AUP, however as noted in Section 2.15.1, the implementation of such measures could be delayed until specific trigger points are met.

Backflow prevention devices or 'check valves' work by allowing flow to discharge from the pipe when the driving head is greater than the receiving tail water level, however, in a storm-surge condition where the levels are reversed, the valve is forced closed, thereby preventing flow back into the pipe. Backflow prevention devices can limit marine growth within the pipe as well as limit sand and debris from entering the pipe, as seen in Figure 3-23, especially when located on a beach which is known to be an outfall closed by intermittent high beach levels. Regular monitoring and maintenance will likely be required for all devices, and debris management should be considered early in the design process.

An additional benefit of these devices for an outlet is that they restrict access into the pipeline from the public. In order to provide access to authorised personnel, such as maintenance and operations teams, having an in-land manhole in close proximity that can be used for flushing is highly beneficial.

These devices do have drawbacks; as with grills and screens they can create an entrapment hazard, may prevent fish passage (described below), they incorporate additional head losses into the system and under some circumstances, they may generate hydraulic issues such as cavitation. Poor installation of the device poses a significant risk which will impact its intended performance; hence emphasis should be made on ensuring correct installation practices are adhered to. These will have to be weighted up against the benefits noted above during optioneering and in some cases, the device may be installed upstream at the first manhole.

3.7.2.1 Flap gate system

A flap gate is a hinged flap which sits in front of the outlet as shown in Figure 3-20. The valve could take the form of a simple rubber fitting fixed to the pipe or a steel-hinged structure. A flap valve is reliable and can be modified to allow for fish passage (see Section 3.7.2.5). However, the flap may be prevented from opening from the outside should sand and/or debris build-up against the outlet. This is especially prevalent on coastlines with an energetic wave environment or a beach where the beach profile varies above the invert of the outlet. It may also be prevented from closing by beach sand ingress.

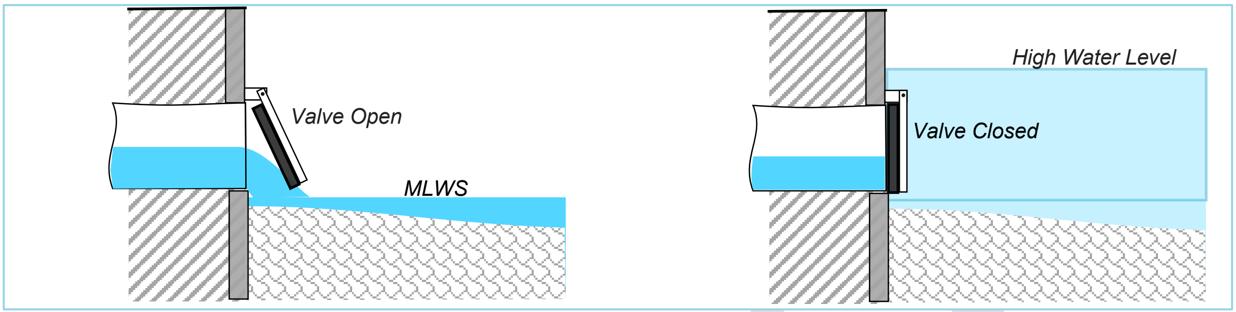


Figure 3-20: Backflow prevention check valve operation

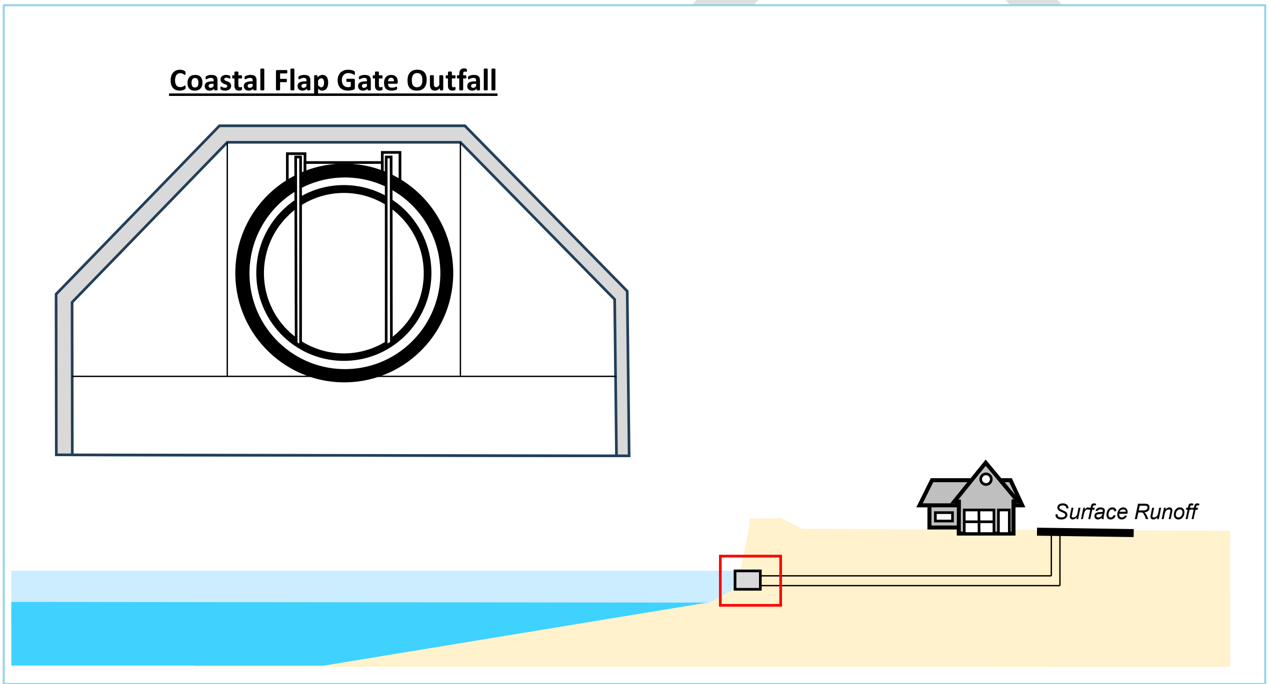


Figure 3-21: Coastal outfall flap gate

3.7.2.2 Louvre system

Installation of a louvre system at the pipe outlet is shown in Figure 3-22. The louvre system will allow stormwater to pass through the outlet and prevent sand and debris from entering the pipe.

Like all check valves, the louvre system works to control flow, as flow from the pipeline forces the louvres, which are hinged in the top, to swing outward allowing discharge. When the pressure on the outside exceeds that behind the louvres, they are forced shut against the frame preventing flow into the pipeline. The louvre system has more moving parts than a flap gate; this allows stormwater to discharge, e.g. even if some of the lower louvres are blocked by beach sand.

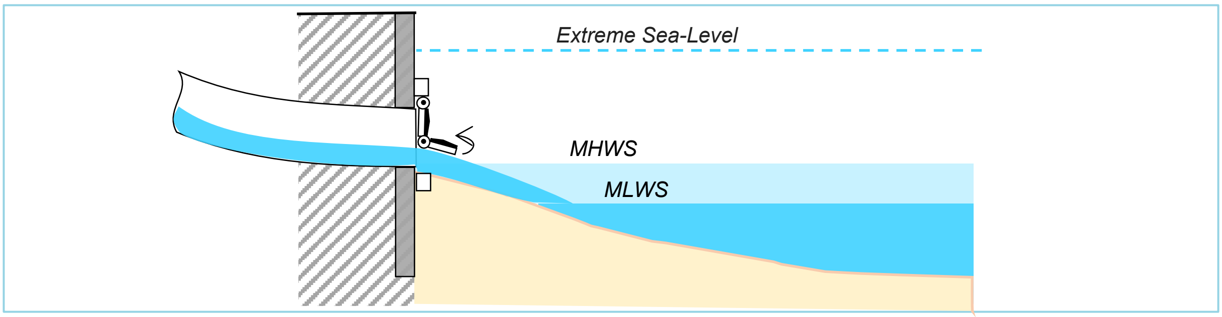


Figure 3-22: Louvre screen coastal outfall

As seen in Figure 3-23, a louvre outfall system allows continuous flow which can be regulated in the design process, a key feature which distinguishes it from other systems such as flap-gates. Louvre systems may blend aesthetically into natural environments more than alternative systems.

Figure 3-23: Louvre outfall example

Other similar appropriate systems employing cylindrical gate leaf and counterweight systems may be equally effective and can be implemented if suitably fit for purpose. This determination should be evaluated on a case-by-case basis.

3.7.2.3 Duckbill check valve

Duckbill check valves can be made of various sizes and stiffness to suit a wide range of applications. They open when the pressure within the outlet exceeds that on the outside, which forces the two rubber faces apart allowing for discharge to occur. Conversely, when the pressure acting on the outside of the valve exceeds that on the inside, the two faces of the valve are forced together closing the aperture and preventing flow into the pipeline. These valves can be retrofitted onto existing outfalls by either bolting onto the headwall or by slipping over an existing pipe and held in place by a clamp, as well as options allowing for installation within the pipe itself.

A duckbill valve has self-scouring capabilities when installed on a beach, e.g. if the top of the 'bill' is exposed on the beach, as seen in Figure 3-25, then even if most of the valve is buried in the sand, flow can work its way out to scour a space in front for the valve to open wider and handle a larger flow. The designer will need to work closely with the supplier to select the correct stiffness to be able to resist any wave loading, while not being too stiff that it allows the sufficient flow to scour any sand.

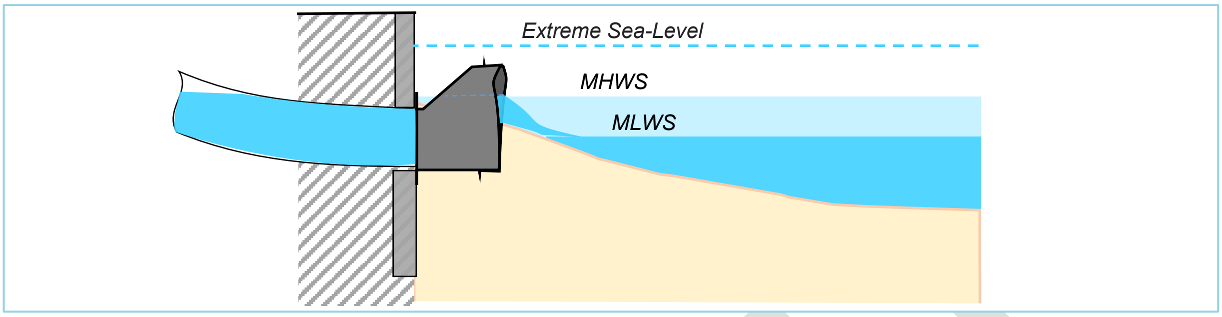


Figure 3-24: Duckbill check valve example installation on a beach

Figure 3-25: Example duckbill check valve installed on a seawall

3.7.2.4 Inline check valve

An inline check valve is a valve which is designed to fit within the pipe to allow stormwater to pass through the outlet while preventing backflow, as well as preventing sand and debris from entering the pipe from the seaward side. The valve can be retrofitted to sit within an existing outlet. If sedimentation is not an issue, the valve can be installed in a manhole upstream to prevent backflow up the network.

For some valves, care should be taken to ensure that sand is not packed into the space between the flexible membrane and the soffit on the seaward side as this could prevent the valve from opening and hence the valve should be installed above the highest anticipated beach level such that it is not buried, as seen in Figure 3-27 and Figure 3-29. Note that the example below is subject to maintenance issues as it is often buried by the beach (Figure 3-29), and the white pipe is an attempt to improve self-scouring.

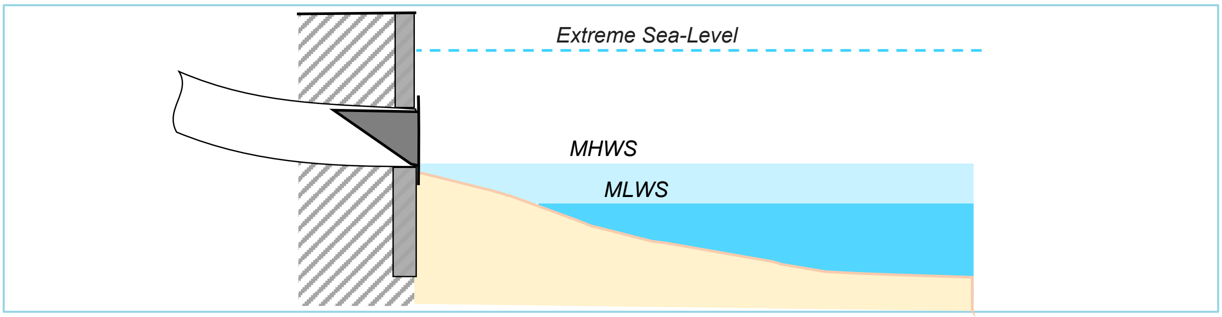


Figure 3-26: Inline check valve example installation on a beach

Figure 3-27: Inline check valve installed within a coastal outfall through seawall

3.7.2.5 Fish-friendly backflow devices

Backflow devices are significant barriers to fish passage and need very careful consideration as to what should be included. Flap gates that are closed or have high flows when open will be a barrier to fish passage. In most cases, these are only required for times during floods or certain tide conditions and the use of a managed flap valve or gate that can remain open when not required for flood/tide or during certain species critical periods should be considered.

At times, an outlet will be required to allow for fish passage as noted in Section 2.7.4. If there is a requirement for backflow prevention, then special consideration needs to be made in selecting the correct device. Options include:

- A flap valve which is limited to remain slightly open
- A flap valve with a secondary bypass valve fitted to a float on the outlet
- A flap valve with a weighted system that closes the valve only at a set level (Figure 3-28)
- Automated tide gates
- A combination of a low-flow fish-friendly outlet and a high-flow outlet with backflow prevention
- Include for a bypass to allow for fish passage when the gate is closed.

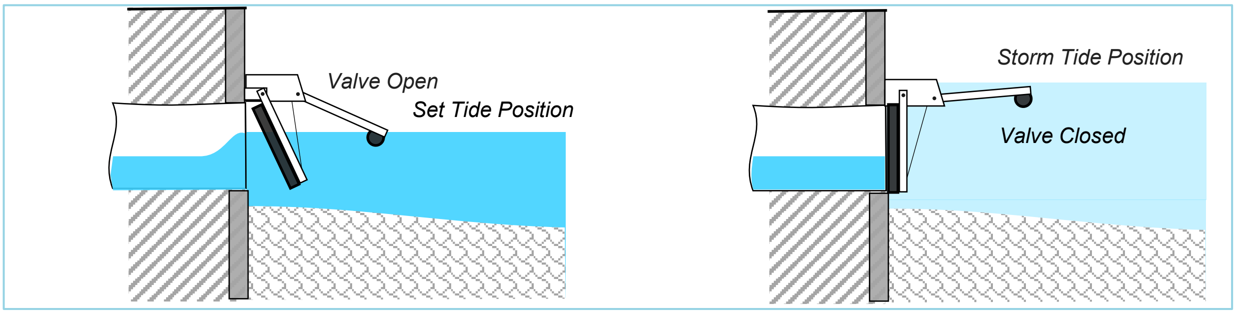


Figure 3-28: Fish friendly cantilever style flap valve example (ATS Environmental)

When considering fish-friendly devices, special consideration needs to be made in terms of debris and sand that is either coming down the network, or could wash up and lodge the valve open, or prevent it from opening. On the coast, the wave climate also needs to be considered as wave loading can damage the valve. Table 3-7 presents an overview of key dissipator devices, and their general performance or suitability to typical coastal environments:

Table 3-7: Dissipator/backflow device options summary with coastal location applicability

Device (*refers to devices used in conjunction with another)	Cliff	Dune field	Beach	Shallow reef
Flap gate system	Unlikely	Unlikely	Unlikely	Yes
Louvre system	Unlikely	Possibly	Possibly	Yes
Duckbill check valve	Unlikely	Possibly	Possibly	Yes
Inline check valve	Unlikely	No	Possibly	Yes
Surge / Bubble-up pit	Yes	Unlikely	No	No
Outlet weir	No	Yes	Yes	No
Outlet drop/weir	Yes	No	No	No
Riprap apron	Unlikely	Unlikely	Unlikely	No
Straight drop structure	Yes	No	No	No
Box inlet drop structure	Yes	No	No	No
Diffuser outfall (beyond foreshore)	Yes	Yes	Yes	Yes
Wingwalls*	Yes	Yes	Yes	Yes
Headwalls*	Yes	Yes	Yes	Yes

Whilst all devices are suitable for application in coastal environments, engineers should consider asset specific performance attributes when implementing them. Energy dissipation requirements in given coastal environments, such as high wave action, will influence an engineer's choice of outfall structure (further discussed in Section 3.8.3.2).

3.7.3 What to avoid

Steep cliffs are prone to erosion and landslides, both of which have detrimental effects on coastal outlet structures. Instability of such areas increases the risk of collapse, posing hazardous situations for the natural environment, operations/maintenance personnel, and the public who share the coastal region. Hence, engineers should avoid discharge at the top of cliffs and banks, as well as avoid installation of large obtrusive structures in coastal environments such as gabion scour protection.

Sole reliance on riprap as a method of energy dissipation should be avoided. Hard engineering methods such as this, while effective in practice, from an ecological and aesthetic perspective, are relatively invasive. If possible, more naturally sourced methods should be evaluated to be used in conjunction with riprap, such as longer naturalised channels or allowing for some beach erosion to take place.

When designing outlets within coastal or cliff areas, consideration should be taken of accessibility in terms of both maintenance and associated risk. There are instances where coastal structures, including outlets, have significant erosion and access challenges due to their placement near steep cliffs. Structures located in precarious locations such as these accelerate degradation and increase maintenance costs, compromising their operational effectiveness. Outlets should be designed to be in more stable areas with better accessibility to enhance the longevity and reliability of coastal infrastructure.

Outfalls are susceptible to wave erosion, which can be exacerbated at the outlet location due to wave focusing and reflection, undermining structural stability and adjacent land. This can be problematic in areas prone to rapid or severe erosion such as soft rock shores and sandy coastal regions without sufficient coastal protection such as riprap revetments. As previously noted, reliance on riprap alone for energy dissipation should be avoided. Emphasis should be made on incorporating an element of futureproofing in erosion protection around coastal outlets to avoid such problems.

Situating coastal outfalls within designated areas of reclamation should be avoided. These areas often have specific regulatory requirements that complicate the design and approval process. If a coastal outfall must be placed within a reclamation area, designers will likely require resource consent, a lengthy and complex process that involves assessments and compliance with regulations related to vested interests in the reclaimed land, as outlined in NZCPS Guidance Note – Policy 10 (2010). To mitigate and minimise additional constraints, designers are encouraged to seek alternative, equivalent areas for development outside of designated reclamation zones.

3.7.3.1 Sedimentation build-up

Outfalls discharging onto a sandy beach may be prone to siltation problems when the beach profile leads to a buildup within the pipe during low flow periods. This buildup can obstruct flow, and lead to blockages or inefficiencies in a system.

When selecting a discharge location along a coastline, thorough consideration should be given to the initial placement in order to mitigate sedimentation accumulation. The outfall discharge location should be diverted from the main beach towards headlands or the ends of the beach where possible.

This will reduce the impact on central beach areas and utilise natural coastal dynamics to manage sediment dispersion effectively.

Figure 3-29: Examples of outfalls with sedimentation issues

3.8 Energy dissipation

The failure or damage of many culverts and detention basin structures is related to unchecked erosion. The erosion potential of a drainage network is normally increased by reduction of pervious areas, interception and concentration of overland flows and constriction of existing waterways. Erosion protection measures should be employed to protect hydraulic structures against such erosion.

While proper design of inlets and outlets can reduce the potential for erosion, in many cases additional energy dissipation solutions are required if the receiving downstream environment (whether natural stream or treatment device) does not have adequate ability to withstand erosive forces, or if the forces are significant. For discharges to natural streams or gullies, erosion potential can be evaluated by calculating the exit velocity and comparing it to the velocities that cause erosion in different channel materials. If the potential for erosion is likely, and velocities cannot be otherwise lowered, then energy dissipation is required.

3.8.1 Types of energy dissipation

There are many types of energy dissipation devices including flow transitions, riprap aprons, in-line outlet weirs, drop structures, concrete aprons with baffles, impact dissipators, forced hydraulic-jump basins and broken-back culverts. The selection of the correct solution will be related to the energy the flow has (higher velocity requires more complex heavily engineered solutions), and also size of the flows involved.


Figure 3-30: Left: Concrete apron and baffle blocks at outlet. Right: Rock riprap at outlet

Left photo courtesy of CDOT Colorado Department of Transportation. Right photo Credit: Nathan Sullivan, USGS, Public domain

3.8.1.1 Inlet scour protection

Erosion protection should be provided at the inlet of all devices (Figure 3-32). Typically, flows will enter the device from either a surface flow system (i.e. roadside kerb, open channel) or a piped drainage system. In most cases, these flows will enter a device as 'concentrated' and as such, it is important to effectively slow and spread the inflows. Rock beaching is a simple method for achieving this but should be positioned below the inlet so as not to obstruct flows.


Figure 3-31: Left: Impact energy dissipater. Right: Baffled chute

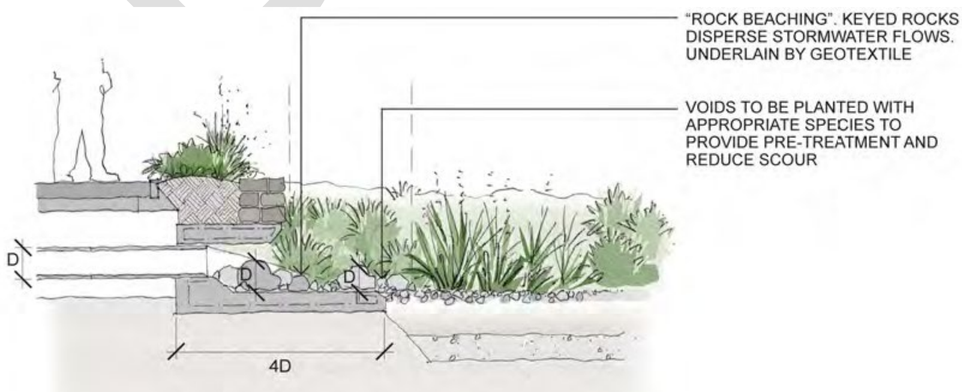


Figure 3-32: Inlet scour protection

3.8.1.2 Stream outlets

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.

Instead of piping to the receiving water body, ephemeral stream gullies can be ideal for locating outlet structures (with energy dissipation measures and appropriate set-back from the stream), 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. In the coastal environment, where a conventional set-back may not be appropriate, consider locating the outlet away from the active beach system (e.g. at, or near, an adjacent headland).

Longitudinal slopes greater than 3° (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 3-33 shows 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 3-33: Rock riprap to protect outlet and stream channel

3.8.1.3 Riprap

Riprap is used to provide a hard surface lining that is not subject to erosion, as well as providing energy dissipation. Some situations where rock riprap can be used for erosion protection are:

- Rock-lined channels
- Protection of overland flow paths
- Emergency spillways
- Stream bank protection below and opposite of outlets
- Inlets into bioretention devices and swales.

It should be noted that the riprap described below is intended to protect scour from river flow velocities and not coastal erosion, which should be considered by a suitably qualified and experienced person.

Riprap comes in a variety of rock types and sizes, depending on the quarry. The median diameter of the riprap range is D_{50} (often used in riprap sizing calculations). Material larger than about 250 mm is often classified as boulders; however, care should be taken, as quarries or providers may define sizing differently.

Angular rock is preferred over rounded rock as it has a much greater angle of repose than rounded rock. Angular rock has greater energy dissipation capability and is easier to lock in place. The rock riprap angle of repose, indicative of angular rock, is 40°. 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 and structures receiving flow from overland flow paths, this would generally be the 1% AEP event. For treatment device outlets, this will typically be the 10% AEP event. Riprap used in temporary works may be designed based on the discharge velocity for the 5% AEP event. When an outfall is located in a coastal environment, wave energy should also be considered when sizing riprap using guidance provided in the CIRA Rock Manual.

For the majority of stormwater inlets and outlets into, or from, a stormwater management device, Equation 3 can be used as a guidance to determine the average required rock size (D_{50}) for different flow velocities.

The following should also be considered:

- The recommended minimum D_{50} of riprap is 150 mm and the maximum size is 500 mm
- The thickness of the riprap protection is recommended to be twice the median rock size (2 x D_{50}) or triple the median rock size (3 x D_{50}) on the foreslope of critical areas such as roadway culverts
- Riprap should be underlain with geotextile, so it doesn't 'sink' into the softer underlying soil
- The length of protection can be judged based on the magnitude of the exit velocity compared with the natural channel velocity. The greater this difference, the longer will be the length required for the exit flow to adjust to the natural channel condition. For natural streams, the use of riprap should be minimised to reduce adverse effects.

Further guidance on riprap sizing for a number of different flow conditions can be found in HEC14[14]. One such equation for rock size can also be calculated for different pipe diameters using this equation: (HEC14 Equation 10.4).

[14] Hydraulic Engineering Circular No.14 (HEC14) Third edition. 2006. Hydraulic Design of Energy Dissipaters for Culverts and Channels. U.S. Department of Transportation, Federal Highway Administration

$$D_{50} = 0.2D\left(\frac{VA}{\sqrt{g}D^{2.5}}\right)^{\frac{4}{3}}\left(\frac{D}{TW}\right) \quad \text{Equation 3}$$

Where:	D_{50}	=	Rock size (m)
	D	=	Culvert diameter (m)
	A	=	Cross-sectional area of culvert (m^2)
	V	=	Velocity of design flow (m/s)
	g	=	Gravity (9.81 m/s)
	TW	=	Tail water depth
Assumptions:	Zero slope		
	If there is no tail water or the tail water depth is unknown, use 0.4D for TW		
	Rock specific gravity is assumed to be 2.65		

If the flow is supercritical at the culver, the diameter is to be adjusted as per equation 10.5 in Hec 14:

$$D' = \frac{D + y_n}{2} \quad \text{Equation 4}$$

Where:	D'	=	adjusted culvert rise (m)
	y_n	=	normal (supercritical) depth in the culvert (m)

Another such reference which could be considered is the Catchments and Creeks field guides - *Background to Rock Sizing and Rock Roughness Equations*.

3.8.1.4 Riprap aprons

Riprap aprons manage the transition from a pipe outlet to the stream channel, and to the foreshore, by increasing roughness and flow width to reduce flow velocity. The riprap apron is one of the most commonly used devices for outlet protection, with or without a standard wing wall. Riprap aprons are preferred over concrete aprons with energy dissipaters (such as baffles) because they are typically less expensive and easier to install. In addition, riprap is more flexible and less obtrusive in the environment. Riprap aprons should be integrated in the landscape with planting. In the coastal environment, site-specific assessment and design is required, and bespoke options can be more appropriate, e.g. incorporate into revetment structure or stabilise sediment scour pad.

Protection is provided by increasing roughness and having sufficient length and flare to dissipate energy by expanding the 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 0% grade for the length of the apron.

The key design elements of the riprap apron are the size of the riprap rocks, and the depth, length and width of the apron as shown in Table 3-8.

The following design steps should be followed when designing a riprap apron:

- Determine the rock size of the riprap (D_{50}) using Equation 3
- Estimate apron dimensions based on Table 3-8, as illustrated in Figure 3-34
- A geotextile should be placed between the riprap and the underlying soil to prevent soil movement into and through the riprap.

Table 3-8: Apron dimensions (from HEC14)

D_{50} (m)	Apron length	Apron depth	Apron width (at apron end)
0.15	4D	$3.3D_{50}$	3D+(2/3)L
0.25	5D	$2.4D_{50}$	
0.35	6D	$2.2D_{50}$	
0.50	7D	$2.0D_{50}$	

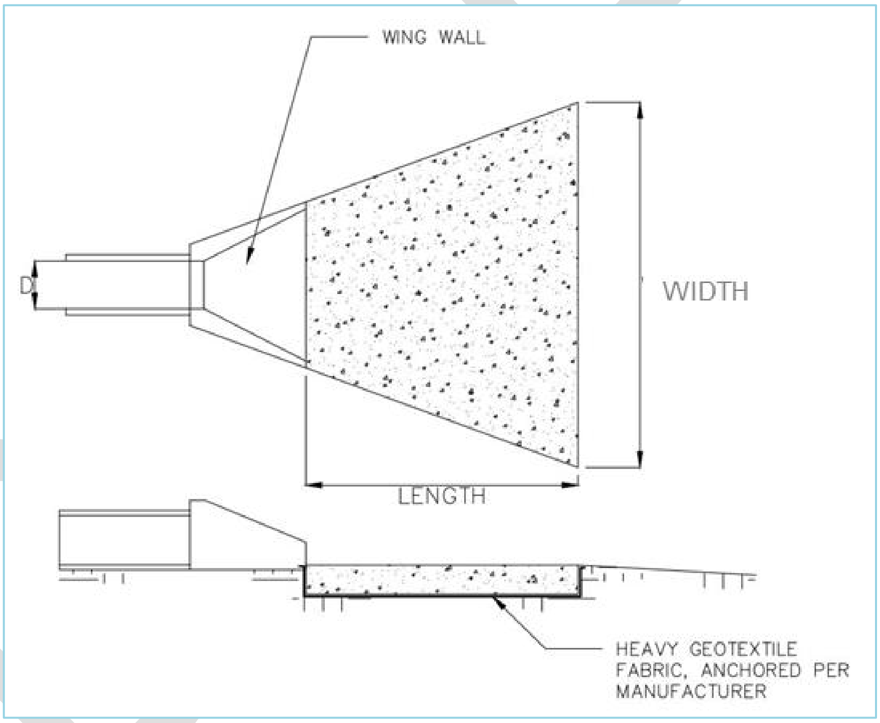


Figure 3-34: Riprap apron design dimensions

3.8.2 Small stilling structures

A range of techniques is available to create a body of water at the discharge point from a network that would aid in dissipation of energy. Commonly employed structures that offer some energy dissipation through stilling include bubble-up pits and drop outlets.

Bubble-up pit	• Subject to site elevations, a bubble-up pit provides energy dissipation into a device through a pre-cast manhole placed at the inlet designed to overflow in design storm conditions (Figure 3-35). • Bubble-up pit outlet configurations may contain multiple pipes which can be designed using orifice equations. • They can be incorporated into existing rocky outcrops of coastal environments (as shown in Figure 2-6). • High-level overflows are required either consisting of an open grate or hinged manhole lid to mitigate safety issues from public access. These may be designed to surcharge without overflowing, or to overflow in design storm conditions.
Drop outlets	• Drop outlets provide for large changes in elevation; the incoming pipe invert elevation is significantly higher than the outlet invert elevation. • They are often combined with bubble-up pits (as shown in Figure 3-35 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. 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.

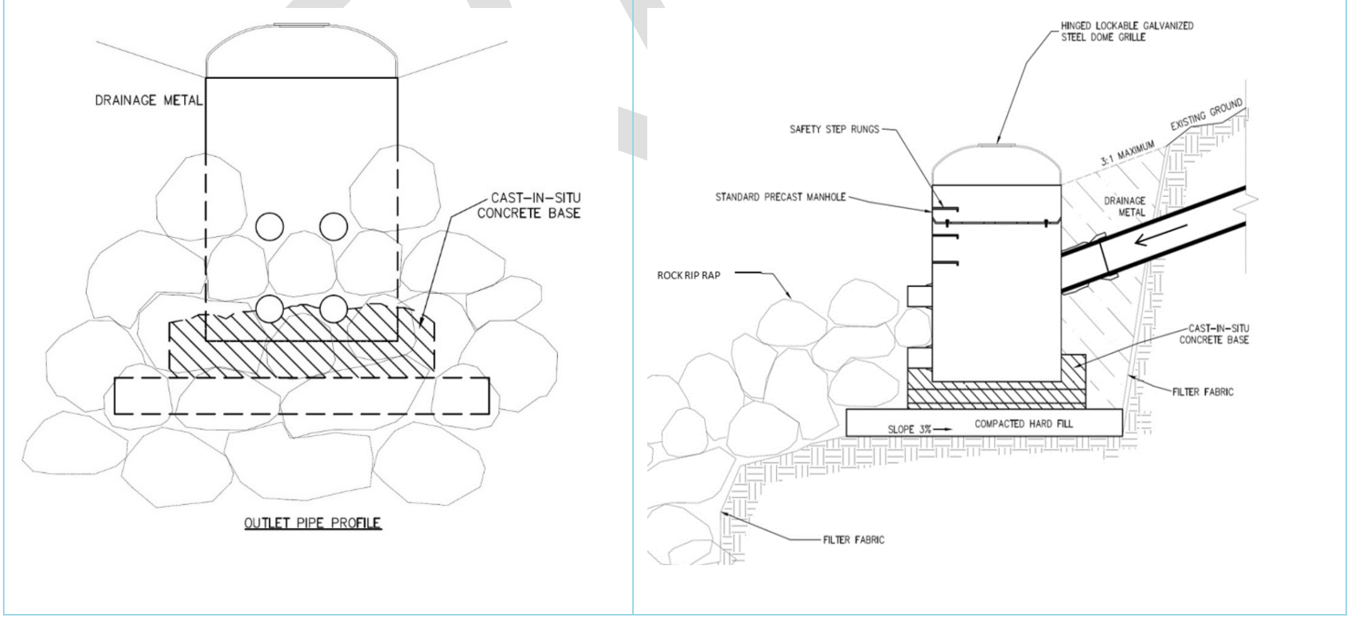


Figure 3-35: Bubble-up pit incorporating drop structures with multiple outlets (profile & long-section)

3.8.3 Medium to large stilling structures

HEC 14 *Hydraulic Design of Energy Dissipaters for Culverts and Channels*[15] provides detailed information for designing energy dissipation problems at culvert outlets and open channels. HEC14 includes design procedures for various configurations which includes below and on the stream bed.

3.8.3.1 Type selection

The dissipater type selected for a site should be appropriate to the location. Several types of energy dissipaters can be designed by using either HEC 14 or HY-8. Energy dissipators are selected based upon a number of parameters including the Froude Number as this is a key measure of how strong the resulting hydraulic jump will be. The following is a general design summary of applicable chapters within HEC 14 that can be used to determine the correct energy dissipation:

- Internal dissipaters (HEC 14, Chapter 7) are used where:
    - The estimated scour hole is not acceptable
    - Debris is not a problem
    - Moderate velocity reduction is required.
- Natural scour holes (HEC 14, Chapter 5) are used where:
    - Undermining of the culvert outlet will not occur
    - Estimated scour hole does not risk damage to property
    - Will not create a nuisance to the public.
- External dissipaters (HEC 14, Chapters 9, 10 and 11) are used where:
    - The estimated outlet scour hole is not acceptable
    - A moderate amount of debris is present
    - The culvert outlet velocity (V_0) is moderate ($F_r \leq 3$).
- Stilling basins (HEC 14, Chapter 8) are used where:
    - The estimated scour hole is not acceptable
    - Debris is present
    - The culvert outlet velocity (V_0) is high).
- Drop structures (HEC 14, Chapter 11) are used where:
    - The downstream channel is degrading, or
    - High stream erosion is present
    - Coastal settings.

15 US Department of Transportation Publication No., FHWA-NHI-06-086 July 2006

Table 3-9: Energy dissipators types (from HEC 14)

HEC 14 chapter	Dissipator type	Froude number (Fr)	Allowable debris			Tailwater (TW)
			Silt/Sand	Boulders	Floating	
4	Flow transitions	N/A	H	H	H	Desirable
5	Scour hole	N/A	H	H	H	Desirable
6	Hydraulic jump	>1	H	H	H	Required
7	Tumbling flow	>1	M	L	L	Not needed
7	Increased resistance	N/A	M	L	L	Not needed
7	USBR Type IX baffled apron	< 1	M	L	L	Not Needed
7	Broken-back culvert	> 1	M	L	L	Desirable
7	Outlet weir*	2 to 7	M	L	M	Not Needed
7	Outlet drop/weir*	3.5 to 6	M	L	M	Not needed
8	USBR Type III stilling basin	4.5 to 17	M	L	M	Required
8	USBR Type IV stilling basin	2.5 to 4.5	M	L	M	Required
8	SAF stilling basin	1.7 to 17	M	L	M	Required
9	CSU rigid boundary basin	< 3	M	L	M	Not needed
9	Contra Costa basin	< 3	H	M	M	<0.5D
9	Hook basin	N/A	M	L	L	Desirable
9	USBR Type VI impact basin	N/A	H	H	H	Not needed
10	Riprap basin	<3	H	H	H	Not needed
10	Riprap apron*	N/A	H	H	H	Not needed
11	Straight drop structure*	<1	H	L	M	Required
11	Box inlet drop structure	< 1	H	L	M	Required
12	USACE stilling well	N/A	M	L	N	Desirable

* Froude number is at the release point of the culvert or channel

* Debris notes: N = None, L = Low, M = Moderate, H = Heavy

* The bed slope for the tumbling flow should be in the range of $4\% < S_0 < 25\%$

* Straight drop structure drop should be less than 4.5 m

* Box inlet drop structure should be less than 3.6 m

* Suitable for coastal environments.

3.8.3.2 Design considerations

The energy dissipater design should consider the following:

Debris control	• Debris control can be designed using HEC 9 and should be considered especially when: o Limited general maintenance access o Dissipater cannot pass debris.
Flood frequency	• The flood frequency of the outlet should be for the same flood frequency as the culvert/pipe/structure design. • Some dissipaters can have a higher velocity than what the receiving environment can manage. If this velocity negatively impacts the downstream environment, it should be mitigated.
Maximum culvert exit velocity	• The culvert exit velocity should be consistent with the natural channel/receiving environment permissible maximum velocities • This can be mitigated by means of: o Channel stabilisation o Energy dissipation.
Tailwater relationship	• The hydraulic conditions downstream are required to be determined for the design of a number of the structures presented above. • Where this information is required or desirable, this should be evaluated to determine a tailwater depth and the maximum velocity for a range of discharges. • Large water bodies should be evaluated using the high-water elevation, which has the same frequency as the design flood for the culvert if it is likely to occur concurrently. • If statistically independent, evaluate the joint probability of flood magnitudes and use a worst-case scenario approach.
Safety (See Section 2.4.1)	• Stilling basins often require construction of hard structures in the flow. These may cause serious injuries to anyone caught in the flow. The designer should assess public access to the upstream system, the hazards created and the safety of the public. • Some stilling basins generate highly aerated flow which may affect the buoyancy of swimmers. The designer should consider the location of these structures, the hazards created and the safety of water users (e.g. swimmers, kayakers, paddle boarders, etc.). • Some stilling basins and weir designs generate tumbling flow and roll waves which may trap swimmers. The designer should consider the location of these structures, the hazards created and the safety of water users (e.g. swimmers, kayakers, paddle boarders, etc.). • Some stilling basins and weir designs create steep drops or deep pools of standing water. The designer should assess public access to the upstream system, the hazards created and the safety of the public.

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