Rectifying Vegetated Stormwater Assets

Draft, February 2012

water by design

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HEALTHY WATERWAYS

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Water by Design

Water by Design is a program of Healthy Waterways Ltd. It helps individuals and organisations to sustainably manage urban water. For more information, visit www.waterbydesign.com.au.

Healthy Waterways

Healthy Waterways is a not-for-profit, non-government organisation working to protect and improve waterway health in South East Queensland (SEQ). We facilitate careful planning and coordinated efforts among a network of member organisations from government, industry, research, and the community to achieve our shared vision for healthy waterways. For more information, visit www.healthywaterways.org.

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Glossary

This glossary defines words commonly used in relation to vegetated stormwater assets. Definitions given here fit the context of the words they are used in this document.

Bathymetry
Bathymetry describes the spatial variations of water depth or the contours of the base of a water body.

Biofilm
A gelatinous sheath or matrix of algae and polysaccharides (sugars) that adsorbs colloids and nutrients. Biofilms often contain diverse and abundant microflora and microfauna. Biofilms form on aquatic vegetation and in wetlands play a critical role in trapping and processing pollutants and nutrients from the water column.

Bioretention systems
Vegetated depressions designed to collect, detain, and treat stormwater. Stormwater infiltrates into a prescribed filter media that is densely planted. Pollutants are primarily removed by adsorption and biological transformation within the filter media. Bioretention systems are also called **biofilters, biopods, biofiltration basins, raingardens, and bioretention swales.**

Chlorosis
When leaves are, partly or wholly, pale green or yellow due to a lack of chlorophyll. It is usually caused by a nutrient problem or soil pH.

Constructed wetland
Constructed wetlands usually consist of a sediment basin followed by a macrophyte zone. The macrophyte zone is a constructed shallow body of water that supports a range of aquatic vegetation. Constructed wetlands remove pollutants from stormwater through enhanced sedimentation, fine filtration, and biological uptake. In this document, a 'constructed wetland' refers to the macrophyte zone.

De-watering
The complete or partial (nearly empty) draining of a permanent pool of water.

Ecosystem
A system formed by the interaction between organisms and their environment.

Ephemeral
When used to describe wetlands, 'ephemeral' refers to habitats that are intermittently inundated and go through periods of wetting and drying.

Erosion
The mechanical process of wearing down or translocating the earth's natural surface by weathering, abrasion, or transportation.

Establishment phase
The period immediately after a vegetated storwmater asset is constructed when vegetation matures. This period will last approximately two years for most vegetated stormwater assets.

Extended detention
An area above a vegetated stormwater asset that temporarily stores water and then slowly releases the water. Extended detention is particularly useful for maximising the volume of water that is treated.

Failed asset
An asset that has stopped functioning or is not meeting a range of performance indicators and therefore is no longer providing the intended stormwater management function.

Filter media
A prescribed soil media used in bioretention systems to filter stormwater and support plant growth.

Gross Pollutant Trap (GPT)
A device designed to intercept coarse particulate material (by sedimentation), trash, and debris (by screens or booms). GPTs may be incorporated into inlet pits, collector drains, or main drains.

Groundwater
Water beneath the ground's surface that is held in, or moving through, saturated layers of soil, sediment, or rock.

High-flow bypass
A structure or device, typically a weir, pit, or channel, that bypasses high flows around a treatment system to avoid scour within the asset.

Hydrologic effectiveness
The proportion of catchment flows treated by the vegetated stormwater asset.

Hydrology
The study of water movement and the water cycle, especially rainfall and runoff processes.

Impervious area
Impermeable surfaces through which water cannot infiltrate to the ground.

Infiltration
The process by which surface water enters the soil.

Lateral inflow
Water that enters the vegetated stormwater asset from the sides, which may not be the main or designed entry point.

Macrophyte
A plant adapted to living in water or periodically inundated (ephermeral) habitats.

Maintenance
Regular actions required to ensure an asset continues to deliver the function for which it was designed but excluding rehabilitation or renewal.

Normal water level
The water level in a wetland or sediment basin equal to the level of the lowest free-draining outlet. After rainfall, water will pond up within the wetland or sediment basin in the extended detention zone, and then after three or four days the water level will return to its normal level.

Nutrients
Substances such as compounds of nitrogen and phosphorus that promote the growth of plants and algae. Excessive nutrients in waterways and other receiving water environments contribute to algal blooms and degrade waterways.

Pollutants
Substances that may naturally occur but are present at harmful levels (e.g. sediment or nutrients in a water body) or that may be unnatural in the environment and capable of producing environmental harm (e.g. chlorinated pesticides).

Problem
A defect or impairment in the asset that is impeding the asset's function e.g. the asset's capacity to provide stormwater management.

Preferential flow path
The flow path of least resistance through a vegetated stormwater asset.

Rectification
The works involved in repairing a failed or under-performing vegetated stormwater asset back to a functional state.

Roughness coefficient (of a channel)
The resistance of a channel to the flow of water in it. For example, a channel with heavily vegetated and dense shrubbery has a higher roughness coefficient than a channel that is turfed.

Terrestrial
Related to the land, as opposed to air or water.

Threatened species
Any species vulnerable to extinction in the near future, although not in the immediate future.

Treatment train
A series of vegetated stormwater assets.

Sediment basin
A basin designed to slow the flow rate of stormwater, allowing sediments and nutrients within the stormwater to sink into the storage zone of the basin.

Swale
A turfed or otherwise vegetated shallow channel that conveys stormwater and removes pollutants.

Under-performing asset
An asset where one or two performance indicators are not being met and the asset is only partially providing the stormwater management function for which it was intended.

Water quality
Physical, chemical, and biological characteristics of the water column.

Weed
A plant that is growing where it is not wanted.

ONE **INTRODUCTION**

1.1 Purpose of this document

Rectifying Vegetated Stormwater Assets provides guidance on how to rectify under-performing or failing vegetated stormwater assets. It sets out a process for determining whether to rectify an asset, provides guidance on how to determine the cause of problems, and lists possible solutions.

1.1 Why use this document

Waterways are an integral part of our lifestyle and economy, and urban stormwater run-off can significantly affect them. Typically, a system of pits and pipes conveys stormwater from urban areas to receiving waterways more frequently and in greater volumes than what happens naturally. This stormwater carries large volumes of pollutants, such as nutrients, sediment, and litter. Vegetated stormwater assets, such as bioretention systems and wetlands, can reduce the impacts of urban stormwater provided they are well planned, designed, constructed, and maintained.

A range of legislative, financial, environmental, and social imperatives is driving the need for vegetated stormwater assets. For example, in Queensland the State Planning Policy 4/10 Healthy Waters requires development to be planned, designed, constructed, and operated to manage stormwater in a way that protects waterways.

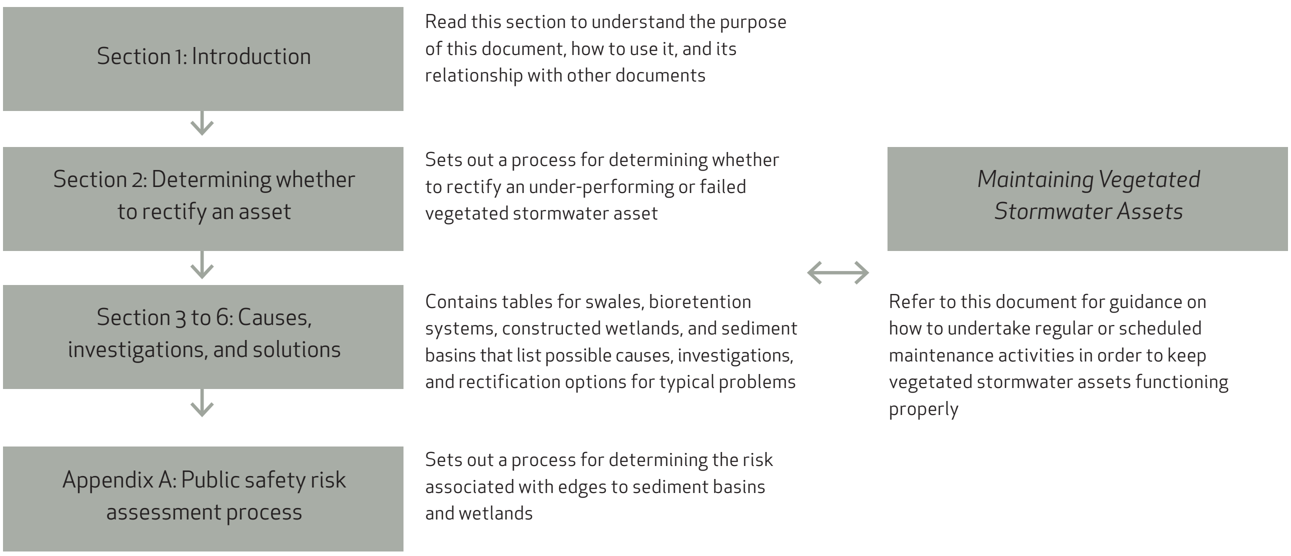
1.2 How to use this document

Figure 1 illustrates how to use *Rectifying Vegetated Stormwater Assets*.

1.3 Who should use this document

Rectifying vegetated stormwater assets requires input and cooperation from a multi-disciplinary team. While those who have a good understanding of the purpose and function of vegetated stormwater assets can use this document, they may need to consult with specialists to determine the cause of a problem or find a suitable solution when the problem is uncommon or complicated, or where a specific skill set (e.g. horticulture) is required.

Figure 1 How to use *Rectifying Vegetated Stormwater Assets*



1.4 Links with other resources

Figure 2 shows the key resource documents that Water by Design provides to help individuals and organisations sustainably manage urban water. These resources assist stakeholders to plan, design, implement, and manage vegetated stormwater assets. Refer to these resources when designing and implementing solutions to repair an under-performing or failed asset.

The documents of most relevance to rectifying vegetated stormwater assets are:

- *Construction and Establishment Guidelines* (Section 1.4.1)
- *Transferring Ownership of Vegetated Stormwater Assets* (Section 1.4.2)
- *Maintaining Vegetated Stormwater Assets* (Section 1.4.3)

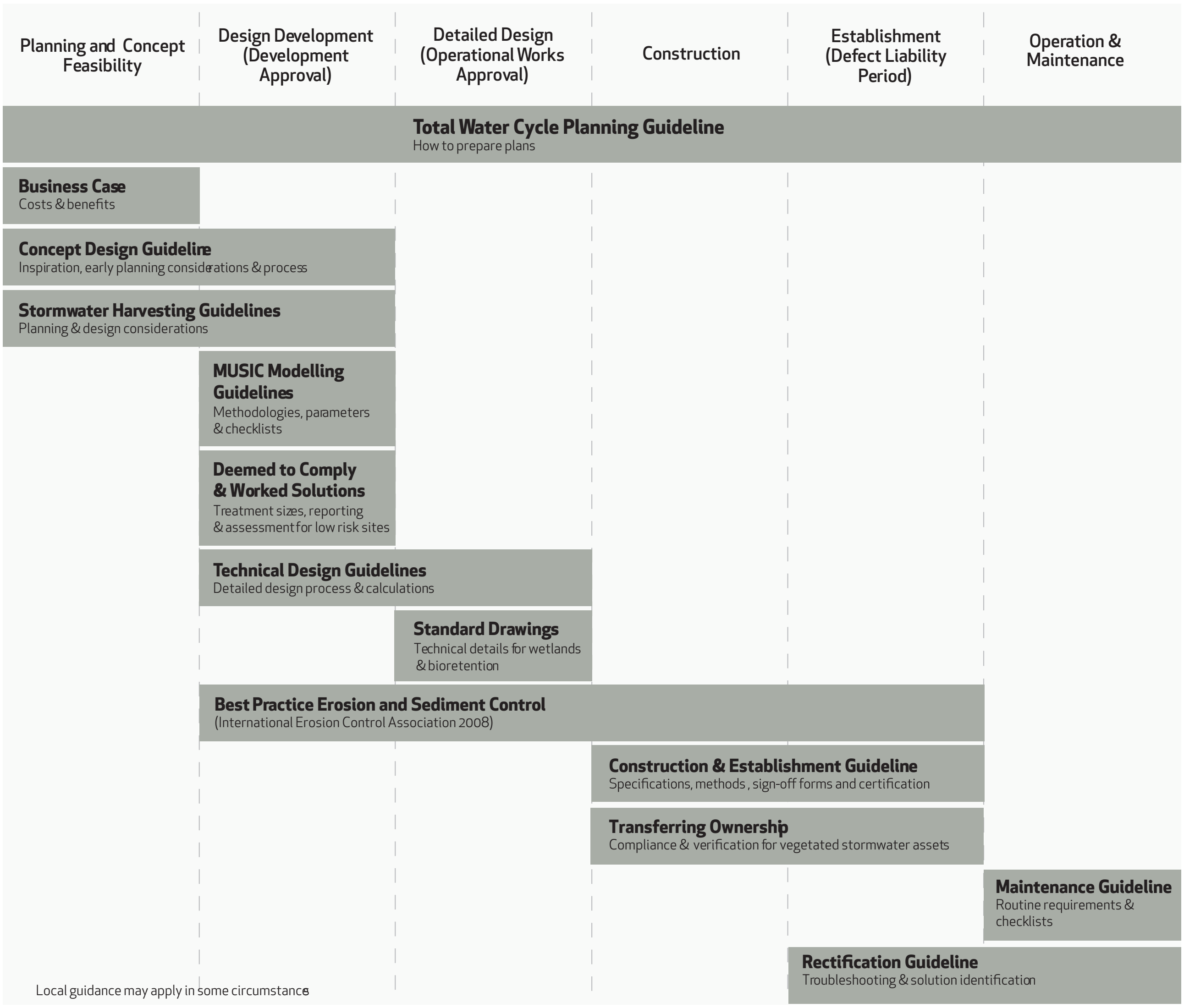
1.4.1 *Construction and Establishment Guidelines*

The *Construction and Establishment Guidelines* outline the methods for constructing and establishing swales, bioretention systems, and wetlands. For each method, step-by-step instructions are included to ensure the assets are constructed properly. The guidelines provide sign-off forms for supervisors and designers to certify the constructed assets before handing them over. For guidance on maintaining vegetated stormwater assets during the construction and establishment phase, see the *Construction and Establishment Guidelines*.

1.4.2 *Transferring Ownership of Vegetated Stormwater Assets*

Transferring Ownership of Vegetated Stormwater Assets provides guidance on how to transfer ownership

Figure 2: Vegetated stormwater asset timeline and supporting resources



of vegetated stormwater assets from the constructing party, typically the developer, to the long-term owners and managers of the assets, typically the local authority or a private entity (such as a body corporate). This is so that owners inherit assets that are functioning properly and that are meeting their design intent. It provides information, processes, and checklists to assist with each stage of the handover process. It covers swales, bioretention systems, constructed wetlands, and sediment basins.

The focus of *Transferring Ownership of Vegetated Stormwater Assets* is vegetated stormwater assets constructed as part of subdivisions. However, as many vegetated stormwater assets are created as part of other developments and remain in private ownership, handover options for private assets are included.

1.4.3 *Maintaining Vegetated Stormwater Assets*

Maintaining Vegetated Stormwater Assets helps asset managers and maintenance staff by providing practical and standard advice for maintaining swales, bioretention systems, constructed wetlands, and sediment basins. It contains:

- information to assist with planning for maintenance, including how often to undertake inspections and maintenance activities
- guidance on how to undertake typical maintenance activities
- checklists for recording the results of inspections and the maintenance activities undertaken

The inspection and maintenance checklists contain key performance indicators that field staff can use to identify whether assets are working properly.

1.5 Maintenance versus rectification

Maintenance involves regular or scheduled activities undertaken to keep vegetated stormwater assets functioning properly. Examples are weeding or removing sediment and litter. To identify if a vegetated stormwater asset is functioning properly, compare the state of the asset against the performance indicators in the inspection and maintenance checklists in *Maintaining Vegetated Stormwater Assets*. If the asset is meeting all of the performance indicators, it can be assumed that it is functioning properly. However, if the asset is not meeting the performance indicators, it needs to be decided whether maintenance will be sufficient to resolve the problem or whether rectification is needed. **Rectification** is required when there is a problem with function (e.g. the asset's ability to treat stormwater) that maintenance activities cannot address. Examples include:

- a design flaw, such as the levels of the hydraulic structures within the asset are not correct
- poor construction, such as incorrectly placed soil or filter media
- the collapse of a hydraulic structure
- mass plant failure within a wetland

Engineering or horticultural experience may be required to identify whether a problem requires rectification and within what timeframe. Problems will develop over different timeframes and some problems, if left unchecked, will develop into problems that are more serious and more difficult to rectify than the original problem. For example, if an issue with the water levels in a wetland is not picked up early, mass plant failure can result. This is a far more costly and difficult problem to repair than changing the wetland outlet to adjust the water level. Generally, addressing problems at the earliest possible stage is more cost efficient. In addition, certain components are more important to the overall functioning of the asset than others and represent different levels of risk to the asset owner. For example, permanent ponding on the surface of a bioretention system, which indicates no or very poor hydraulic conductivity of the filter media, is likely to require rectification works and should be addressed more rapidly than a recurrent patch of weeds or excess litter, which may benefit from temporarily increasing the frequency of maintenance.

If the asset has not met one or more of the performance indicators on at least two consecutive maintenance inspections, increase the maintenance frequency. If increased maintenance is still not resolving the problem, investigate the need to rectify the asset in accordance with this document.

TWO **DETERMINING WHETHER TO RECTIFY AN ASSET**

This section sets out a process for determining whether to rectify an under-performing or failed vegetated stormwater asset. It may not be possible to rectify an asset when:

- there is a serious function or design defect e.g. the surface of the bioretention system is lower than the receiving waterway and levels cannot be amended, or the asset does not accept any stormwater inflows as it is in the wrong location
- the problem is large and costly to repair and better environmental, social, and economic outcomes would result from the owner investing in works elsewhere

2.1 Identify the cause of the problem and possible solutions

Vegetated stormwater assets under-perform or fail for a variety of reasons (see Table 1). To identify the cause (or combination of causes) of the problem, undertake a site inspection and identify if the observed problem is listed in the tables in Sections 3.1 to 3.4. These tables describe possible causes for a range of problems and specify the investigations that an asset owner should undertake to confirm each cause. Solutions are listed for each cause. If the tables in Sections 3.1 to 3.4 do not list the problem or the cause cannot be identified, seek specialist advice.

In many instances, identifying the cause(s) of the problem will require an understanding of the levels (i.e. elevations) of various components of the asset. If no as-constructed survey information exists for an asset, a topographic survey should be undertaken. As a minimum, a dumpy level can be used to confirm relative heights within the asset, between the asset elements, and of upstream and downstream drainage systems.

Table 1 Typical reasons why vegetated stormwater assets under-perform or fail

Reason	Explanation
Design faults	Design faults can result in a range of operational problems. Miscalculation of the hydrologic regime, undersized outlet structures, or the wrong levels used in the design can cause problems. For example, permanent ponding in a bioretention system because the outlet is lower than the receiving drainage system can result from the asset being designed and constructed with incorrect survey data.
Poor construction and establishment	Poor or inappropriate construction techniques can lead to ongoing problems with an asset. For example, a damaged or incorrectly installed wetland liner can cause a wetland to leak, leading to excessive water loss and plant failure.
Lack of maintenance	A lack of maintenance can cause problems, such as excess sediment accumulation or weed infestation.
Unusual/unforseen influence	Unusual activities within a catchment can create an abnormally high amount of sediment, pollutants, or weeds being delivered to the asset. Other actions can affect the functioning of an asset. For example, if a swale is filled in because its function is not understood.

2.2 Determine liability

Competent design and development assessment, proper construction and establishment, inspections during the asset transfer process, and adequate maintenance can avoid a range of problems with vegetated stormwater assets.

Investigations into the cause of the problem should also determine liability, in order to identify:

- whether the cost of rectifying the works may be recovered in part or in full
- mechanisms and strategies to prevent similar problems recurring (e.g. better use of checklists as part of development assessment or additional training of compliance staff)

Determining liability may involve reviewing detailed design and as-constructed drawings, development assessment documents, construction and establishment sign-off forms, compliance checklists, or inspection and maintenance checklists.

2.3 Undertake a feasibility assessment

A feasibility assessment may be required to determine whether to implement a solution. Important factors to consider include:

- regulatory requirements (Section 2.3.1)
- costs and benefits (Section 2.3.2)
- environmental considerations (Section 2.3.3)
- alternative solutions (Section 2.3.4)

2.3.1 Regulatory requirements

There are certain federal, state, and local regulatory requirements that drive the need to rectify an under-performing or failed asset. Examples of statutory requirements include, but are not limited to, the following:

- public safety and health, e.g. managing public access and potential algae blooms
- declared weeds
- impacts on the natural environment
- water quality obligations, e.g. in Queensland, requirements to protect and maintain waterways are enacted through the *Environmental Protection Act (1994)* and the State Planning Policy 4/10 Healthy Waters
- hydrology and hydraulics, e.g. flooding

2.3.2 Cost and benefits

A feasibility assessment should consider the estimated cost of rectifying the asset, the budget available for maintenance and rectification works, the benefit of undertaking the works, and the costs associated with delaying the works. In some instances where the problem is large and costly to repair, better environmental, social, and economic outcomes may result from the owner investing in works elsewhere.

It is usually more cost effective to rectify an asset as soon as possible for a range of reasons:

- undertaking works to address a recurring problem (e.g. persistent ingress of weeds or excess sediment deposition) should reduce maintenance requirements
- if there is a significant delay between identifying the problem and rectifying it, the problem may expand to a larger problem that is more costly to repair
- undertaking works early may reduce environmental degradation in the downstream waterway and avoid the need to rehabilitate the waterway
- rectifying an asset can help maintain property values by improving aesthetics

The value the community places on vegetated stormwater assets can also influence the decision to repair a failed or under-performing asset. Consider if:

- the asset has important environmental values
- more importance may be placed on aesthetics because the asset is located in a prominent location
- the asset provides passive recreational opportunities

2.3.3 Environmental considerations

A feasibility assessment needs to consider the impacts of an under-performing or failed asset, and the impacts of rectifying it, on ecosystem services and the broader ecological context. This includes the effect on the:

- downstream receiving environment, e.g. the failed asset may be causing sediment or weeds to enter a downstream wetland
- stormwater treatment train, e.g. removing a streetscape bioretention system could overload a downstream bioretention system or wetland
- connectivity with surrounding ecosystems, e.g. transforming a bioretention system to a wetland may help to link the asset with a regional wetland or riparian zone
- habitat, e.g. a wetland may provide habitat for a rare frog species

Factors, such as protected plant or animal species and the vicinity of conservation areas within or adjoining assets, can influence the solution chosen, the timing of works, and the process and approvals required.

2.3.4 Alternative solutions

If the problem is large or costly to repair, consider if there are alternative solutions that could meet regulatory requirements and provide better environmental, social, and economic outcomes. Options include converting the asset into a different vegetated stormwater asset (e.g. changing a bioretention system to a wetland) or filling the asset in, replacing it with a suitable stormwater conveyance network, and investing in works elsewhere.

2.4 Document the findings

When reporting the findings of an investigation, document the:

- location of the failed asset, the catchment it is within, and, if applicable, the asset's reference or identification number from the local authority's data or asset management system
- problem, cause, and interim measures needed to manage the failed asset
- (if applicable) liability for poor design, construction, establishment, or maintenance to determine whether the costs of works may be recovered in part or in full
- feasibility and risk assessment process and outcomes, including cost, public safety, environmental obligations and hazards, and ecological context
- solution or alternatives that provide the same outcomes as the decommissioned asset
- interim management measures[1]
- mechanisms and strategies to prevent similar problems recurring (e.g. better use of checklists as part of development assessment or additional training of compliance staff)

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1. There may be some time between identifying a problem and rectifying an asset. While developing a solution, undertake a minimum level of maintenance to ensure that the asset is not causing a public safety or environmental hazard. Refer to *Maintaining Vegetated Stormwater Assets* for more information on interim management of non-functional systems.

THREE **CAUSES, INVESTIGATIONS, AND SOLUTIONS**

3.1 Swales

Section 3.1 provides guidance to rectify swales. Problems with swales include:

- ponded water or boggy conditions (Figure 3)
- localised flooding (Figure 4)
- excess accumulated sediment (Figure 5 and Figure 6)
- scour of the base (Figure 7 and Figure 8)
- erosion (Figure 9)

Table 2 sets out possible causes, investigations, and options for rectifying problems with swales.

Figure 3 Swale with ponded water due to uneven longitudinal profile and poorly draining soil

(Photo: Jason Sonneman, DesignFlow)

Figure 4 Localised flooding due to the swale being partially filled in

(Photo: Shaun Leinster, DesignFlow)

Figure 5 Swale with excessive sediment

(Photo: Jason Sonneman, DesignFlow)

Figure 6 Swale with excessive sediment

(Photo: Paul Dubowski, Healthy Waterways)

Figure 7 Scour of the base of a swale

(Photo: Georgie Wettenhall, DesignFlow)

Figure 8 Scour of the base of a swale

(Photo: Georgie Wettenhall, DesignFlow)

Figure 9 Eroded swale with preferential flow path

(Photo: Alan Hoban, Healthy Waterways)

Table 2 Guidance for rectifying swales

Problem	Possible causes	Investigations	Options
Ponded water or boggy conditions (Figure 3)	The under-drain pipe is blocked.	Check that the under-drain pipe is free draining.	– Use high-pressure water to flush the under-drain pipe via inspection or access pits and pipes.
	There is no under-drain pipe.	Partially excavate the swale invert to inspect if there is an under-drain pipe.	– Install an under-drain pipe and sand trench.
	Fine sediment is clogging the filter sock over the under-drain pipe. (Filter cloth is not recommended).	Check whether the filter cloth around the under-drain pipe is free draining and undertake the following simple dispersibility test to assess whether the soil contains fine clays, which are likely to be clogging the filter cloth: put some of the soil in a jar of water, shake, and see how long the water takes to clear. If it takes more than about two hours to clear, then the soils consist of fine clays that will block filter cloths.	– Remove the filter cloth from around the under-drain pipe. This will generally require partial or full removal of the base of the swale to expose the pipe. – If there is excessive clay or fine sediments, replace the soil media in the invert. If clay soils cannot be avoided, use a layer of gravel or sand to separate the under-drainage and soils, remove filter fabrics, and ensure good vegetation cover.
	The soil is poorly drained, e.g. there is an impermeable clay layer below the soil surface.	Investigate soil quality. A detailed assessment may be required to determine the soil profile (using cores) or to test the saturated hydraulic conductivity of the soil media.	– If the upper soil layer is impermeable, replace the soil media. Retrofit the swale with under-drainage and sand trench.
	The swale is uneven from sag points caused by poor construction, local erosion, or patches of accumulated sediment.	Check for local sag points after rain and identify the cause with reference to 'Scour of the base or erosion' and 'Excess sediment' in this table.	- Fill localised sag points with topsoil or remove excess sediment. Re-grade the swale batters and invert. Re-establish vegetation if required. - If the sag points are caused by erosion, refer to 'Scour of the base or erosion' in this table. - If the sag points are caused by excess sediment, refer to 'Excess sediment' in this table.
	Groundwater is intruding via a raised groundwater level.	Check invert and batters for signs of groundwater intrusion, e.g. diffuse discharge (seeps) or precipitation of minerals (typically iron oxides) at the groundwater–soil surface interface. The investigation may require shallow monitoring wells to be installed adjacent to the swale in order to track groundwater levels and determine which way the groundwater is flowing.	- Install a sand trench and under-drain pipe within the invert of the swale to drain ponding water. - Install under-drainage sand trenches either side of the vegetation within the swale (i.e. subsurface trenches within the batters) and under-drain pipe. - Rebuild the swale with an impervious liner in the base, considering where groundwater will discharge.

Problem	Possible causes	Investigations	Options
	Unexpected inflows to the asset e.g. from a baseflow or due to a cross-connection	Confirm the presence of and details of any baseflow entering the asset, including flow rate and quality. Otherwise, identify if there is a cross connection.	- Construct a bypass (e.g. low-flow pipe or channel) to divert the baseflows around the asset.
	The asset was incorrectly designed or constructed without adequate grade (>1%) so the swale is unable to drain freely via gravity.	Check the invert and profile of the swale, undertaking a survey if needed.	- Re-grade the swale invert.
Localised flooding	The swale has been filled in (Figure 4).	Compare the longitudinal profile of the swale with adjacent properties. Check the as-constructed survey.	- Remove fill, re-establish design cross section, and vegetate. Inform the residents about the functional requirements, the importance of the swale in treating stormwater, and the risks of localised flooding if the swale is modified. - Decommission the swale. Replace with an underground pipe system and stormwater treatment elsewhere in the catchment.
	The sediment basin is under-sized in relation to its catchment.	Verify if the swale is adequately sized by: - confirming the upstream catchment area and land use - (if applicable) reviewing the hydraulic/hydrologic or water quality models used to size the swale - determining if the swale is adequately sized in relation to the design flow rate	- Increase the size (cross-sectional area) of the swale.
	Vegetation that is too dense or high has reduced the flow area.	Identify if the vegetation in the swale matches the design channel roughness coefficient (refer to the *Technical Design Guidelines* for further explanation).	- Remove the vegetation and replace with species that provide the design channel roughness coefficient (i.e. are less dense).
	Excess sediment has reduced the flow area.	Refer to 'Excess sediment accumulated in the invert of the swale.'	
	Culverts at driveway cross overs are undersized.	Assess if the culverts are sized correctly by confirming the design flow and verifying the pipe and culvert sizes required to convey the design flow.	- Install a correctly sized culvert.
	Coarse debris and litter is blocking culverts at driveway crossovers.	Investigate the source(s) of the debris and litter.	- Retrofit the catchment with litter control mechanisms. - Educate the public to help reduce the volume of litter entering the drainage system.

Problem	Possible causes	Investigations	Options
Excess sediment (Figure 5 & Figure 6)	Increased or unexpectedly large sediment loads are coming from the catchment due to unforeseen activities or because of poor erosion and sediment control.	Investigate upstream catchment activities to identify the sediment source.	- Enforce erosion and sediment control on construction sites within the catchment. - Install additional sediment capture upstream of the asset (e.g. sediment forebays).
Scour of the base (Figure 7 & Figure 8) or erosion (Figure 9)	If the batters have eroded, flows may be entering the swale laterally (i.e. run-off is discharging down the batters) and there is no erosion dissipation or surface protection (i.e. vegetation).	Inspect the swale (during rainfall if possible) to determine where lateral inflows are coming from and their velocity. If there is no vegetation, it may be necessary to investigate why. Refer to 'Plant failure' in this table.	- Direct lateral flows to small, reinforced channels that feed down the batters to the swale base. - Re-establish vegetation.
	The asset has poor vegetation cover, which has left the surface susceptible to erosion.	Refer to 'Plant failure' in this table.	
	The soil is inappropriate, i.e. it has high: - clay content (e.g. > 30%) - sand content (e.g. >70%) - salt levels or low carbon levels (<5%) - sodium adsorption ratio[2] (>10)	Undertake an analysis of the soil to identify if it meets the specifications in AS4419—*Soils for landscaping and garden use* (2003), considering: - soil particle size distribution - soil pH - salinity (soluble salts) - organic matter (carbon) - sodium adsorption ratio (SAR) Collect soil samples near the scour at surface and mid-depth (100 mm).	- Seek advice from the soil laboratory for options on how to remediate the soil in order to meet the specifications. In most cases, in-situ remediation of the soil will be possible. If not, remove and replace the soil or cover it (e.g. with hydromulch, pinned down mulch, or organic matting). - Re-establish the vegetation, using species that can stabilise the soil.
	The batter slopes are too steep.	Determine whether the soils have a suitable structure (see above) to provide the necessary stability for the slope of the batter.	- Flatten out the batters of the swale, ensuring that the overall cross-sectional area of the swale is retained and hydraulic conveyance checks are undertaken.
	Vehicles or other activities, such as trampling, grazing, walking, bike riding, or vandalism, have damaged the vegetation or the surface and created preferential flow paths.	Refer to 'Plant failure' in this table.	

2. Sodium Absorption Ratio (SAR) is often related to high pH or salinity. Soils with high SAR values (>10) tend to have poor structure and low water infiltration and percolation rates.

Problem	Possible causes	Investigations	Options
	The velocities within the swale are too high and there is no energy dissipation, e.g. rock protection or surface protection (vegetation).	Confirm the swale is designed and constructed in accordance with best practice (see the *Technical Design Guidelines* and *Construction and Establishment Guidelines*), considering: - batter slopes - longitudinal slope of swale - configuration of the high-flow bypass - height and density of the vegetation compared to the design channel roughness coefficient - MUSIC model (or other method) used to size the swale - size in relation to the design flow rate - need for energy dissipation and flow distribution If there is no vegetation, it may be necessary to investigate why. Refer to 'Plant failure' in this table.	- Stabilise the upslope extent of erosion with rocks or filter cloth. - Replace topsoil and plant eroded zones with appropriate plant species. - Modify the swale cross-section to accommodate the design flow rate, which may require re-grading the swale batters and invert, replacing topsoil, and revegetating. - Provide flow control to divert stormwater flows from the swale. - Remove the existing vegetation and replace it with plant species that provide the design channel roughness coefficient. - Provide energy dissipation at the stormwater outfall by installing rock protection or re-configuring the inflow system, e.g. inlet pipes, flow distribution. - Re-configure the high-flow bypass. - Redirect lateral flows to small, rock-lined channels that flow down batters to the swale invert.
Plant failure	The vegetation was planted too sparsely or using an incorrect technique.	Review the construction and establishment documentation to identify if the asset was properly constructed.	- Plant additional vegetation to increase the density. More established seedlings (e.g. 150 mm tubes and pots) may need to be used.
	The plants received inadequate water or fertilizer during establishment.	Review the construction and establishment documentation to identify if the asset was properly established.	- Apply fertilizer and water in accordance with the *Construction and Establishment Guidelines*.
	The wrong depth (>200mm) or type of topsoil was used (see the *Construction and Establishment Guidelines*).	Undertake an analysis of the soil to identify if it meets the specifications in *AS4419—Soils for landscaping and garden use* (2003), considering: - soil pH - salinity (soluble salts) - organic matter (carbon) - nutrient content - sodium adsorption ratio (SAR) - water holding capacity (field capacity) Collect soil samples at surface and mid-depth (100 mm).	- Seek advice from the soil laboratory for options on how to remediate the soil in order to meet the specifications. In most cases, in-situ remediation of the soil will be possible. If not, remove and replace the soil and revegetate in accordance with the *Construction and Establishment Guidelines*.

Problem	Possible causes	Investigations	Options
	The wrong depth or type of mulch was used, or it has washed away.	Identify the depth and type of mulch and compare with the recommendations in the *Construction and Establishment Guidelines*.	- Replace the mulch in accordance with the *Construction and Establishment Guidelines*. - If the mulch layer is > 75 mm, remove the excess mulch.
	Inappropriate species were planted.	Identify if the species planted were appropriate for the soil type, climate, and inundation frequency. This may include reviewing the design drawings to identify if the species were planted in accordance with the design and checking whether the correct species were specified in the design.	- Re-establish the vegetation with species that are growing well in other parts of the asset or that an ecologist or horticulturist recommends. Refer to the *Construction and Establishment Guidelines* for replanting methods.
	Vehicles or other activities, such as trampling, grazing, walking, bike riding, or vandalism, have damaged the vegetation.	Check for evidence of physical damage, e.g. tyre depressions, trampled vegetation, or parked cars.	- Educate residents or use signage to raise awareness of the asset's importance and functional requirements. - Discourage access by using rocks, bollards, or dense species along the edges of the asset. If necessary, install a temporary protective barrier while the vegetation is establishing. - Create a preferable pedestrian route.
	The vegetation was maintained incorrectly.	Look for evidence of mowed or cut vegetation or for evidence of sprayed herbicide.	- Provide training for maintenance staff on vegetated stormwater assets. - Install a hard edge between the edge plantings and mown areas to delineate the area to mow.
	The plants are water logged.	Check plants for signs of water logging, which include: - slow or stunted plant growth - fungal disease, particularly rotting around lower stem - reduced ground or canopy cover - premature senescence, plant death, or composition change - moss or algae growth on the surface Refer to 'Surface ponding or boggy conditions' in this table to identify the cause of the water logging and options.	

Problem	Possible causes	Investigations	Options
	The plants are diseased or have been damaged by insects.	Check for symptoms of plant disease or insect damage, which may include: - chlorosis or foliage discoloration - browning of the leaves - wilting - powdery mildew or rust (fungal infections) - stunted growth - insect bore holes - callus development - physical leaf damage (portions of the leaf are missing where it has been eaten) - leaf roll	- In most cases, plants can be expected to recover from minor diseases or insect damage without intervention. If the plant damage or loss persists, consider: • mitigating disease and insects • selecting plants that are resistant to disease and insects • timing inspection and maintenance activities to align with peak risk times for plant disease or insect damage Refer to the *Construction and Establishment Guidelines* for replanting guidance.
	Lack of soil moisture due to drought.		- Replace the vegetation with drought-tolerant species or establish a temporary irrigation program.
	Weeds are preventing the plants from propagating.	Determine what proportion of plants are weed species and refer to 'Weeds' in this table.	
Weeds – persistent weed ingress or excessive cover (greater than 20%) that cannot be managed effectively via maintenance activities	Weeds are present/uncontrolled in the catchment. Excess sediment has accumulated. Inspections and maintenance are not undertaken regularly. The soil conditions are favorable for weeds. The fill or mulch is contaminated.	Identify the weed species present and the cause of the weed infestation, including checking upstream waterways and adjoining land areas for the presence of weeds (particularly noting areas directly connected to the asset).	- Completely remove the weed species using the methods listed in *Maintaining Vegetated Stormwater Assets*. Weed removal or control strategies will vary according to the biological characteristics of the species (e.g. growing habits, seeding times, water tolerance), the extent of cover, the location of the asset, and the potential impacts on the desirable vegetation within the basin and the downstream ecosystem. Prevent the future ingress of weeds by planting the batters with species that provide dense cover and shade and by increasing the frequency of inspections and maintenance.
	Water is ponding on the surface or the surface is boggy.	Refer to 'Surface ponding or boggy conditions' in this table.	

Problem	Possible causes	Investigations	Options
	The plant density is insufficient or the vegetation has died.	Compare the vegetation density with the performance indicators in *Maintaining Vegetated Stormwater Assets* and refer to 'Plant failure' in this table to identify why there is a lack of plant cover.	
Moss or algae growth	The swale is constantly wet.	Refer to 'Surface ponding or boggy conditions' in this table.	
The batters or edge treatments are too steep or provide a trip hazard	The swale was poorly designed. The batters have eroded.	Assess the suitability of the: - batter slopes - edge treatments (e.g. concrete revetments, walls) - perimeter vegetation (species used, density, height) Refer to 'Scour of the base or erosion' in this table.	- Modify the cross-sectional profile to provide safe batters. Maximum batter slope recommended is 1:4. - Raise the base of the swale to reduce wall heights or batter slopes. This may require the installation of a surcharge system to get flows onto the raised swale surface. - Modify edge treatments (e.g. concrete revetments, curbs). - Replant the perimeter with appropriate plant species, considering density and height. - Decommission the swale and replace with an underground pipe system and stormwater treatment system elsewhere in the catchment.
	The batters have severely eroded.	Refer to 'Scour of the base or erosion' in this table.	
Mosquitoes	There is shallow ponded water.	Check if shallow pools of water remain in the swale more than 48 hours after rain and refer to 'Water logging' and 'Groundwater is intruding via a raised groundwater level' in this table to determine the cause of the ponded water.	

3.2 Bioretention systems

Section 3.2 provides guidance to rectify bioretention systems. Problems with bioretention systems include:

- ponded water or boggy conditions (Figure 10 and Figure 11)
- backwatering (Figure 12)
- poor distribution of water across the surface (Figure 13 and Figure 14)
- scour at outlet pit (Figure 15)
- scour of inlet or filter media (Figure 16 and Figure 17)
- erosion on batter slopes due to poorly structured soils (Figure 18)
- sparse plant cover due to wrong species planted and inadequate water or fertilizer during establishment (Figure 19)
- inappropriate mulch (Figure 20)
- poor plant cover due to groundwater interaction and acid sulfate soil ingress (Figure 21 and Figure 22)
- extensive weeds
- blinding of the surface due to algal biofilms and deposition of fine sediment (Figure 23)
- moss growth on the surface due to incorrect filter media and lack of plant density (Figure 24)

Table 3 sets out possible causes, investigations, and options for rectifying problems with bioretention systems.

Figure 10 Bioretention system with water ponded on the surface

(Photo: Jason Sonneman, DesignFlow)

Figure 11 Bioretention system with water ponded on the surface due to inappropriate filter media

(Photo: Jason Sonneman, DesignFlow)

Figure 12 Bioretention system subject to backwatering: the surface level has been set below the level of the downstream receiving waterway

(Photo: Alan Hoban, Healthy Waterways)

Figure 13 Bioretention system where there is poor distribution of water across the surface because the surface level of the filter media has been incorrectly constructed above the inlet level

(Photo: Jason Sonneman, DesignFlow)

Figure 14 Bioretention system where there is poor distribution of water across the surface because the surface is not flat

(Photo: Leon Rowlands, Sunshine Coast Regional Council)

Figure 15 Scour at the outlet pit of a bioretention system due to lack of compaction. Erosion and scour are typical issues for the interface between structural elements (such as a concrete walls or pits) and 'soft' elements (such as soil filter media)

(Photo: Shaun Leinster, DesignFlow)

Figure 16 Severe erosion at inlet to a bioretention system

(Photo: Paul Dubowski, Healthy Waterways)

Figure 17 Bioretention system where the filter media has been scoured-out and displaced

(Photo: Paul Dubowski, Healthy Waterways)

Figure 18 Erosion on batter slopes of a bioretention system due to dispersive soils

(Photo: Ralph Williams, DesignFlow)

Figure 19 Bioretention system with sparse plant coverage due to wrong species selection and poor establishment (e.g. the plants received inadequate water or fertilizer during establishment)

(Photo: Shaun Leinster, DesignFlow)

Figure 20 Bioretention system with inappropriate mulch that is preventing plant propagation

(Photo: Shaun Leinster, DesignFlow)

Figure 21 Bioretention system with poor plant coverage due to interaction with groundwater and acid sulfate soil ingress

(Photo: Shaun Leinster, DesignFlow)

Figure 22 Bioretention system with poor plant coverage due to interaction with groundwater and acid sulfate soil ingress

(Photo: Shaun Leinster, DesignFlow)

Figure 23 Blinding of the surface of a bioretention system due to algal biofilms and deposition of fine sediment

(Photo: Andrew O'Neill, DesignFlow)

Figure 24 Moss growth on the surface of a bioretention system due to incorrect filter media and low plant density

(Photo: Paul Dubowski, Healthy Waterways)

Table 3 Guidance for rectifying bioretention systems

Problem	Possible causes	Investigations	Options
Ponded water or boggy conditions (Figure 10 and Figure 11)	The surface of the filter media is blinded or blocked with sediment.	Confirm by scraping back the surface of the sediment to the filter media and filling the void with water to see if it drains. If the filter media does not readily drain, investigate the sediment source(s) and undertake in-situ hydraulic conductivity testing at the surface, middle, and bottom of the filter media in accordance with *Practice Note 1: In-Situ Measurement of Hydraulic Conductivity* (Hatt and Le Coustumer, 2008). If the testing finds that the low hydraulic conductivity (<10 mm/hr) is confined to the surface, the cause of the ponding is most likely surface blinding. **Note**: the hydraulic conductivity within most bioretention systems will decrease in the first 12–15 months after the plants have established but it should recover to within the design range.	- Enforce erosion and sediment control on construction sites within the catchment. - Install additional sediment capture upstream of the asset (e.g. sediment forebays). - For basins with >15 mm of fine sediment over the filter media, remove as much fine sediment as possible and rake or scarify the surface. - Allow existing plants to propagate to break up the surface. If the vegetation density is less than four to six plants per m^2 [3], plant rushes, grasses, and trees (if the filter media depth is sufficient) to increase plant and root density. - If these solutions do not result in improved infiltration (>50 mm/hr) after 12 months, remove the surface layer of sediment, re-install filter media to achieve the design surface level, mulch, and replant.
	The transition layer or drainage layer is blocked with sediment.	Undertake sediment cores all the way to the base of the drainage layer at a number of locations, noting any changes in soil layers, particularly the transition and drainage layers. The number of cores depends on the size of bioretention system and area of ponding. Collect samples in the transition layer and drainage layer, particularly in the areas of suspected fine accumulation. Test samples for particle size distribution and saturated hydraulic conductivity in accordance with the *Guidelines for Filter Media in Bioretention Systems* (FAWB).	- The only solution for rectifying blockages in the transition layer or drainage layer is to remove the filter media, transition layer, and drainage layer and potentially remove the under-drains. Re-install the various layers of the bioretention system and re-establish with vegetation in accordance with the *Construction and Establishment Guidelines*. If reusing the filter media, test in accordance with the *Construction and Establishment Guidelines*.

3. The density depends on the species. Refer to the *Technical Design Guidelines* for more information.

Problem	Possible causes	Investigations	Options
	Fine sediment is clogging the filter cloth over the under-drain pipe or between the filter media and transition layer or drainage layer. (Filter cloth is not recommended).	Inspect drainage within the bioretention system and partially excavate the bioretention filter layers.	- If the cloth is permeable, check for other possible causes of blockage before removing the filter cloth. - If the cloth is blocked, remove it from between the filter layers or the under-drain pipe. This will generally require partial or full removal of the bioretention filter bed (filter media, transition, and drainage layers) to expose the under-drain pipes. Re-install the various layers of the bioretention system and re-establish with vegetation in accordance with the *Construction and Establishment Guidelines*. If reusing the filter media, test in accordance with the *Construction and Establishment Guidelines*.
	The under-drains are blocked.	Check if flow is exiting all the under-drains during or immediately after rainfall to determine which under-drains are blocked. Inspect the blocked under-drains using cameras through the cleanout points to confirm the blockage (i.e. sediment, roots or other). The design or as-constructed drawings will confirm the location of the under-drains and cleanout points.	- If sediment is blocking the under-drain pipes, flush with high-pressure water at the cleanout points. - If roots are blocking the under-drain pipes, use a cutting tool.
	The asset was incorrectly designed or constructed with the outlet below the receiving water level or invert level, or the surface is backwatered by the tailwater level (Figure 12).	Determine the outlet level, then compare with the water level and invert level of the receiving system.	– If downstream water levels are causing backwatering into the system, investigate ways to lower the water or invert levels. – Investigate raising the outlet structure to allow free drainage by reducing the depth of the filter media or converting the asset to have a saturated zone. Changes to water quality treatment will need to be considered. – Investigate using a surcharge system at the inlet and raising the surface level of the filter media. Flooding and other conveyance impacts on the upstream drainage system will need to be considered. – If none of these options is possible, consider converting the bioretention system to a constructed wetland or a swale. Changes to water quality treatment will need to be considered e.g. additional treatment may be needed to meet the water quality objectives for the catchment.

Problem	Possible causes	Investigations	Options
	The media has structurally collapsed[4] because of incorrect or poorly compacted media during construction. The filter media has insufficient hydraulic conductivity.	Determine the hydraulic conductivity rate of the filter media. Test at the surface, middle, and bottom of the filter media profile in accordance with *Practice Note 1: In-Situ Measurement of Hydraulic Conductivity* (Hatt and Le Coustumer, 2008). Take sediment cores at a number of locations, noting any changes in soil layers. The number of cores depends on the size of the system and the area of ponding. Collect samples at the surface, bottom, and one or two other depths within the profile, particularly in the areas of suspected fine accumulation. Test samples for particle size distribution and saturated hydraulic conductivity in accordance with the *Guidelines for Filler Media in Bioretention Systems* (FAWB, 2008).	- Allow existing plants to propagate to break up the surface. If the vegetation density is less than four to six plants per m^2 [5], plant rushes, grasses, and trees (if the filter media depth is sufficient) to increase plant and root density. - If these solutions do not result in improved infiltration (>50 mm/hr) after 12 months or if the structural collapse results in constant surface ponding, install new filter media, mulch, and replant in accordance with the *Construction and Establishment Guidelines*.
	The under-drains are not connected into the outlet pit or are connected into the pit at the wrong level.	Check the pit to see if the under-drains have been connected into the pit. If the under-drains are connected into the pit, take level measurements in relation to the filter media surface to ensure the connections are at the correct level.	If the under-drains are not connected into the pit: - Locally excavate the bioretention layers adjacent to the pit by hand to uncover the under-drains. This may be a challenge if the under-drains are not close to the pit. Dewatering with a pump may be required. - Cut holes into the pit at the correct level to ensure free drainage. Review the initial designs. - Allow the excavated area to drain into the pit through the holes and dry out. - Connect the under-drains into the pit and seal around perimeter of the pit. - Watch how the bioretention system operates during rainfall to ensure it is functional .
	Unexpected inflows to the asset e.g. from a baseflow or due to a cross- connection	Confirm the presence of and details of any baseflow entering the asset, including flow rate and quality. Otherwise, identify if there is a cross connection.	- Construct a bypass (e.g. low-flow pipe or channel) to divert the baseflows around the bioretention system .

4. Structural collapse is where the soil structure is unable to hold fine soil in place. A concentration of fine sediment particles in the lower profile of the filter media can block the movement of water through the system.
5. The density depends on the species. Refer to the *Technical Design Guidelines* for more information.

Problem	Possible causes	Investigations	Options
	The bioretention system is undersized in relation to its catchment (so it is inundated too frequently).	Verify if the bioretention system is adequately sized by: - obtaining the as-constructed survey, including all of the hydraulic structures - confirming the bathymetry matches the design to ± 25 mm - confirming the design is consistent with the *Technical Design Guidelines*	- Resize and re-construct the system. - Re-configure the inflow system (e.g. inlet pipes) to restrict the volume of water able to enter the bioretention system. - Re-configure the outlet pit to lower the extended detention depth and bypass additional stormwater volume from the asset. - Replace the filter media to increase hydraulic conductivity and so improve the filter's ability to cope to with higher than expected inflows. - Select plant species that are able to cope with an increased inundation frequency.
Poor distribution of water across the surface	The surface of the bioretention system is not flat or even due to: - poor construction - damage caused by high flows or by another source such as vandalism or fauna - subsidence of the filter bed - excessive sedimentation on the filter bed surface	Check the surface is flat. This may involve surveying the surface of the filter media at a number of locations using a dumpy level.	- Modify the surface of the bioretention system to create a flat, even level. This may involve temporarily removing the vegetation, modifying the filter bed surface level, and re-establishing the vegetation.
	The asset was incorrectly designed or constructed with: - incorrect surface levels, e.g. the filter media is above the inlet level (Figure 13) - inappropriate inflow configuration, e.g. the inlet is not allowing enough water to enter the asset - incorrect outlet structure, e.g. the outlet structure level is lower than the filter surface area in some locations.	Check that the bioretention system has been constructed as per the design, considering the: - filter bed surface levels - inlet structures - outlet structures (high-flow bypass) If there is no problem with the construction, consult an engineer to ensure the design is appropriate and the levels are functional.	- Remove excess filter bed material to re-set the filter bed to the correct level. This will require removing and then re-establishing the vegetation. - Re-configure the inlet or outlet structures (considering a distribution system) so the outlet allows ponding over the entire surface of the bioretention system. - If the grade across the system is significant, convert to a terraced system.

Problem	Possible causes	Investigations	Options
	Preferential flow paths from excess sediment spread unevenly on the surface. (Excess sediment may not always be obvious as it is similar in colour and texture to soil. Organic litter on the surface can also obscure sedimentation.)	- Refer to 'Excess sediment' in this table.	
	Slumping and failure of the filter media because of tunneling caused by the under-drains not being sealed into the outlet pit.	Check for evidence of short-circuiting around the outlet pit or edges of the filter media . Identify if the under-drains are connected and sealed into the pit.	- Connect and seal the under-drains into the pit by: • locally excavating the bioretention layers adjacent to the pit using hand tools to uncover the under-drains (dewatering with a pump may be required). • cutting holes into the pit at the correct level or at the base of pit, provided the pit base is at or below the gravel drainage layer to ensure free drainage (review the designs for the correct level) • allowing the excavated area to drain into the pit, through the holes, until it is dry • connecting the under-drains into the pit and seal around perimeter of the under-drains with concrete, grouting, or synthetic sealant • placing water in the base of the excavation to confirm the under-drains are sealed • replacing the drainage layer, transition layer, and filter media layer in accordance with the *Construction and Establishment Guidelines* • re-establishing the vegetation • to ensure it is functional, observing how the bioretention system operates during rainfall

Problem	Possible causes	Investigations	Options
	There is scour around the apron or concrete spill of the outlet pit (interface issues) (Figure 15).	Check that the hydraulic structures are constructed as per the design. Check for short-circuiting around the outlet pit or edges of the filter media. Check for signs of surface subsidence across the filter bed.	- Dig out the eroded sections of the bioretention profile, including the filter media, transition layer, and drainage layer well beyond the bounds of the scour. Remove the concrete apron or spill. Install a layer of filter cloth to the pit and extend it down the side of the pit into the filter media to a depth of 300 mm. Refer to the *Construction and Establishment Guidelines* for more information on this technique. Replace the drainage layer, transition layer, and filter media layer in accordance with the *Construction and Establishment Guidelines*. Re-establish the vegetation.
	A rock wall or wall without a flat vertical surface has been used to line the sides of a bioretention system and flow is scouring at the interface with the wall.	Check for evidence of short-circuiting down the edge of the wall. Ideally, this inspection should occur when it is raining.	- Place filter fabric on the wall, extending it at least 1 m onto the filter media. Install filter media or topsoil over the filter cloth to create a batter against the wall, extending the top of the batter well above the likely flood level. Wrap the filter cloth back over the top of the batter and place more topsoil on the surface. Compact, mulch, and plant. If filter cloth is not required, the topsoil can be compacted without the filter cloth. - Dig out the eroded sections of the bioretention profile, including the filter media, transition layer, and drainage layer to at least 0.5 m away from the wall. Install clay within the 0.5 m space, from the edge of the filter media to the wall. Compact the clay to ensure there is no potential flow connection from the wall to the drainage layers of the bioretention system. Install the filter fabric up the vertical edge of the clay and across the flat surface. Install the drainage layer, transition layer, and filter media and compact the layers. Mulch and plant out. For sketches of these options, refer to the *Construction and Establishment Guideline*.
	Flow has scoured down the interface between the filter media, filter cloth, and in-situ soil.	Check for evidence of short-circuiting down the edge of the wall. Ideally this inspection should occur during rainfall. Check for evidence of subsidence and scour around the edges of the filter media and adjacent in-situ soils.	- Dig out the eroded sections of the bioretention profile, including the filter media, transition layer and drainage layer, well beyond the bounds the scour. Install new filter cloth from the base of the bioretention system up the edge to extend at least 500 mm up the batters. Pin in place. Replace the drainage layer, transition layer, and filter media, and compact the layers. Place topsoil over the filter cloth on the batters.

Problem	Possible causes	Investigations	Options
	The bioretention system is oversized for the upstream catchment.	Identify if the asset is adequately sized by: - confirming the upstream catchment area and land use - (if applicable) reviewing the hydraulic/hydrologic or water quality models used to size the bioretention system	- Divert additional stormwater to the bioretention system by modifying the upstream drainage system. - Re-configure the bioretention system to create a smaller filter bed area. This may involve flattening and increasing the width of the batters. - Modify the bioretention inlet system, e.g. if there is a diversion arrangement at the bioretention inlet - Provide a distribution system from the inlet to allow water to cover the full surface area. - Convert the system to a wetland.
Excess sediment	Increased or unexpectedly large sediment loads are coming from the catchment due to unforeseen activities or because of poor erosion and sediment control.	Investigate upstream catchment activities to identify the sediment source.	- Enforce erosion and sediment control on construction sites within the catchment. - If the problem is recurring, enlarge or adjust the sediment forebay area or install additional sediment capture upstream of the asset.
Scour of inlet or filter media (Figure 16 and Figure 17)	The inflow velocities are too high and there is no energy dissipation structure or mechanism.	Determine if there is a high-flow bypass, an energy dissipation structure at the inlet, or an even flow distribution from the inlet (during rainfall if possible). Check if the asset was sized correctly during design, confirming the upstream catchment area and land use compared to the bioretention size. If the bioretention system is small for its catchment and there is no high-flow bypass, the asset will be more prone to scour. Calculate the inflow velocities. Review the inlet arrangement, considering the inlet velocities and the need for energy dissipation.	- Re-configure the inflow system by: • installing energy dissipation structures • extending the apron length on the inlet • altering the structure to encourage even flow distribution from the inlet to the rest of the surface - Re-configure the high-flow bypass to ensure that high velocity and damaging flows are prevented from entering the bioretention system. - If the bioretention system is incorrectly sized for the contributing catchment, modify or re-construct the bioretention system.
	Slumping and failure of the filter media from tunneling caused by the under-drains not being sealed into the outlet pit.	Refer to 'Poor distribution of flow across the surface' in this table.	

Problem	Possible causes	Investigations	Options
	There is erosion around the apron or concrete spill of the outlet pit (interface issues) .	Refer to 'Poor distribution of flow across the surface' in this table.	
	A rock wall or wall without a flat vertical surface has been used to line the sides of a bioretention system and flow is scouring at the interface with the wall.	Refer to 'Poor distribution of flow across the surface' in this table.	
	Flow has scoured down the interface between the filter media, filter cloth, and in-situ soil.	Refer to 'Poor distribution of flow across the surface' in this table.	
Eroded batters	The batters have poor vegetation cover, which has left the surface susceptible to erosion.	Refer to 'Plant Failure' in this table.	
	Flow is entering the system laterally.	Inspect the bioretention system (during rainfall if possible) to confirm sources of flow and how scour is occurring.	- Direct the lateral flows to small, rock-lined channels that feed down the batters to the bioretention system. Re-establish vegetation, using organic mesh or netting to avoid erosion of the batters and assist with stabilising the batters as the plants establish.
Erosion or failure of the bunds	Poorly structured soils were used to construct the batters, e.g. sodic soils (Figure 18).	Determine whether the soil has a suitable structure.	- Remediate the soil (e.g. treat sodic soils with additives). - Replace soils used for the batters. - Use filter cloth to ameliorate or limit further erosion and re-establish vegetation.
	Poorly structured soils were used to construct the bunds, e.g. sodic soils. The bund height is incorrect, i.e. crest of bund set too low resulting in overtopping. There is a lack of protection from scour, i.e. inadequate or no vegetation cover. There is no high-flow weir.	Complete a site inspection (during rainfall if possible) to identify where the flow is coming from and its velocity.	- Raise the bund wall above the top of the potential flood levels in the bioretention and provide rock protection in high velocity locations. - Install an overflow weir. Rectify scour and ensure the bund has geotechnical certification for stability and water-holding capacity. This may involve construction and clay coring, re-enforcing the berm with rock beaching, or re-establishing adequate vegetation cover.

Problem	Possible causes	Investigations	Options
Scour around the overflow weir	Flow is skirting the weir where the weir crest and grouted rock protection does not extended up the batters. (This needs to be rectified as soon as possible to avoid failure of the weir).	Check whether the weir crest and grouted rock protection extend up the batters.	- Re-construct or modify the weir crest to the correct configuration. - Extend the concrete weir crest and grouted rock batters at least 0.5 m along the top of the batter to 'key in' the weir.
Plant failure	The vegetation was planted too sparsely or using an incorrect technique.	Review the construction and establishment documentation to identify if the asset was properly constructed.	- Plant additional vegetation to increase the density. More established seedlings (e.g. 150 mm tubes and pots) may need to be used.
	The plants received inadequate water or fertilizer during establishment (Figure 19).	Review the construction and establishment documentation to identify if the asset was properly established.	- Apply fertilizer and water in accordance with the *Construction and Establishment Guidelines*.
	The wrong depth or type of mulch was used, or it has washed away (Figure 20).	Identify the depth and type of mulch and compare with the recommendations in the *Construction and Establishment Guidelines*.	- Replace the mulch in accordance with the *Construction and Establishment Guidelines*. - If the mulch layer is > 75 mm, remove the excess mulch.
	Inappropriate species were planted (Figure 19).	Identify if the species planted were appropriate. This may include reviewing the design drawings to identify if the species were planted in accordance with the design and checking whether the correct species were specified in the design.	- Re-establish the vegetation with species that are growing well in other parts of the asset or that an ecologist or horticulturist recommends. Refer to the *Construction and Establishment Guidelines* for replanting methods.
	Vehicles or other activities, such as trampling, grazing, walking, bike riding, or vandalism, have damaged the vegetation.	Check for evidence of physical damage, e.g. tyre depressions, trampled vegetation, or parked cars.	- Educate residents or use signage to raise awareness of the assets importance and functional requirements. - Discourage access by using rocks, bollards, or dense species along the edges of the asset. If necessary, install a temporary protective barrier while the vegetation is establishing. - Create a preferable pedestrian route.
	The vegetation was maintained incorrectly.	Look for evidence of mowed or cut vegetation or for evidence of sprayed herbicide.	- Provide training for maintenance staff on vegetated stormwater assets. - Install a hard edge between the edge plantings and mown areas to delineate the area to mow.

Problem	Possible causes	Investigations	Options
	The plants are water logged.	Check plants for signs of excessive inundation or drowning, which include: - loss of plants - rotting stems at the soil surface - browning foliage - water-logged filter media Refer to 'Surface ponding or boggy conditions' in this table to identify the cause of the water logging and options.	
	The plants are diseased or have been damaged by insects.	Check for symptoms of plant disease or insect damage, which may include: - chlorosis or foliage discoloration - browning of the leaves - wilting - powdery mildew or rust (fungal infections) - stunted growth - insect bore holes - callus development - physical leaf damage (portions of the leaf are missing where it has been eaten) - leaf roll	- In most cases, plants can be expected to recover from minor diseases or insect damage without intervention. If the plant damage or loss persists, consider: • mitigating disease and insects • selecting plants that are resistant to disease and insects • timing inspection and maintenance activities to align with peak risk times for plant disease or insect damage Refer to the *Construction and Establishment Guidelines* for replanting guidance.
	There is insufficient water accessing some or all of the bioretention system due to: - filter media with a hydraulic conductivity rate that is too high - the whole filter area not being inundated because the asset is oversized or there is a problem with the levels - an extended dry period or drought	Determine the hydraulic conductivity rate of the filter media. Test at the surface, middle, and bottom of the filter media profile in accordance with *Practice Note 1: In-Situ Measurement of Hydraulic Conductivity* (Hatt and Le Coustumer, 2008). Check if the filter bed surface is fully engaged during stormwater runoff events. Following stormwater runoff events look for organic litter lines around the margins of the filter bed which indicates the top water level, and dry areas within the filter bed area.	- If the hydraulic conductivity of the bioretention filter media exceeds 750 mm/hr then amend the top 150-200 mm of filter media with organics, compost, and slow release fertiliser to increase water holding capacity and nutrients to support vegetation grow. If this fails, consider replacing the filter media or the top 200 m of filter media. - if the filter area is not fully engaged during stormwater runoff events, refer to the advice on 'Filter area not fully engaged' in this table. - Replace the vegetation with drought-tolerant species or establish a temporary irrigation program.

Problem	Possible causes	Investigations	Options
	Weeds are preventing the plants from propagating.	Determine what proportion of plants are weed species and refer to 'Weeds' in this table.	
Excessive algal or moss growth on the surface (Figure 23 and Figure 24)	The bioretention filter bed surface is constantly wet.	Refer to 'Ponded water or boggy conditions' in this table to identify the cause of the wetting.	- Refer to 'surface ponding or boggy conditions' to resolve why the filter surface is constantly wet, then allow the bioretention system to dry out, remove algae by hand (optional), and replant the asset as required. Observe the asset over the next 12 months to confirm the problem is resolved.
Weeds – persistent weed ingress or excessive cover (greater than 20%) that cannot be managed effectively via maintenance activities.	Weeds are present/uncontrolled in the catchment. Excess sediment has accumulated. Inspections and maintenance are not undertaken regularly. The soil conditions are favorable for weeds. The fill or mulch is contaminated.	Inspect the bioretention system to determine vegetation cover and density. If the plant density is less than five plants per m2 or the vegetation cover is less than about 80%, it is likely that the vegetation cover is too sparse, allowing weeds into the asset. Check the bioretention system for: - weed species present within and adjacent to the bioretention system - weed cover and distribution - seed germination from within mulch or fill - stage of weed maturity and evidence of reproduction—flowers, seed heads - weed invasiveness, e.g. mass germination of seedlings	Replant where necessary according to the *Construction and Establishment Guidelines*. A minimum plant density of 6–10 plants per m2 is recommended. Responses to excessive weed invasion vary according to species, the extent of cover, and the control methods available. Consider methods that have minimal impact on desirable vegetation in the bioretention system. Options include: - Completely remove the weed species according to the control methods listed in *Maintaining Vegetated Stormwater Assets* and fully re-establish the bioretention system vegetation. Seek advice from a horticulturalist or weed specialist if chemical control is necessary. - Re-plant the bioretention system with plant species that provide dense cover and shade. Shade will inhibit the growth of weeds. - Remove contaminated fill or mulch and replace it with appropriate material. Replant, where necessary, according to the *Construction and Establishment Guidelines*. Note: In Queensland, controlling declared weeds is mandated under the *Land Protection (Pest & Stock Route Management) Act* 2002. Declared weeds must be dealt with as part of the regular maintenance schedule. Refer to *Maintaining Vegetated Stormwater Assets* for general advice about managing declared weeds.

Problem	Possible causes	Investigations	Options
	Water is ponding on the surface or the surface is boggy.	Refer to 'Surface ponding or boggy conditions' in this table.	
	The plant density is insufficient or the vegetation has died.	Compare the vegetation density with the performance indicators in *Maintaining Vegetated Stormwater Assets* and refer to 'Plant failure' in this table to identify why there is a lack of plant cover.	
The batters or edge treatments are too steep, provide a trip hazard, or allow unsafe public access into the system.	The system was poorly designed. There is a lack of access control, e.g. dense perimeter vegetation. The batters have eroded.	Assess the suitability of the: - grade of the batter slopes - edge treatments (e.g. concrete revetments, walls) - perimeter vegetation (species used, density, height) Refer to 'Plant failure' in this table. Refer to 'Eroded batters' in this table.	- Control access to hard edge treatments (e.g. concrete revetments, curbs) and remove potential trip hazards using barriers such as fences or vegetation. - Revegetate the perimeter. - Modify the bathymetry to provide safe batters. A maximum 1:4 slope is recommended for most applications.
Mosquitoes	There is ponded water or boggy conditions.	Refer to 'Ponded water or boggy conditions' in this table. If the problem persists, seek advice from a mosquito specialist.	
Lack of adequate maintenance access	The design did not allow for maintenance requirements, such as vehicle access. Vegetation or unplanned structures are blocking access to the system.	Check the approved plans to identify the proposed maintenance regime and proposed access arrangements.	- Retrofit access to the coarse sediment forebay, hydraulic control structures, and filter media. - Remove blockages.

3.3 Constructed wetlands

Section 3.3 provides guidance to rectify constructed wetlands. Problems with constructed wetlands include:

- leaking (Figure 25)
- plant failure (Figure 26)
- blocked outlet (Figure 27)
- no inlet pond (Figure 28)
- lack of vegetation (Figure 29)
- insect damage (Figure 30)
- weed invasion (Figure 31 and Figure 32)

Table 4 sets out possible causes, investigations, and options for rectifying problems with constructed wetlands.

Figure 25 A wetland with no inter-event permanent pool due to leaking. Incorrect water levels within wetlands may cause individual plant species to fail, plants within a particular zone of a wetland to fail, or mass plant failure across the whole wetland. Poor health of plants or failing plants is a sign that the water level regime may be inadequate.

(Photo: Alan Hoban, Healthy Waterways)

Figure 26 Plant failure in a wetland with establishment of a preferential flow path down the centre of the wetland. Scour of vegetation can occur when flows entering the macrophyte zone from the inlet pond are large or have high velocity. The density and arrangement of planted species can also affect flow paths.

(Photo: Jason Sonneman, DesignFlow)

Figure 27 Blocked wetland outlet structure resulting in higher standing water levels in wetland and failure of wetland vegetation due to drowning

(Photos: Shaun Leinster, DesignFlow)

Figure 28 Online wetland with no inlet pond. Coarse sediment is smothering the vegetation.

(Photos: Shaun Leinster, Ecological Engineering)

Figure 29 Example of constructed wetland with low vegetation coverage (<20%) due to water depths greater than 0.5m

(Photos: Shaun Leinster, DesignFlow)

Figure 30 Insect damage on *Baeumea articulata*

(Photo: Jason Sonneman, DesignFlow)

Figure 31 Weed invasion in a constructed wetland—para grass. Regular maintenance activities address weed management; however, weeds can be a recurring issue or can even over-run some assets.

(Photo: Jason Sonneman, DesignFlow)

Figure 32 Examples of weed invasion in a constructed wetland—Salvinia.

(Photo: Jason Sonneman, DesignFlow)

Table 4 Guidance on how to rectify constructed wetlands

Problem	Possible causes	Investigations	Options
Plant failure	Fauna, including water birds and carp, have damaged the vegetation.	Check for signs of obvious damage to wetland vegetation, including: - large amounts of floating macrophyte debris - evidence of extensive grazing, trampling, or nesting, e.g. areas >5 m2 where macrophytes have been physically trampled form walk lines - areas where the vegetation has been physically displaced, e.g. areas where carp have uprooted plants	- Use netting to reduce bird access to sensitive vegetation. - Remove or cull birds. - Encourage swamp hens to leave the area by dropping the water level before and during breeding time. - Remove or reduce the population of fish. - Use signage to encourage visitors not to feed birds. - Re-establish large areas of damaged macrophytes. In most cases, the damaged macrophytes will recover rapidly once the source of the problem is removed.
	Siltation due to: - failure in the inlet zone (inlet pond), causing large amounts of sediments to be released into the macrophyte zone - no inlet zone (inlet pond)	Check for the presence on an inlet pond and high-flow bypass. Check that sufficient storage depth is available within the inlet pond. The top of the sediment storage level should be at least one metre below the depth of the water level in the sediment basin. Check that the inlet zone's high-flow bypass weir is not blocked or impeded. If these checks do not reveal the problem: - check sediment basin sizing - check that the maximum flows through the sediment basin do not exceed 0.5 m/s - check that the high-flow bypass weir is adequately sized - confirm the catchment size and current land use (development activities and an increase in the developed area may create greater sediment loads, greater stormwater runoff volumes, and higher flow velocities through the sediment basin)	- If accumulated silt has resulted in the height of the wetland macrophyte zone bed being increased by more than 150 mm, remove silt from the macrophyte zone. Removing silt from the macrophyte zone may require the vegetation to be removed and re-established. Many water plants can be harvested pre-works and transplanted post silt removal. Note: Removing accumulated silt from the macrophyte zone should always be accompanied by an investigation into the cause of the siltation. - If there is no inlet pond or high-flow bypass, redesign this part of the wetland. - If insufficient storage volume is available within the sediment basin, the sediment basin may need to be enlarged based on expected sediment loads or based on additional sediment capture infrastructure provided upstream of the existing sediment basin. Refer to the Sediment Basin table in Section 3.4. - Excessive velocities of >0.5 m/s within the sediment basin may need energy dissipation devices, such as baffles. If this is not possible, the size or configuration of the sediment basin may need to be altered to increase the flow area. **Note:** Avoid compacting soil during sediment removal as water plants grow best when their roots can easily penetrate substrate.

Problem	Possible causes	Investigations	Options
	Shade is reducing growth and vigour, and increasing susceptibility to disease and insect attack. Most water plants used in constructed wetlands grow best with full sun.	Check that sunlight is reaching most of the water plants for most of the day.	- Reduce shading. - Plant species that are shade tolerant.
	Wetland vegetation is being scoured because : - there is no high-flow bypass channel and all higher flows are passing through the wetland - local velocities may be high where large flows are entering the macrophyte zone from the inlet pond - a preferential flow path has established within the wetland	Check the inlet design of the wetland. Calculate the maximum inlet velocities. Check the energy dissipation method used in the macrophtye inlet zone. Check the cross sectional profile (flow area) of the wetland. If the maximum velocities within the wetland are > 0.5 m/s, then the velocities are too high. Check the distribution and set-out of the macrophytes. If there is patchy distribution of emerging macrophytes, this can influence the internal flow patterns and directions. Ensure planting is even throughout wetland.	- Where possible, redirect high flows around the wetland by constructing a bypass channel. - If the inlet velocity is >0.5 m/s, retrofit an energy dissipation structure, such as erosion protection, or create a deeper pool of water at the inlet area to the macrophyte zone. - If the cross-sectional profile of the wetland is under-sized and flows within wetland are >0.5 m/s, then the inflow will need to be restricted or the cross-sectional flow profile in the wetland enlarged. Rock protection can be placed in areas of high velocity. - If robust vegetation is not even and perpendicular to the flow path, modify the planting layout to obtain an even distribution. Replant the wetland in accordance with the *Construction and Establishment Guidelines*. - If there is a preferential flow path and vegetation is inadequate to resolve the matter, a low line of rocks placed with spaces between them (like stepping stones) can assist in dispersing flows.
	The plants are drying out because the water level is consistently below the normal water level in between rainfall periods.	Refer to 'Water Level' in this table.	
	The plants are drowning because the water level is consistently above the normal water level in between rainfall periods.	Refer to 'Water Level' in this table.	

Problem	Possible causes	Investigations	Options
	The topsoil is of poor quality or insufficient depth.	Check topsoil depth in areas of plant failure by either draining the wetland or undertaking in-situ coring. Minimum depth should be 150 mm.	- Drain the wetland and re-profile with correct soil depth (minimum 200 mm, preferably 300 mm).
	The plant species are unsuitable.	Check that the correct plant species, according to the wetland design, have been planted in the correct depth zones. Check that the species recommended in the wetland design are appropriate.	- Replace plants with appropriate species. Refer to the *Construction and Establishment Guidelines* for replanting methods. - Adjust the hydrologic regime (i.e. raise or lower the water level), but only where approximately 50% or more of the wetland planting has failed.
	Saline water is tidally intruding into the wetland.	Inspect the outlet structure during large tidal events to observe if flow is backwatering into the wetland. Undertake salinity monitoring both after rain and during long dry periods to observe changes in salinity. Monitoring should occur at a minimum of three locations in the wetland (inlet, middle, and outlet), as well as in the receiving drainage system.	- If observations during large tide events and salinity monitoring confirm tidal backwatering into the wetland, consider: • Raising the water level within the wetland so that saline water cannot enter through the riser outlet. This will require modifying the configuration of the outlet structure. Note: Raising the water level within the wetland may potentially impact the health of the plants, and therefore consideration will also need to be given to the plant species present within the wetland, and their tolerance to the altered hydrologic regime. • Installing a flap gate on the outlet pipe to the downstream saline environment. Note: The use of flap gates within saline environments requires a high level of maintenance due to the constant build up of encrusting biofilms and susceptibility to blockage. - If it is not possible to isolate the wetland from saline water intrusion, then it may be necessary to replant the wetland with saline or brackish tolerant plant species. There is an increased risk of mosquitoes in saline/brackish wetlands, which will need to be monitored.

Problem	Possible causes	Investigations	Options
	Saline groundwater is ingressing into the wetland.	Look for areas of clear water due to increased flocculation of suspended solids, potential filamentous algal growth adjacent to groundwater ingress areas, and localised macrophyte bleaching or dieback adjacent to groundwater intrusion. Undertake water quality testing to determine salinity immediately after rain and during periods of dry. This may include installing shallow monitoring wells adjacent to the wetland to compare and track water levels over time. This monitoring can show the way the groundwater is flowing and conductivity between the wetland and shallow groundwater. A groundwater specialist will be required to assist with this process. The intrusion of low salinity (<1500 mS/cm) is unlikely to be problematic to the health of wetland vegetation.	- If saline groundwater intrusion is in the wetland and impacts on vegetation health are obvious, replace or repair the wetland liner. - Replant the wetland with saline or brackish tolerant plant species. There is an increased risk of mosquitoes in saline/brackish wetlands, which will need to be monitored. - Trench along the wetland batter and place a clay or bentonite barrier across the groundwater intrusion site. - When the groundwater ingress issue has been resolved, replace any contaminated topsoil and replant. Refer to the *Construction and Establishment Guidelines* for replanting advice.
	The water has a low pH due to the exposure of acid sulfate soils within the wetland.	Check margins of the wetland for evidence of acid sulfate soils. This may include: - yellow and/or red mottling in the soil profile - soil pH < 4.0 (will require field testing) - areas of poor plant health - clear water (with a blue or green tinge) Measure water pH in wetland to determine whether acidic water is present. Seek advice from a geotechnical specialist if the water pH is below 6 or there is evidence of acid sulfate soils present within the wetland. The geotechnical investigation should include laboratory analysis of soil samples from the wetland in order to confirm the presence of acid sulfate soils.	- If acid sulfate soils are present or the wetland is subject to acid sulfate leaching, an acid sulfate management plan should be prepared in accordance with State Planning Policy 2/02 Planning and Managing Development involving Acid Sulfate Soils.
	The sediment is contaminated.	It is very difficult to determine if sediment contamination is contributing to plant failure. Seek specialist advice if sediment contamination is suspected.	- Seek specialist advice.

Problem	Possible causes	Investigations	Options
	The plants are diseased or damaged from insects.	Plant disease is uncommon in macrophytes. However, it can occur in certain plants such as *Schoenoplectus validus*, which is susceptible to rust. When all other causes have been explored, plant disease may be the problem. Insect damage is also uncommon in macrophytes. Insect damage is often manifested by premature senescence, insect bore holes, or callus development in gas-transport pathways.	- In most cases, the vegetation can be expected to recover without treatment. - If vegetation loss is large-scale, a horticulturalist can provide guidance regarding disease and insect damage mitigation and plant species selection.
Water level is consistently below the normal water (or is drying out)	The wetland outlet and associated risers are at the wrong level (i.e. too low) due to incorrect design or construction.	Verify that the inflow and outflow structures of the wetland are appropriately configured and constructed. This will require: - obtaining the as-constructed survey of all the hydraulic structures, including the riser perforations - confirming the design is consistent with the *Technical Design Guidelines* and that it matches the desired depths through the macrophyte zone (maximum 0.5 m depth at normal water level to support vegetation)	- Re-configure wetland inflow or outflow structures to raise the normal water level in the wetland. This may involve adjusting the outlet riser perforations only (preferred) or modifiying the whole outlet structure. - If modifications to the outlet are made, then the level of the high-flow bypass weir may need to be altered to preserve the extended detention depth (typically 0.5 m).
	The bathymetry of the wetland is not correct (depths or levels are wrong) as a result of incorrect design or construction.	Verify the wetland bathymetry has been constructed to the correct levels and the actual design is correct. This will require: - obtaining the as-constructed survey - confirming the bathymetry matches the design to + 50 mm - confirming the design is consistent with the *Technical Design Guidelines* and matches the desired depths through the macrophyte zone (maximum 0.5 m deep at normal water level to support vegetation)	- Reconfigure the hydraulic control structures to raise the normal water level in the wetland (preferred). - Drain the wetland, remove or temporarily relocate any existing vegetation, rectify the wetland bathymetry, and re-establish the vegetation.

Problem	Possible causes	Investigations	Options
	The wetland is not receiving flows or only a small portion of flow due to: - the design inflow has been miscalculated (under-estimated) and therefore the inlet to the wetland is too small and restricting the volume of water entering the wetland - the wetland is oversized compared to its catchment - the catchment is not discharging to the wetland, e.g. flow bypasses the wetland because a temporary blockage that was installed during construction was never removed	Inspect the wetland and upstream stormwater drainage system when it is raining to ensure flows are entering the wetland under gravity and the wetland is filling. Inspect any diversion structures when it is raining to ensure they are operating and flows are entering the wetland. Check the catchment area compared to the macrophyte zone area. If the wetland is more than 8% of the catchment area, then the wetland may be oversized for the catchment. Verify that the wetland has been constructed as per design and that the inlet structures are appropriately sized to allow up to the 1-year average recurrence flow into the wetland.	- If there is a restriction in the upstream drainage system (e.g. diversion structure), then unblock or modify the configuration to allow flows into the wetland. Consult with a specialist for major works, such as readjusting a weir. - If the wetland is over-sized for its catchment, re-design the wetland considering the surface area, bathymetry, and hydraulic control (detention time). - If the inlet control is too small, replace or amend inlet structures (pipes, weirs) with appropriately sized structures.
	The seepage collars around the wetland pipe outlets have failed (i.e. water is leaking from wetland via the perimeter or outside of the pipe outlets).	Check the wetland pipe outlet after rain to observe any signs of flow or seepage around the margin of the pipe or headwall.	- Repair or install seepage collars (typically 500 mm around pipe).
	The wetland liner was constructed incorrectly or has been damaged resulting in water losses. If there is no liner, the soil type may be too free draining (sandy).	If all other investigations fail to identify the water level problem, the liner may be leaking. Monitor levels within wetland for a number of weeks after rain to determine if water is leaking from the wetland liner. Alternatively, split the macrophyte zone into a series of cells using sealed earth bunds. Monitor water levels within each cell. If the water level in one of these cells drops more rapidly than the other cells, there may be liner damage within that cell.	- Where the only purpose of the wetland is to improve water quality, it can be left as an ephemeral wetland. The wetland may need to be planted with other species that can survive both wet and dry conditions. - Where the wetland must hold water, e.g. if it is part of a stormwater harvesting scheme, the leak will need to be fixed. Block the inlet to the wetland to isolate it from catchment flows and draw down the wetland. Apply a bentonite clay mixture. The bentonite will settle over time and may seal the leak. Remove the inlet blockage. This approach will not always solve the problem. - Alternatively, reconstruct the wetland liner in stages. - Where there is no liner, the wetland may require application of a clay soil over all surfaces below normal water level.

Problem	Possible causes	Investigations	Options
Water level is consistently too high above the normal water level	The outlet pipe is blocked.	Identify whether a poor design has exposed the outlet to floating debris. Check the downstream drainage system for excessive siltation or blockage that is causing backwatering up the pipe.	- Clean the outlet riser and inspect regularly. - Remove siltation or blockage from the drainage system. - To decrease the future risk of blockage, redesign the outlet as per the *Technical Design Guidelines* .
	The outlet riser pipe has been designed or constructed at the wrong level resulting in wetland areas that are too deep to support vegetation (>0.5m).	Verify that the inflow and outflow structures of the wetland are appropriately configured and constructed. This will require: - obtaining the as-constructed survey of all the hydraulic structures, including the riser perforations - confirming the bathymetry matches the design to + 25 mm - confirming the design is consistent with the *Technical Design Guidelines* and that it matches the desired depths through the macrophyte zone (maximum 0.5 m depth at normal water level to support vegetation)	- Re-configure wetland inflow or outflow structures to raise the normal water level in the wetland. This may involve adjusting the outlet riser perforations only (preferred) or modifying the whole outlet structure. - If modifications to the outlet are made, then the level of the high-flow bypass weir may need to be altered to preserve the extended detention depth (typically 0.5m).
	The receiving drainage system has elevated water levels or the normal water level of the wetland was designed too low (i.e. the design did not allow for raised water levels in the receiving system during the wet season).	Check for elevated water levels in the receiving drainage system. If the water level in the drainage system is dictating water levels in the wetland, a water level survey may be required within the wetland and receiving drainage system. Consulting the as-constructed survey of the wetland outlet system, including the risers, may also be required.	- Investigate options to reduce the water level in the receiving drainage system to below the preferred normal water level of the wetland (preferred). - To ensure free drainage to the receiving system, raise the water level of the wetland by changing the outlet structure. This may require an adjustment to the bathymetry to ensure the water depth can support wetland plants (typically <0.5 m depth at normal water level).

Problem	Possible causes	Investigations	Options
	The wetland has low hydrologic effectiveness. The extended detention depth is engaged for long periods following rain rather than draining back to the normal water level within 3–4 days) because: - the wetland is small in relation to the catchment (i.e. smaller than the best practice size for the specific climatic region) - the notional detention time of the wetland is too long (> 72 hrs) Both of these issues can cause water levels to remain high for long periods of time.	Confirm the size of the catchment. Check the size of the wetland in relation to the catchment and compare to the best practice wetland size for the climatic zone. Check the design of the outlet riser. Undertake an inundation frequency analysis and confirm the correct plants for the inundation levels are in place.	- Re-configure the outlet riser to reduce the notional detention time in the wetland. - Adjust the bathymetry to reduce the depth to <0.5m. This will require a complete resetting of the wetland macrophyte zone. - Replant the wetland with plant species more tolerant to deeper water. - Instigate a system for pumping the water level down at key times (such as after replanting).
	The extended detention of the wetland is too high (>0.5 m).	Check there are no blockages in the outlet riser or in the downstream drainage system. Check the difference in levels between the top and bottom orifices on the wetland outlet riser. This correlates to the extended detention depth.	- If the extended detention depth is too deep, reconfigure the outlet riser to ensure the maximum ponded depth is no more than 0.5 m and no more than 0.2 m when the plants are replanted. That is, have the water level no more than 1/3 the height of the plant. Post replanting, a pump may have to be used to keep the water level down. Adjust the water level so recently planted water plants are totally covered by water for less than 48 hours. If the water level cannot be dropped adequately, then replanting should be done with advanced (large) plants or transplants.
	Areas of permanent water that are too deep to support vegetation (>0.5 m) because the bathymetry through the macrophyte zone of the wetland was designed or constructed incorrectly.	Verify that the wetland bathymetry has been constructed to the correct levels and the actual design is correct. This will require: - obtaining the as-constructed survey - confirming the bathymetry matches the design to + 50 mm - confirming the design is consistent with the *Technical Design Guidelines* and matches the desired depths through the macrophyte zone (maximum 0.5 m deep at normal water level to support vegetation)	- Reconfigure the wetland hydraulic control structures to accommodate raising the normal water level in the wetland (preferred). - Drain the wetland, remove any existing vegetation by temporarily relocating it, rectify the wetland bathymetry to reduce permanent water depths to <0.5m, and re-establish the vegetation.

Problem	Possible causes	Investigations	Options
There is no draw-down mechanism	No hydraulic control structure was designed or constructed to allow water level manipulation, i.e. there is no draw-down pipe, valve, or weir.	Inspect the outlet riser of the wetland. The outlet should have a valve or other system that allows the wetland to drain under gravity to levels below the normal water level, preferably to the lowest point in the wetland. If the wetland does not have an outlet riser, the wetland can only be drained by pumping or by constructing a gravity-based water level control. To confirm if a gravity-based water level control will work, survey the normal water level and the inverts of the downstream drainage system or the ponded water levels.	- Where the downstream drainage system inverts or ponded water levels are below the normal water level, a gravity-based water level control can be constructed. Refer to the *Technical Design Guidelines* for guidance. Ideally, this is a series of small pipes connecting the deeper zones of the wetland to the outlet (or new pit), which contains a valve. This valve can be opened to drain the deeper zones of the wetland. - Where the downstream drainage system inverts and ponded water levels do not allow drainage of the wetland below the normal water level, pumping will be required. Refer to the *Technical Design Guidelines* for guidance. To support easy pumping, a series of small pipes connecting the deeper zones of the wetland to the outlet (or new pit) that contains a valve will need to be installed. The pit should be located close to a power source. This will allow the wetland to be drained via a single pump connected to mains power. - The absence of a hydraulic control structure generally means that the wetland has been inadequately designed. In these cases, a comprehensive review of the wetland design is recommended.

Problem	Possible causes	Investigations	Options
Weeds – persistent ingress or excessive cover (greater than 10% cover of emergent, floating, or submerged weeds) that cannot be managed effectively via maintenance activities[6]	- Uncontrolled weeds in the upstream catchment - Excess sediment has accumulated - High nutrient concentrations/ loads - Lack of regular inspection and maintenance - Type and density of perimeter vegetation (e.g. shading of the wetland margins) - Vegetation failure has allowed weeds to colonise - Vectors (e.g. birds) - Contaminated fill and mulch - Water level control (e.g. the water level is too high resulting in plant mortality and colonisation by weeds)	Confirm the weed species present. Identify the cause of the weed infestation. This includes checking upstream waterways and adjoining land areas for the presence of weeds (particularly noting areas that are connected directly to the wetland). Determine weed removal or control strategies The biological characteristics of the weed species, e.g. growing habits, seeding times, water tolerance and control options, should be considered. Consider the potential impacts of chemical herbicides on the desirable vegetation with the wetland and downstream.	- Completely remove the weed species using control methods listed in *Maintaining Vegetated Stormwater Assets*. One method involves draining and drying out the wetland to kill the weed species to allow access to remove by hand. Obtain specialist advice about the required drying-out period. - Prevent the future ingress of weeds by planting the batters with species that provide dense cover and shade. Shade will impede weeds such as para grass, which typically invades from the edges. - Fill-in deep-water areas so the maximum depth is 0.5 m. This is shallow enough to support healthy vegetation.
Unacceptable public safety	Public access and potential safety hazards (i.e. drowning) within the wetland may be due to: - steep batters or walls - lack of access control - lack of perimeter vegetation	Complete a public safety risk assessment in accordance with Appendix A. Design elements that need to be considered include: - site access and barriers, such as fencing or perimeter vegetation - batter slopes both below and above the normal water level - vegetation cover and height Identify if the constructed wetland was designed and constructed in accordance with the *Technical Design Guidelines* and *Construction and Establishment Guidelines*. Refer to 'Eroded batters' in this table.	The outcome of the risk assessment findings (Appendix A) and the local site context will guide the response. - Install access control using barriers such as fencing or vegetation. - Modify the wetland to provide safe batters. A maximum slope of 1:4 is recommended. - Modify the layout to provide safe access for inspection and maintenance activities.

6. In Queensland, the *Land Protection (Pest & Stock Route Management) Act 2002* imposes a legal responsibility for landowners to control declared weeds on their land. Regular maintenance must manage these weeds. Refer to *Maintaining Vegetated Stormwater Assets* for general advice about managing weeds.

Problem	Possible causes	Investigations	Options
Excessive mosquitoes	Excessive mosquitoes can be caused by: - stagnant or stratified water - lack of mosquito predators due to the shallow bathymetry of the wetland - isolated pools of water in the wetland due to poor bathymetric design or poor construction - litter creating small pools of water	Consult a mosquito specialist. Tasks that may be undertaken include: - checking for evidence of mosquito breeding around the margins of the wetland and also in any isolated shallow pools - auditing adult mosquito species and population density within the wetland and adjacent habitats If isolated or stagnant pools of water are present within the wetland, verify that the wetland bathymetry has been constructed to the correct levels and the actual design is correct. This will require: - obtaining the as-constructed survey - confirming the bathymetry matches the design (to +/- 50 mm) - confirming the actual design is consistent with the *Technical Design Guidelines* and matches the desired depths through the macrophyte zone of the wetland	- Ensure that any isolated pools are filled and planted out. - Remove litter. - Dredge the wetland to remove accumulated sediment from the deep areas. - Introduce predators (native fish). - Seek advice from a mosquito specialist if the use of control agents, such as larvicides, is deemed necessary. Pre- and post-treatment surveys of the target area should be undertaken when using larvicide treatments in order to ascertain what effect the treatment has had on the mosquito larvae. - In some situations, it may be necessary to modify the bathymetry of the wetland in order to minimise potential mosquito breeding habitat and to enhance predator access to mosquito breeding areas. This may involve: • increasing the batter slopes on the wetland margins to a minimum slope of 1:4 (e.g. eliminating flat, shallow banks or benches) (using vertical edges is ideal, however this may not be practical in many situations) • increasing the depth of the wetland, e.g. providing deep pools in order to provide habitat for mosquito predators and to enhance access for mosquito predators to the macrophyte zones (open water areas also promote wave action that disrupts larval respiration) • increasing ephemeral zones within the wetland in order to remove mosquito breeding habitat - Install an aeration or reticulation device to reduce or remove stagnant areas. - Install a fountain to disturb water surface. Run the fountain particularly at dusk and during the night.

Problem	Possible causes	Investigations	Options
Excessive litter	Excessive litter can be caused by: - loads of litter from the catchment are higher than the design mitigated for - public littering - a failed gross pollutant trap upstream	Check for primary sources of litter. This may include the inlet zone (upstream drainage system), directly connected drains, catchment, or adjacent public open space. Any areas of industrial, commercial, retail, or main roads are probably a high source of litter to the wetland.	- Retrofit upstream drainage system with litter controls, e.g. a gross pollutant or a trash rack. - Incorporate a trash rack with easy access to the inlet zone of the wetland. - Provide litter disposal bins in adjacent public open space. - Undertake an education campaign on litter and its impact on downstream ecosystems.
Eroded batters	There is no high-flow bypass upstream of the macrophyte zone, so all catchment flows, including large event flows, are entering the macrophtye zone.	Undertake a site inspection and review the design and as-constructed information to confirm the inlet pond, high-flow bypass weir, and channel system. Bypassing high flows may be via underground structures. If the outlet structure to the macrophyte zone is a weir, it is likely that high flows will pass through the wetland. A specialist or engineer can confirm the hydraulic function of the structure. However, a site inspection during rain should be satisfactory. If there is no high-flow bypass, the constructed wetland is 'online' and the macrophyte zone will receive flows that may be causing scour.	- Review opportunities for bypassing high flows around the macrophyte zone. This could involve creating an inlet pond and high-flow bypass weir and channel, which may reduce the size of the macrophyte zone. Note it is better to have a properly functioning, but smaller, wetland than a larger wetland that is not functional.
	The inlet structures are incorrectly sized, allowing too much flow into the macrophyte zone.	Undertake a site inspection of the hydraulic structures and review the design and as-constructed information to confirm how flows move through the wetland. Inspect during rain to identify where scour is occurring and why.	- Redesign and re-construct the hydraulic structures.
	An extreme storm has produced high discharge and high velocities. Lateral surface flows enter the wetland from a small catchment directly adjacent to the wetland. There are localised high velocities.	Complete a site inspection (during rainfall if possible) to confirm: - the location of the scour - the reason for the scour - where flow is coming from and its velocity	- Re-enforce the eroded areas with rock protection and beaching. - Direct lateral flows to small, rock-lined channels that feed down the batters to the wetland. - Re-place topsoil in scoured zones and re-establish the wetland vegetation. - Modify wetland hydraulic control structures, i.e. inlet and outlet pipes and weirs.

Problem	Possible causes	Investigations	Options
	The soil is inappropriate, ie it has high: - clay content (eg. > 30%) - high sand content (eg. > 70%) - salt levels or low carbon levels (<5%) - sodium adsorption ration (> 10)	Undertake an analysis of the soil to identify if it meets the specifications in AS4419—*Soils for landscaping and garden use* (2003), considering: - soil particle size distribution - soil pH - salinity (soluble salts) - organic matter (carbon) - sodium adsorption ratio Collect soil samples at surface and mid-depth (100 mm) in the vicinity of the batter erosion.	- Seek advice from the soil laboratory for options to meet the specifications. In some cases, in-situ repair may be possible. However if not, remove and replace the soil.
Weir erosion or failure	If the weir crest and grouted rock protection is not extended up the batters of the wetland and the high-flow bypass channel, scour can occur around the edge of the weir with flows skirting the weir. Where wetlands are constructed with a moderate grade along the high-flow bypass, scour can occur as a result of high velocity.	Undertake a site inspection, preferably during rain, to confirm scour adjacent to the weir. Where soil has been eroded, a rapid response to fix the scour is needed to avoid complete erosion and failure of the weir.	- Re-construct or modify the weir crest to its correct configuration. - Extend the concrete weir crest and grouted rock batters up the full length of the batters and to at least 0.5 m along the top of the batter to 'key in' the weir.
Scour of the high-flow bypass channel	Where wetlands are constructed with a moderate grade along the high-flow bypass, scour can occur as a result of high velocities. Where the vegetation has failed in the channel, scour may occur.	Complete a site inspection (during rainfall if possible) to confirm: - the location of the scour - the reason for the scour - where flow is coming from and its velocity Implement a response as soon as practical to avoid further scour.	- Re-enforce the eroded areas with rock beaching. Re-place the topsoil in scoured zones and re-establish the vegetation. Plant species may need to be re-selected and hydro-mulches or bonded fibre matrix mulches used . Consider the bypass velocities and existing surface treatments (i.e. rock battering, vegetation). Consider the advice provided in *Technical Design Guidelines* when designing scour management.

Problem	Possible causes	Investigations	Options
Scour around structures other than the weir	The wetland was poorly constructed, i.e. structures are not keyed in properly. The interaction of concrete, soil, and water can result in soil failures and scour.	Complete a site inspection (during rainfall if possible) to confirm: - the location of the scour - the reason for the scour - where flow is coming from and its velocity Implement a response as soon as practical to avoid further scour or potential failure of the structure.	- Redirect flows to avoid interaction with the structure. - Excavate the adjacent areas to the structure in order to provide adequate 'keying in' of the structure to the surrounding soil. - Install a collar around the pipe outlet within the embankment. - Excavate the adjacent areas to the structure and compact the soil into the void. - Raise the surrounds to the structure to avoid inundation. - Remove and re-construct the structure.
Embankment failure	The bunds are eroding due to: - use of poorly structured soils (i.e. sodic soils) - tunneling and failure around the outlet pit and pipe - incorrect bund height (i.e. crest of the bund is set too low resulting in overtopping) - lack of protection from scour (i.e. inadequate or no vegetation cover)	Complete a site inspection (during rainfall if possible) to confirm: - the location of the scour - the reason for the scour - where flow is coming from and its velocity Implement a response as soon as practical to avoid further scour and the potential failure of the bund or embankment.	- Where required, raise the bund well above the top of the potential flood levels in the wetland and provide rock protection in high velocity locations. - Install a collar around the pipe outlet within the embankment. - Rectify scour and ensure geotechnical certification of the bund for stability and water-holding capacity, which may involve constructing a clay core, re-enforcing the berm with rock beaching, or re-establishing adequate vegetation cover.
Vegetation scour	If appropriate energy dissipation is not provided in the design, local velocities may be high where the flows entering the macrophyte zone from the inlet pond are large.	Refer to 'Vegetation failure' in this table.	

Problem	Possible causes	Investigations	Options
Short-circuiting of flows	The wetland length-to-width ratio is less than 5(L):1(W). The outlet is close to the inlet and parts of the macrophyte zone are not engaged by flow. Robust water plants are growing in clumps and diverting the water around them.	Review the wetland configuration to verify the length-to-width ratio (it should be more than 5(L):1(W), the location of the inlet and outlet structures, and to identify any 'dead zones' that may not accept flows. This will require: - obtaining the as-constructed survey - confirming the bathymetry matches the design to +/-50mm - confirming the actual design is consistent with the *Technical Design Guidelines* and matches the desired length-to-width ratio and inlet and outlet locations. - observing if the wetland has a patchy distribution of plants	- Move the inlet or outlet structures. - Retrofit bunds at given locations to promote longer flow lengths and ensure dead zones are engaged by flow. - Completely reshape the macrophyte zone. The steps required for redesigning or reconstructing a wetland are provided in *Technical Design Guidelines* and the *Construction and Establishment Guideline*.
	The bathymetry contains deep zones that directly connect inflows to the outlet. There are missing bunds. Bunds are important to ensure water engages with the whole wetland area.	Verify that the wetland bathymetry is constructed to the correct levels and that the design is correct. This will require: - obtaining the as-constructed survey - confirming the bathymetry matches the design to +/- 50 mm - confirming the design is consistent with the *Technical Design Guidelines*, matches the desired depths through the macrophyte zone of the wetland (maximum 0.5 m deep at normal water level to support vegetation), and the bunds are in the correct place	- Drain the wetland, re-profile the relevant parts of the bathymetry to reduce depths to <0.5 m, and re-establish the vegetation. - Retrofit with bunds in order to facilitate even flow through the wetland. - Install an ephemeral zone within certain locations in the wetland to stop short-circuiting.
	Vegetation has established unevenly, vegetation has failed, or there is weed ingress. (Vegetation with uneven densities may encourage the development of preferential flow paths within the wetland.)	Check the distribution and density of vegetation within the wetland, including areas where of large robust weeds have ingessed into the permanently wetted macrophyte zones has occurred (e.g. *Olive hymenachne*). Ideally, there should be bands of vegetation through the wetland that are perpendicular to the flow. This will promote a consistent resistance to flow at each band of vegetation. Wetland vegetation will mix and consistent bands will not always be possible.	- Where bands of vegetation are missing, replant the vegetation to establish suitable conditions for propagation of vegetation. - Refer to 'Weeds' and 'Vegetation failure' in this table.

Problem	Possible causes	Investigations	Options
Excessive algae	The vegetation has failed.	Check the vegetation cover and density in the area of the algae.	- If algal biomass has developed due to the lack of vegetative cover, immediately re-establish vegetation. Refer to 'Vegetation failure' in this table. Well-established, dense vegetation helps to control excessive algal growth due to shading, and is less susceptible to physical smothering by filamentous algae. - If high nutrient concentrations within the wetland are contributing to high algal biomass development, options include: • Remove sediments that are saturated with nutients and organics, as indicated by a redoc potential of < 0 m V. • Lower the water level and dry out the wetland for 1–2 weeks to kill algae. • Run the wetland as an ephemeral system while the source of nutrients is resolved and habitat for algae is removed. • Replant the wetland as required at 10–12 plants/m^2. - If the wetland has more than 20% open water (where water depth is >0.5 m), drain it and add topsoil to reduce depths. The final planted wetland depths should range between 0.5 m below the normal water level to 0.3 m above the normal water level. - Potential management responses to blue-green algae include: • Place signage around the sediment basin to inform of the potential health risks. • Restrict public access to the sediment basin with temporary fencing. • Carbon dose to eliminate toxins. Specialist advice should be sought before this action is undertaken. • Closely monitor downstream water bodies, such as wetlands or lakes, for evidence of blue-green algal blooms.
	Higher than expected nutrient inflows have combined with a low macrophyte cover.	Undertake long-term water quality monitoring of nutrient levels within the wetland. Recommended nutrients to monitor include total phosphorous (TP), soluble phosphorous (P), Total Nitrogen (TN), and Nitrate-N (NOx). If nutrient concentrations are consistently high (if TP > 0.15 mg/L, TN > 2 mg/L), then further investigation is required to determine the source of the nutrient and to consider other catchment management solutions. Measure dissolved oxygen and redoc potential of the sediment.	
	The wetland has more than 20% open water.	Check the percentage of vegetation cover within the wetland and identify open water zones. Check that macrophytes are present in the submerged marsh zones. Survey the as-constructed wetland bathymetry and identify areas that are deeper then 0.5 m.	

Problem	Possible causes	Investigations	Options
Persistently high turbidity and faecal coliform contamination	There are excessive total suspended solids (TSS) or total dissolved solids (TDS).	Monitor turbidity levels within the wetland. Investigate sources of TSS or TDS from the catchment. Investigate sources of TSS and TDS within the wetland. This may involve checking: - clay content of the topsoil used within the wetland - exposure of the wetland clay liner To check the wetland topsoil, take one soil sample per 250–500 m^2 and test in accordance with AS4419.	- Install additional sediment capture upstream of the wetland (e.g. a sediment basin). - Identify sources of TSS and TDS and undertake source control by managing sediment runoff on construction sites. - Replace topsoil used within the wetland and repair areas of the wetland where the clay liner has been exposed. Seek specialist advice if turbidity is associated with the presence of clay colloids (fine suspended clay particles that are permanently suspended within the water column).
	There are excessive areas of open water and algal blooms.	Refer to 'Algal blooms' in this table.	
	Fish populations (e.g. carp, tilapia) are resulting in bioturbation.	Undertake a fish survey to determine fish species, biomass, and size distribution present.	- Trap and remove or reduce the fish population. This may involve draining the wetland.
	Large populations of birdlife are resulting in removal of vegetation and faecal coliform contamination.	Complete a number of inspections of the wetland at different times of the day and during different climatic conditions to view bird life. Undertake water quality monitoring in consultation with a water quality specialist to determine the source of faecal coliform contamination.	- Remove waterfowl from the wetland. - Treat faecal contamination sources from the catchment, including illegal sewer connections.

3.4 Sediment basins

Section 3.4 provides guidance to rectify sediment basins. Problems with sediment basins include:

- floating weeds (Figure 33)
- lack of vegetation cover on the batters (Figure 33)
- excessive algae (Figure 34)

Table 5 sets out possible causes, investigations, and options for rectifying problems with sediment basins.

Figure 33 A sediment basin that is infested with floating weeds and lacks vegetation cover on the batters

(Photos: Shaun Leinster, DesignFlow)

Figure 34 Sediment basin with filamentous algae covering the surface

(Photo: Paul Dubowski, Healthy Waterways)

Table 5 Guidance for rectifying sediment basins

Problem	Possible causes	Investigations	Options
Little or no sediment capture	Sediment does not have time to settle within the basin as the dimensions (i.e. surface area or shape) are too small.	Identify if the sediment basin is too small for the catchment size and inflows by obtaining the as-constructed survey and determining: - if the as-constructed bathymetry matches the design to ± 25 mm - the upstream catchment area and land use - whether the design is consistent with the *Technical Design Guidelines*	- Install additional sediment capture infrastructure upstream of the asset. - Increase the settling area of the sediment basin by increasing the length of the basin.
	High velocities inflows (i.e. greater than 0.5m/s) are scouring and resuspending sediment.	Identify if the maximum design velocity during peak storm events exceeds 0.5 m/s.	- Install energy dissipation at the inlet of the basin. - Increase the cross-sectional profile of the sediment basin to reduce velocities. - Modify the existing bypass or create a high-flow bypass so that high flows do not pass directly through the sediment basin.
	The basin is full of sediment.	Refer to *Maintaining Vegetated Stormwater Assets.*	
Basin requires very frequent clean outs	Increased or unexpectedly large sediment loads are originating from the catchment due to unforeseen activities or because of poor erosion and sediment control.	Inspect the catchment to identify the source(s) of sediment.	- Enforce erosion and sediment control on construction sites within the catchment. - Install additional sediment capture infrastructure upstream of the asset.
	The sediment basin is under-sized in relation to its catchment.	Identify if the sediment basin is too small for the size of the catchment and expected inflows by obtaining the as-constructed survey and determining: - if the as-constructed bathymetry matches the design to ± 25 mm - the catchment area and land use - whether the design is consistent with the *Technical Design Guidelines*	- Increase the storage capacity (i.e. size) of the sediment basin. - Install additional sediment capture infrastructure within the upstream catchment.

Table 5 Guidance for rectifying sediment basins

Problem	Possible causes	Investigations	Options
Failure of hydraulic control structures or banks	The basin was poorly designed, e.g. the banks are too steep. The basin was poorly constructed, e.g. the structures were not properly keyed into the adjoining soils, which is causing interface issues, or poorly structured soils were used. The basin was damaged incidentally. The batters or bedding material is eroding. The soil is unstable from groundwater ingress or poor compaction.	Identify if the hydraulic structures are appropriately configured and constructed, considering: - incidental damage - stresses or deformation - type of materials used - defects in materials used - deterioration or water damage - structural design - construction technique used Identify if a suitable soil structure was used to construct the basin. Consider: - type of soil or bedding material used (e.g. dispersive or sodic soils) - evidence of subsurface erosion (voids) - evidence of groundwater ingress - compaction and thickness of bedding material	- In accordance with the *Construction and Establishment Guidelines*, design and re-construct the failed hydraulic structure and re-set the adjoining landscape or soil. Provide an engineer's report outlining the cause of the failure and the steps taken to resolve the problem. Bring gross engineering design faults to the attention of Engineers Australia, as the body responsible for certifying Registered Professional Engineers in Queensland.
	The basin is at the end of its expected lifecycle.	Refer to the authority's asset management system, or as-constructed plans, to determine the age of the asset and the structures.	- If the asset has reached the end of its lifecycle, re-set the sediment basin by replacing all the structural elements, removing excess sediment, and re-profiling.
Persistent blockage of outlet pit	The catchment is contributing unexpectedly high loads of gross pollutants. An upstream gross pollutant trap is performing poorly. There is no gross pollutant trap upstream.	Determine the source of the litter. Investigate the upstream drainage system to determine if there is a gross pollutant trap, if it is being maintained, and how well it is performing.	- Increase the frequency of maintenance of the gross pollutant trap or sediment basin outlet. - Install a gross pollutant trap upstream. - Provide litter disposal bins in the adjacent public open space. - Undertake an education campaign on litter and its impact on downstream ecosystems.

Problem	Possible causes	Investigations	Options
Scour that is undermining the foundation of structures	The velocities within the basin are too high.	Complete a site inspection, during rainfall if possible, to confirm where the flow is coming from and the flow velocity.	Rectify as soon as possible to avoid further scour and potential failure of the structure. - Modify the design of the hydraulic structure to cope with the expected velocities. - Provide energy dissipation at the inlet. - Modify the high-flow bypass configuration so that high flows do not pass directly through the sediment basin. - Provide additional scour protection, such as rock-reinforced batters.
	The basin was poorly constructed, e.g. poorly structured soils were used or the structures were not properly keyed into the adjoining soil, which is causing interface issues.	Assess whether the asset was constructed property (refer to the *Construction and Establishment Guidelines*).	Rectify as soon as possible to avoid further scour and potential failure of the structure. - Redirect flows to avoid interaction with the structure. - Excavate the areas adjacent to the structure for adequate keying in of the structure to the surrounding soil. - Place collars around stormwater pipes through the embankment. - Excavate the areas adjacent to the structure and compact the soil into the void. - Raise the surrounds of the structure to avoid inundation.
Eroded batters	The inlet structure was incorrectly sized, which is allowing too much flow into the basin. Flows are entering the asset laterally. The basin is subject to high velocities. The batters are too steep. The fill used to construct the sediment basin was not adequately compacted.	Complete a site inspection, during rainfall if possible, to confirm the location of the erosion, the reason for the erosion, where flow is coming from (e.g. lateral inflow from a small catchment), and the flow velocity.	- Re-enforce the eroded areas with rock protection and beaching. - Direct lateral flows to small, rock-lined channels that feed down the batters to the basin. - Re-place topsoil in scoured zones and re-establish the vegetation. - Modify hydraulic control structures, i.e. inlet and outlet pipes and weirs.

Problem	Possible causes	Investigations	Options
	The soils are poorly structured, e.g. dispersive or sodic soils.	Identify if the batters were constructed with soils of a suitable structure.	- Remediate soil, e.g. use soil additives for sodic soils. - Cover dispersive soils with clay, topsoil, and vegetation. - Replace soils used for the batters. - Use filter cloth, biodegradable matting, or hydro-mulch on the batters. - Plant vegetation that has soil stabilising characteristics on the batters.
	The batters lack vegetation.	Refer to 'Lack of vegetation cover on the batters' in this table.	
Lack of vegetation cover on the batters (Figure 33)	The vegetation was planted too sparsely or using an incorrect technique. The plants received inadequate water or fertilizer during establishment.	Review the construction and establishment documentation to identify if the asset was properly constructed and established.	- Plant additional vegetation to increase the density. More established seedlings (e.g. 150 mm tubes and pots) may need to be used. - Apply fertilizer and water in accordance with the *Construction and Establishment Guidelines*.
	The wrong depth (>200mm) or type of topsoil was used (see the *Construction and Establishment Guidelines*).	Undertake an analysis of the soil to identify if it meets the specifications in AS4419—*Soils for landscaping and garden use* (2003), considering: - soil pH - salinity (soluble salts) - organic matter (carbon) - nutrient content - sodium adsorption ratio (SAR) - water holding capacity (field capacity) Collect soil samples at surface and mid-depth (100 mm).	- Seek advice from the soil laboratory for options on how to remediate the soil in order to meet the specifications. In most cases, in-situ remediation of the soil will be possible. If not, remove and replace the soil and revegetate in accordance with the *Construction and Establishment Guidelines*.
	The wrong depth or type of mulch was used.	Identify the depth and type of mulch and compare with the recommendations in the *Construction and Establishment Guidelines*.	- Replace the mulch in accordance with the *Construction and Establishment Guidelines*. - If the mulch layer is > 75 mm, remove the excess mulch.

Problem	Possible causes	Investigations	Options
	Inappropriate species were planted.	Identify if the species planted were appropriate for the soil type and climate. This may include reviewing the design drawings to identify if the species were planted in accordance with the design and checking whether the correct species were specified in the design.	- Re-establish the vegetation with species that are growing well in other parts of the asset or that an ecologist or horticulturist recommends. Refer to the *Construction and Establishment Guidelines* for replanting and establishment methods.
	Vehicles or activities, such as trampling, grazing, walking, bike riding, or vandalism, have damaged the vegetation.	Check for evidence of physical damage, e.g. tyre depressions or trampled vegetation.	- Educate residents or use signage to raise awareness of the asset's importance and functional requirements. - Discourage public access by planting dense species along the edges or fencing the basin. Plant to a density of at least 4–10 plants per m^2. If necessary, install a temporary protective barrier while the vegetation is establishing.
	The vegetation was maintained incorrectly.	Look for evidence of mowed or cut vegetation, or sprayed herbicide.	- Provide training for maintenance staff on vegetated stormwater assets. - Install a hard edge between the edge plantings and mown areas to delineate the area to mow.
	The plants are diseased or have been damaged by insects.	Check for symptoms of plant disease or insect damage, which may include: - chlorosis or foliage discoloration - browning of the leaves - wilting - powdery mildew or rust (fungal infections) - stunted growth - insect bore holes - callus development - physical leaf damage (portions of the leaf are missing where it has been eaten) - leaf roll	- In most cases, plants can be expected to recover from minor diseases or insect damage without intervention. If the plant damage or loss persists, consider: • mitigating disease and insects • selecting plants that are resistant to disease and insects • timing inspection and maintenance activities to align with peak risk times for plant disease or insect damage

Problem	Possible causes	Investigations	Options
	Lack of soil moisture due to drought		- Replace the vegetation with drought-tolerant species or establish a temporary irrigation program.
	Weeds are preventing the plants from propagating.	Determine what proportion of plants are weed species and refer to 'Weeds' in this table.	
	The water has a low pH due to exposure of in-situ acid sulfate soils or imported topsoil that has acid sulfate contamination.	Check the margins of the sediment basin for evidence of acid sulfate soils. This may include: - yellow or red mottling in the soil profile - soil pH < 4.0 (determined by field testing) - areas of poor plant health or failure on the batters of the sediment basin - clear water in the sediment basin with a blue-green tinge Measure the water pH to determine if acidic water is present (i.e below 6). If there is evidence of acid sulfate soils or acidic water, undertake a geotechnical investigation. This may include laboratory analysis of soil samples or identification of the source of the acidic groundwater.	- Prepare an Acid Sulfate Management Plan in accordance with State Planning Policy 2/02 Planning and Managing Development involving Acid Sulfate Soils. Options for dealing with acid sulfate soils include: - soil capping - soil remediation (lime treatments) - soil replacement
	The water has a low pH due to acidic groundwater that is discharging into the basin.		- Remediate or control the leaching of acidic groundwater.
Excessive algae (Figure 34)[7]	Stormwater inflows have high nutrient concentrations. Anoxic sediments are releasing nutrients. A combination of high nutrient concentrations, high turbidity, and low macrophyte cover is providing ideal conditions for algal growth, particularly blue-green algae.	If a noticeable surface bloom persists in a basin that is in a prominent location with public access, collect water samples to identify the algal species.	- If access is restricted and there is minimal public health risk, there may be no need to take further action. - If action is required: • place signage around the sediment basin to inform the public of the potential health risks associated with the algae • restrict public access with temporary fencing • closely monitor downstream water bodies (such as wetlands or lakes) for evidence of blue-green algal blooms

7. Most sediment basins will experience algal growth due to their role as the first treatment system that accepts untreated stormwater. While excessive algae will not affect the function of a sediment basin, blue-green algae can be a public health risk.

Problem	Possible causes	Investigations	Options
Persistent weed ingress or excessive cover (greater than 20%) (Figure 33) that cannot be managed effectively via maintenance activities	Weeds are present/uncontrolled in the catchment. Excess sediment has accumulated. The basin has high concentrations/ loads of nutrients. Inspections and maintenance activities are not undertaken regularly. Vectors are present, e.g. birds. Fill and mulch (on batters) is contaminated.	Identify the weed species present and the cause of the weed infestation, including checking upstream waterways and adjoining land areas for the presence of weeds (particularly noting areas that are connected directly to the asset).	- Completely remove the weed species using the methods listed in *Maintaining Vegetated Stormwater Assets*. Weed removal or control strategies will vary according to the biological characteristics of the species (e.g. growing habits, seeding times, water tolerance), the extent of cover, the location of the asset, and the potential impacts on the desirable vegetation within the basin and the downstream ecosystem. Prevent the future ingress of weeds by planting the batters with species that provide dense cover and shade, and by increasing the frequency of inspections and maintenance.
	The plant density is insufficient or the vegetation has died.	Compare the vegetation density with the performance indicators in *Maintaining Vegetated Stormwater Assets* and refer to 'Plant failure' in this table to identify why there is a lack of plant cover.	
The batters or edge treatments are too steep, provide a trip hazard, or allow unsafe public access into the basin.	There is a lack of access control, e.g. dense perimeter vegetation. The batters have eroded. The basin was poorly designed.	Complete a public safety risk assessment in accordance with Appendix A. Design elements that need to be considered include: - site access and the barriers in place, such as fencing or perimeter vegetation - batter slopes both below and above the normal water level - vegetation cover and height Refer to 'Eroded batters' in this table. Identify if the sediment basin was designed and constructed in accordance with the *Technical Design Guidelines* and the *Construction and Establishment Guidelines*.	The outcome of the risk assessment findings (Appendix A) and the local context will guide the response. - Install access control using barriers, such as fencing or vegetation. - Modify the bathymetry to provide safe batters below and above the normal water level. A maximum slope of 1:4 is recommended. - Modify the layout to provide safe access for inspection and maintenance activities.

Problem	Possible causes	Investigations	Options
Mosquitoes	The water is stagnant or stratified. There is a lack of predators. Litter is providing habitat (e.g. shallow pools of water).	Identify if there is litter or shallow, isolated pools of water.	- Remove litter. - Fill in and reprofile shallow, isolated pools of water. Replant if necessary. - If the problem persists, seek advice from a mosquito specialist.
Lack of adequate maintenance access	The design did not allow for maintenance requirements, such as vehicle access, access to hydraulic structures, and an area for de-watering.	Check the approved plans to identify the proposed: - methods of sediment extraction, including equipment - access requirements to the site for maintenance personnel and vehicles - access to hydraulic control structures - safety requirements - de-watering requirements	- Construct an access ramp or a lateral hard-stand area for maintenance vehicles and equipment. - Modify the bathymetry for safe access to the lower batter areas. - Construct a de-watering area adjacent to the basin or, if a de-watering area cannot be provided, use alternative methods of sediment extraction (e.g. suction pump).
	Vegetation or unplanned structures are blocking access to the sediment basin.		- Remove blockages.
Odours	Organic matter, such as leaves and debris, is decomposing within the sediment. Floating water plants or algal biomass is decomposing. Blue-green algae are present. The water quality is poor due to: - stormwater quality (nutrients, chemicals) - anoxic sediments - bacterial contamination (fauna such as birds) - cross-connections and overflows from sewerage	Check for evidence of the following sources of odour: - decomposing organic matter - algal blooms (e.g. surface scums) - anoxic sediments (surface bubbling, sulfur-based odours) - chemical residues on the water surface - large populations of water birds - chemical spillage (via the stormwater drainage system) - sewage	- Manage catchment-related causes (e.g. a chemical spill or sewerage cross connection). - Seek advice from a pest specialist if a large bird population is present and deemed to be contributing to odours. Potential actions may involve: • deterrents to discourage birds • removing or modifying bird habitat • removing or culling birds • installing recirculation or aeration devices to get oxygen through the sediment. - If the odour persists, clean out the sediment in accordance with *Maintaining Vegetated Stormwater Assets*.

FOUR **REFERENCES AND USEFUL SITES**

Planning, designing and constructing vegetated stormwater assets

Water by Design. http://www.waterbydesign.com.au/

Water by Design. *Construction and Establishment Guidelines*. Healthy Waterways, Brisbane.

Water by Design. *Maintaining Vegetated Stormwater Assets*. Healthy Waterways, Brisbane.

Water by Design. *Technical Design Guidelines*. Healthy Waterways, Brisbane.

Bioretention systems

Facility for Advancing Water Biofiltration. http://www.monash.edu.au/fawb/

General engineering

Institute of Public Works Engineering Australia. http://www.ipwea.org.au

Natural Resources and Water. 2007. *Queensland Urban Drainage Manual*. Queensland Government, Brisbane.

Weed management

Weeds Australia. http://www.weeds.org.au/weedeck.html

Pest management

Department of Land and Water Conservation. 1998. *The Constructed Wetlands Manual* (Volume 1). DLWC, NSW.

Protected species management

Environment Protection and Biodiversity Conservation Act 1999.

Legislation and policies

Land Protection (Pest & Stock Route Management) Act 2002.

General references

Australian Standard AS1926.1-2007—*Swimming pool safety – Safety barriers for swimming pools*.

Australian Standard AS4419—*Soils for landscaping and garden use* (2003).

Facility for Advancing Water Biofiltration. *Guidelines for Filter Media in Bioretention Systems*. Facility for Advancing Water Biofiltration, Monash University.

Hatt and Le Coustumer (2008). Practice Note 1: *In-Situ Measurement of Hydraulic Conductivity*, Facility for Advancing Water Biofiltration, Monash University.

Natural Resources and Water. 2007. *Queensland Urban Drainage Manual*. Queensland Government, Brisbane. www.derm.qld.gov.au/water/regulation/pdf/guidelines/flood_risk_management/qudm_1.pdf. Accessed 26 August 2010.

APPENDIX A PUBLIC SAFETY RISK ASSESSMENT FOR EDGES TO SEDIMENT BASINS AND WETLANDS

The treatment of approaches to permanent water, and the surface immediately under the permanent water level, should be configured with consideration for public safety and structural stability. It is recommended that the risk scores in Table B1, and the recommended treatments in Table B2, are used as a guide. Also consider local authority specific requirements. These tables are adapted from *Batter Slope Treatment and Fencing Guidelines for Constructed Wetlands and Detention Basins* (Lake Macquarie City Council, 2009).

The total risk score should be determined by summing the scores associated with each category in Table B1. The minimum edge treatment for the total risk score should be determined by referring to Table B2.

Note that these scores are not evidence or probability based. Therefore, **the outcomes recommended by these tables are not prescriptive and should be used as a guide only.**

Table B1 Risk score table

	Risk score
Approach batters (above normal water level)	
Batter 1:6 or shallower	0
Batter 1:4 up to 1:6	2
Batter steeper than 1:4	6
Vertical wall ≤ 0.9 m within perimeter wetted by top of extended detention	8
Vertical wall > 0.9 m within perimeter wetted by top of extended detention	16
Vertical drop at water edge (below normal water level)	
No vertical drop or drop ≤ 0.15 m within 4 m from normal water level edge	0
Vertical drop > 0.15 m and ≤ 0.3 m within 4 m from normal water level edge	2
Vertical drop > 0.3 m and ≤ 0.5 m within 4 m from normal water level edge	8
Vertical drop > 0.5 m within 4 m from normal water level edge	17
Water depth 4 m from inside of normal water level extent	
≤ 0.5 m	0
> 0.5 m and ≤ 0.67 m	4
> 0.67 m and ≤ 1.0 m	8
> 1.0 m	17

	Risk score
Frequency of use of adjacent land	
Low/occasional/uninvited use (e.g. densly planted garden bed)	0
Regular high use e.g. pedestrian/cycle path	4
Distance from closest property boundary to normal water level	
> 20 m	0
≤ 20 m	6
Surveillance	
Good regular surveillance ≤ 150 m of normal water level	0
Good regular surveillance > 150 m of normal water level	4
Presence of young children	
Class C or Class D contact classification in Table 12.04.1 of QUDM (Natural Resources and Water, 2007)	0
Class A or Class B contact classification in Table 12.04.1 of QUDM (Natural Resources and Water, 2007)	8

Table B2 Recommended edge treatment

Recommended minimum edge treatment	Total risk score
Grass batter or densely vegetated batter (preferred)	≤ 11
Densely vegetated batter (2.5 m wide, > 0.75 m high, no spaces, > 0.15 m between adjacent plants)	12-16
Densely vegetated batter plus accidental entry fence (1.2 m high cable fencing, curb, kick or equivalent)	17-21
Exclusion fencing (in accordance with AS 1926.1-2007)	> 21

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