City of Melville Stormwater Quality Management Guidelines

June 2019

South East Regional Centre for Urban Landcare

City of Melville

Acknowledgments

This report was prepared by the South East Regional Centre for Urban Landcare (SERCUL) and Vivacious Surrounds for the City of Melville.

Disclaimer

SERCUL has made every effort to certify that the information described in this document is accurate, but cannot guarantee, express or imply its currency, accuracy or flawlessness as new information becomes available since the time of its writing.

Contents

1. Introduction

The City of Melville is situated along the southern bank of the Swan Canning estuary with an 18 km length of foreshore. The City contains natural and artificial wetlands, streams and drainage infrastructure that host a diverse range of biota, including threatened ecological communities and endangered species. Residents of the City also enjoy many of these areas and their associated reserves for their recreational and aesthetic value. Stormwater produced within the City's largely urban environment discharges to these existing waterbodies, with the potential to have negative impacts on water quality and other environmental values. It is recognised that management is required to minimise these threats.

The City has a *Stormwater Environment Management Plan* (GHD 2015), which includes a capital works plan for structural stormwater interventions to improve water quality. These Stormwater Quality Management Guidelines have been devised to work alongside this Plan by providing a holistic operational process for the City's stormwater management to maintain and enhance water quality, biodiversity and overall health of stormwater receiving bodies. The Guidelines therefore have the following objectives:

- Provide information regarding best practice approaches to stormwater management within the City of Melville;
- Provide information regarding environmental considerations for the implementation of the stormwater capital works program proposed in the *Stormwater Environment Management Plan* (GHD 2015, page 21).

2. Existing environment

2.1. Land uses

The City of Melville is a largely urban local government area in the Perth metropolitan region. It is comprised of the following approximate proportions of land use areas (City of Melville 2017):

- Private residential: 48%;
- Streets and roads: 22%;
- Institutional: 9%;
- Parks and recreation: 8%;
- Bushland reserves: 7%;
- Private/commercial/industrial: 5%;
- Other: 1%.

2.2. Soils and geology

The majority of the soils in the City are highly permeable sands, comprised of Perth Coastal Zone (Quindalup and Spearwood) sands in the west with some areas of Bassendean Zone sands in the east (Department of Primary Industries and Regional Development 2018). Some foreshore and wetland areas have clayey to sandy alluvial soils (Pinjarra Zone).

2.3. Acid sulfate soils

Within the City area, areas of Pinjarra Zone soils (mainly around wetlands and the foreshore area) are classed as "moderate to high risk of acid sulfate soils, and areas of Bassendean sands in the eastern portion of the City are classed as "low to moderate risk of acid sulfate soils" (Department of Water and Environmental Regulation [DWER] 2017a).

2.4. Stormwater drainage

2.4.1. Historic stormwater pathways

Historically, due to the highly permeable soils present within the City of Melville area, the majority of rainfall would have infiltrated through the soil into the groundwater. Several wetlands were present in the City, which were expressions of the groundwater level. Bull Creek was a significant overland flow path for water moving through the City area, with historic images showing what appears to be a series of seasonal damp lands flowing into Bull Creek (**Figure 1**).

Figure 1: Aerial photograph of Bull Creek and surrounding catchment, 1965 (© Landgate)

2.4.2. Current stormwater pathways

Currently, due to the City's predominantly urban land uses, a large proportion of the City's land is covered by relatively smooth impervious surfaces, including roofs, roads, footpaths, and paved areas. As such, in contrast to the pre-developed land where the majority of rainfall within the City's boundary would have infiltrated and entered groundwater, much of the rainwater that falls in the City is now transported as overland flow (stormwater) until it reaches a receiving waterbody. Traditional stormwater convincing channels present within the City facilitate the flow of much of this stormwater, with the aim to remove the most water from a site in the shortest time possible. Both the smooth ground surfaces and the traditional conveyance design increase the volume and velocity of stormwater during rain events. GHD (2015) identified 264 stormwater catchments, both exorheic (draining to the sea) and endorheic (draining internally), throughout the City based on both topographic data and stormwater pit and pipe network data.

2.4.3. Stormwater receiving environments

Wetlands

Wetlands are areas that are permanently, seasonally or intermittently waterlogged or inundated with water. In the City, there are 25 wetlands which receive water from the stormwater network, including 14 conservation category wetlands, 7 resource enhancement wetlands, 2 multiple use wetlands and 2 unclassified wetlands, as classified by Hill et al (1996) (GHD 2015). The City considers 14 of these to be “very high value wetlands” and two of these to be “high value wetlands” (Woodgis 2011). These wetlands support many species of flora and fauna, including a number of frogs, the Mourning Skink (*Egernia luctuosa*) and the Western Petalura (*Petalura hesperia*) that are considered high value species (Woodgis 2011). The types of wetlands present within the City include permanent, seasonal and ephemeral freshwater lakes and wetlands, creeks (e.g. Bull Creek) and estuarine floodplains (e.g. Alfred Cove). It is important to note that many floodplains of the Swan Canning Estuary, including Alfred Cove, can support salt marsh habitats, which are nationally recognised Threatened Ecological Community (TEC) listed under the *Environment Protection and Biodiversity Conservation Act 1999* (WA)).

Many of the wetlands in the City existed prior to urbanisation of the catchment and were historically surface expressions of the groundwater, receiving minimal overland flow. As many of these wetlands are endorheic (i.e. do not directly drain to the river) they can accumulate some of the pollutants that are conveyed through the stormwater network. These wetlands can also be impacted by stormwater runoff entering from the area immediately surrounding the wetland. Both natural and constructed wetlands themselves can also provide the conditions required for water quality improvement. As water in these wetlands is connected to the superficial groundwater aquifer, any water quality improvements afforded by these wetlands will not only provide benefits to the wetlands themselves, but also to any waterbodies connected to groundwater downstream.

Sumps and bioretention basins

In the City, there are 71 sumps and 29 bio retention basins that receive water from the stormwater network (GHD 2015). Sumps are structures engineered to receive stormwater for flood mitigation purposes, with examples of both “wet” (often with a base above groundwater level) and “dry” (base below groundwater level) present in the City. Many dry sumps are often located within parks, some of which have high public amenity. Sumps often do not have significant environmental value, but some may support vegetation and fauna. Dry sumps that allow water to infiltrate (sometimes called infiltration basins) can provide water quality improvements, whereas wet sumps may experience water quality problems resulting from stagnant water, weed and algal proliferation and pollutant accumulation. Bioretention basins, a form of biofilters, are discussed in **Section 8**.

Swan Canning River system

The Swan Canning River system is recognised as a public asset for it natural beauty and its cultural and recreational significance. This system, like all rivers, responds to the influences of its catchment, including rural farmland in the wider catchment and concentrated urban use activities within the greater Perth metropolitan area. The drying climate and declining groundwater levels are resulting in decreased flow into the system, increasing its vulnerability to nutrient and non-nutrient pollutants entering through the stormwater network (Swan River Trust [SRT] 2009).

Groundwater

The City overlies the unconfined Jandakot groundwater mound. Stormwater infiltrates to the groundwater mound both at source (i.e. where rainfall lands on pervious surfaces) and via infiltration into the sumps and other stormwater infiltration assets that form part of the City’s stormwater network. Groundwater flows through the City in a north or north-westerly direction towards the Swan Canning River (Department of Environment [DoE] 2004a) and also intersects many of the City's wetlands. As such, groundwater impacts the surface water quality of the Swan Canning River and wetlands in the City.

3. Impacts of stormwater on wetlands and waterways

The combination of high volume, high velocity surface flow and increased pollutant availability results in stormwater that has the potential to have multiple negative impacts on receiving water bodies, such as decreased water quality, increased water quantity, erosion and sedimentation and spread of weeds and pathogens.

3.1. Water quality issues

Urban areas, such as the City of Melville, are expected to produce a range of pollutants (refer to **Appendix A** for sources of specific pollutants). Gross particles (such as litter and organic material), fine particles (often referred to as sediment) and dissolved materials can all be sources of pollutants. Such pollutants, particularly when present on smooth, impervious surfaces, are able to be mobilised by stormwater, with the majority of pollutants mobilised during the first 15 of rainfall (New South Wales Environmental Protection Authority 2013), resulting in their transport through the stormwater network. Some urban pollutants enter the stormwater network through infiltration into groundwater that intersects with surface water bodies or slotted stormwater pipes.

3.1.1. Eutrophication

Eutrophication is the presence of excessive amounts of nutrients, mainly nitrogen and phosphorus, in a waterbody resulting in excessive plant growth. Eutrophication is a major issue in urban waterbodies as nutrients are often derived from either diffuse or point sources of anthropogenic pollution. Organic material, such as leaves from deciduous trees and grass clippings, can also contribute nutrients to stormwater.

Possibly the worst outcome of eutrophication is the formation of algal or blue-green algal blooms, which can produce toxins, impacting environmental health, human health and amenity. The growth of other types of vegetation in water bodies can restrict the flow of water, leading to potential issues with flooding and mosquito breeding. Any excessive form of plant growth will eventually produce large amounts of decomposing material, which produces foul odours and consumes oxygen dissolved in the water. This can, in turn, lead to the death of biota. The water quality conditions (low oxygen, available nutrients, high pH) that can occur in eutrophic waters are favourable to growth of *Clostridium botulinum*, an organism which produces toxins that can result in paralysis and/or death in animals and humans (Department of Environment and Primary Industries (Vic) 2014). This toxin often affects wetland birds (avian botulism) and can result in large numbers of large numbers of birds dying within a short period of time.

3.1.2. Toxicity to biota

A wide variety of pollutants found in urban catchments can be toxic to biota, including metals (commonly aluminium, arsenic, copper, chromium, lead and zinc), ammonia, oils, surfactants, pesticides and herbicides.

3.1.3. Turbidity

Stormwater can contain great numbers of particulates that, as well as being a source of nutrients and other toxicants, contribute to turbidity in receiving waterbodies. Light cannot penetrate as far through turbid water as it can through clear water, and as such turbid water cannot support the growth of some submerged macrophytes. Suspended particulates can also affect the function of fish gills and affect predator prey relationships.

3.1.1. Acid sulfate soils

Poorly designed or managed drainage infrastructure can result in the oxidation of acid sulfate soils, which can result in the acidification of stormwater and receiving waterbodies. Acidity can increase the availability of manganese, copper, zinc and aluminium, which can in turn have toxic effects on biota. Acid sulfate soil oxidation is also often associated with formation of iron flocs, which can smother benthic vegetation and organisms and reduce dissolved oxygen, and the production of monosulfidic black ooze. This monosulfidic black ooze settles at the bottom of water bodies, but during rain events can be mobilised and rapidly remove dissolved oxygen from the water column due to its high chemical oxygen demand. The drop in dissolved oxygen can lead to large releases of phosphorus from the sediments, triggering algal blooms (Department of Environment Regulation [DER] 2015a).

3.1.2. Changes to natural conditions

Stormwater can have quite different characteristics to receiving waterbodies and thus the large volumes of stormwater that are produced in urban catchments can change the water quality of receiving waterbodies. Stormwater influx can result in changes to pH, conductivity and temperature that while not toxic, can cause harm to biota that are accustomed to certain conditions. For example, if an industrial premise were to discharge a large volume of highly saline water into stormwater received by a small, naturally fresh waterbody, this could result in the death of plant and aquatic invertebrate species that cannot tolerate saline water. The resultant decrease in species diversity can allow for increases in the abundance of more tolerant species, such as water boatman or mosquito larvae, or weedy plant species.

Salt marsh ecosystems have evolved to tolerate high salt concentrations with a regime of inundation and drying, and as such under natural conditions salt marsh vegetation is able to out-compete other invasive species. Discharges of fresh water (i.e. stormwater) into salt marsh areas can dilute salt concentrations and alter the inundation and drying cycles of the habitat, allowing other (often invasive) vegetation species to colonise and out-compete the native salt marsh species. This colonisation of invasive species can potentially further alter the hydrological cycles of inundation and drying.

3.2. Increased water quantity

High volume stormwater flows can alter natural hydrological regimes in receiving waterbodies. For example, naturally ephemeral or seasonally flooded waterbodies can become perennially flooded. The sediment drying that occurs in seasonal or ephemeral wetlands has been shown to result in a loss of nitrogen in water and more compacted sediment upon re-flooding, which may be beneficial for water quality and plant growth in many wetlands. Changing from a seasonal or ephemeral to perennial water regime could also result in the displacement of species that rely on the habitats produced in seasonal or ephemeral wetlands. High volume, fast flowing stormwater can erode the banks of receiving waterbodies, which can alter waterbody shape, wash soil particles into the waterbody and potentially damage bank vegetation.

It should be noted that increased water quantity can also result in flooding, which can cause significant damage to property and infrastructure, and pose risks to human health and life. Flood mitigation is not the focus of this document and should be managed by suitably qualified professionals.

3.3. Sedimentation

Soil particles from eroded banks or carried by runoff flowing over areas with exposed or loose soil (e.g. construction sites or cleared land) can enter the stormwater network and either be deposited at the point of entry or further downstream. Large sediment loads can change the shape of wetlands, impede flow or change flow-path in channels and or block hydraulic structures. Sediment particles, particularly those originating from stormwater flowing over roads or industrial areas, may contain toxic substances that are released into the water column over time or under certain water physicochemical conditions. The deposition of fine or organic sediment can result in the formation of a flocculent layer that plants cannot anchor their roots into.

Sediment can also have a considerable impact on the ecological health on the macroinvertebrate population within WSUD assets and the receiving environment. Fine sediment accumulation in a wetland is the preferred establishment site for midge larvae, with the larvae forming a J-type tunnel in surface of the sediment. As such fine sediment accumulation can provide conditions for increased numbers of nuisance midges. Midges are not a vector species but can be a source of significant irritation, and can create a negative community perception of waterbodies. A layer of new sediment covering the substrate of a waterbody can bury eggs of other aquatic invertebrate species, some of which predate on mosquitoes and midges. Thus sedimentation can reduce the diversity and abundance of aquatic invertebrates within the water body and upset the overall ecological balance of the system.

3.4. Spread of weeds and pathogens

Stormwater has the potential to collect and transport a number of pathogens, including those that can cause harm to humans (e.g. faecal coliforms) or biota (e.g. *Phytophthora cinnamonni* (known as "dieback"). Stormwater can also spread propagules of weedy plant species into wetlands and parklands where weeds are not currently present. Some weeds, and particularly some aquatic weed species (such as *Hydrocotyle ranunculoides* or Amazon frogbit (*Limnobium laevigatum*)), can grow prolifically, resulting in poor water quality and displacement of native species.

4. Risk assessment

A risk assessment, with methodology modified from chapter 5 of the Stormwater Management Manual (Department of Water [DoW] and SRT 2007a) was conducted to characterise the likelihood and severity of the impact for potential threats to environmental and aesthetic values for each of the priority stormwater receptors (taken from Table 4 GHD 2015) within the City of Melville (**Table 1**). It is noted that only risks to environmental and aesthetic values have been assessed: flood and health risks imposed by stormwater are outside the scope of this matrix and require assessment by suitably qualified professionals.

The threat likelihood for each receptor was determined by examining the catchment maps in GHD (2015), the land use zoning maps from the City of Melville Intramaps, the contaminated sites database (DWER 2019), the Perth Groundwater Atlas (DoE 2004a), mapping (ESInet – Water Corporation 2019) of Water Corporation assets (particularly sewer pump stations and stormwater drainage assets) and information provided by the City of Melville regarding future development. When considering the severity of impacts of threats, the conservation category (or lack thereof) as prescribed by Hill et al (1996), hydrological regime, aesthetic value and presence of biota reliant on water quality/quantity in each receptor was considered.

Table 1: Risk assessment for potential stormwater threats to environmental and aesthetic values for priority stormwater receptors in the City of Melville.

Receptor	Conservation Category (Hill et al 1996)	Main water quality issues	Wetland type	Threat posed by stormwater										
				Residential land use runoff	Industrial land use runoff	Commercial land use runoff	Construction and development sites	Road and carpark runoff	Surface runoff flow modification	Groundwater level modification	Open space runoff (e.g. golf courses and sporting grounds)	Inadequate maintenance of stormwater devices (e.g. drains, sumps, gross pollutant traps and side entry pits)	Landfill and contaminated sites	Septic and sewer leakage
Swan River Estuary	Conservation Category	• High N & P[1] • Low DO[1] • Non nutrient contaminants in sediment (Zn, Pb, Cu, Hg, DDE, dieldrin, PAHs)[2]	Estuary	High likelihood High impact	High likelihood High impact	High likelihood High impact	High likelihood High impact	High likelihood High impact	High likelihood High impact	High likelihood High impact	High likelihood High impact	High likelihood High impact	High likelihood High impact	Medium likelihood High impact
Elizabeth Manion Park	Unclassified	• High N & P[3] • High metals in water (Al, Cu, Zn)[3]	Sump in POS	High likelihood Low impact	Low likelihood Low impact	Medium likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	Medium likelihood Medium impact	Low likelihood Low impact	Low likelihood High impact
Winnacott Reserve	Unclassified	ND	Sump in POS	High likelihood Low impact	Low likelihood Low impact	Low likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	Medium likelihood High impact	Low likelihood Low impact	Low likelihood High impact
Booragoon Lake Reserve (EAST)	Conservation Category	• Very high N & P[3] • Low DO[3] • Acid sulfate soils[4] and low water pH[3] • High Fe in water[3] • High sediment Pb[3]	Seasonal/ permanent lake	High likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Medium likelihood High impact	Low likelihood High impact	Medium likelihood High impact
Alfred Cove	Conservation Category	ND	Estuarine floodplain (saltmarsh)	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Medium likelihood High impact	Low likelihood High impact	Medium likelihood High impact
Brockman Park (EAST)	Conservation Category	• Very high N (esp. NH_3/NH^{4+})[3] • Low DO[3]	Channel (Bull Creek)	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Medium likelihood High impact	High likelihood High impact	Low likelihood High impact
Trevor Gribble Park (EAST)	Resource Enhancement	ND	Dampland	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	Medium likelihood High impact	High likelihood Low impact	Medium likelihood High impact
Harry Buckley Park	Resource Enhancement	ND	Permanent modified lake	High likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood Medium impact	High likelihood High impact	Medium likelihood High impact	Low likelihood High impact	Low likelihood High impact
Bill Sweet Park	Unclassified	ND	Sump in POS	High likelihood Low impact	Low likelihood Low impact	Low likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	Medium likelihood Medium impact	Low likelihood Low impact	Low likelihood High impact
Gemmel Park	Unclassified	ND	Sump in POS	High likelihood Low impact	Low likelihood Low impact	Low likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	Medium likelihood High impact	Low likelihood Low impact	Low likelihood High impact
Laurie Withers Reserve	Unclassified	ND	Sump in POS	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	Medium likelihood Low impact	Medium likelihood High impact	Low likelihood Low impact	Low likelihood High impact
Phillip Jane Park	Unclassified	ND	Sump in POS	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	High likelihood Low impact	High likelihood Low impact	Low likelihood Low impact	Medium likelihood Low impact	Medium likelihood High impact	Medium likelihood Low impact	Low likelihood High impact
Piney Lakes Reserve (EAST)	Conservation Category	• Low DO[3] • Low pH[3] • High Al in water[3]	Seasonal lake system	High likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood High impact	Medium likelihood High impact	Medium likelihood High impact	Low likelihood High impact	Medium likelihood High impact

Table 5-1 (continued): Risk assessment for potential stormwater threats to environmental and aesthetic values for priority stormwater receptors in the City of Melville.

Receptor	Conservation Category (Hill et al 1996)	Main water quality issues	Wetland type	Threat posed by stormwater										
				Residential land use runoff	Industrial land use runoff	Commercial land use runoff	Construction and development sites	Road and carpark runoff	Surface runoff flow modification	Groundwater level modification	Open space runoff (e.g. golf courses and sporting grounds)	Inadequate maintenance of stormwater devices (e.g. drains, sumps, gross pollutant traps and side entry pits)	Landfill and contaminated sites	Septic and sewer leakage
Blue Gum Reserve (EAST)	Conservation Category	• Very high N & P[3] • Low DO[3] • Low pH[3] • High Fe in water[3]	Seasonal/ permanent lake	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Medium likelihood High impact	Low likelihood High impact	Medium likelihood High impact
Reg Bourke Park (WEST)	Resource Enhancement	ND	Sumpland	High likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood High impact	Medium likelihood High impact	Medium likelihood Medium impact	Medium likelihood High impact	Low likelihood High impact
All Saints Dampland	Conservation Category	ND	Dampland	High likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood High impact	Medium likelihood High impact	Medium likelihood High impact	Medium likelihood High impact	Low likelihood High impact
North Lake	Conservation Category	• High N & P[5] • Low water pH and acid sulfate soils[5]	Seasonal lake	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Medium likelihood High impact	Low likelihood High impact	Medium likelihood High impact
Bateman Park (WEST)	Conservation Category	• High NH_3/NH^{4+} and NOx[3]	Upstream channel (Brentwood Main Drain) and downstream estuarine floodplain	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood High impact	Medium likelihood High impact	Medium likelihood High impact	Low likelihood High impact	Medium likelihood High impact
Frederick Baldwin Park lake	Unclassified	• Low DO[3] • High Zn in water[3] • High sediment Pb[3]	Permanent modified lake	High likelihood High impact	Low likelihood High impact	High likelihood High impact	Low likelihood High impact	High likelihood High impact	High likelihood High impact	Low likelihood Medium impact	Medium likelihood High impact	Medium likelihood High impact	Low likelihood High impact	Medium likelihood High impact
Richard Lewis Park (WEST)	Conservation Category	ND	Sumpland	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	Low likelihood High impact	Medium likelihood Medium impact	Medium likelihood High impact	Low likelihood High impact

1 DWER (2018a)
2 Nice (2009)
3 SERCUL (2019a)
4 Oldweather (2012)
5 Bourke et al (2015)
ND No data available

Likelihood	Consequence		
	High	Medium	Low
High	(red)	(orange)	(blue)
Medium	(orange)	(blue)	(green)
Low	(blue)	(green)	(green)

5. Relevant legislation, policies and guidelines

It should be noted that the information below is general information only and is not legal advice. It is recommended that legal advice be obtained if required. The relevant legislation should be consulted for further information and to ensure amendments to legislation are taken into account.

5.1. Western Australian legislative requirements

***Environmental Protection Act 1986* (WA)**

This Act provides for the prevention, control and abatement of pollution and environmental harm; and for the conservation, preservation, protection, enhancement and management of the environment. Wetlands are protected by provisions under this Act. It establishes the functions and powers of the Environmental Protection Authority (EPA), the process of creation of environmental protection policies and the requirement for environmental impact assessments to be completed for proposals likely to have a significant impact to the environment. It provides for the regulation of certain activities, including the clearing of native vegetation and the operation of certain prescribed premises. It establishes the actions of polluting, dumping or discharging waste, discharging emissions, or otherwise causing environmental harm as offenses. The *Environmental Protection (Unauthorised Discharge) Regulations 2004* (WA) prohibit the discharge of scheduled materials into the environment, which includes stormwater drainage.

Clearing can only be conducted if a clearing permit is granted by DWER or if the clearing is for an exempt purpose. However exemptions do not apply in “environmentally sensitive areas” (for more information including a link to online mapping of these areas see *Clearing regulation fact sheet 24 - Environmentally Sensitive Areas, Environmental Protection Act 1986* (DER 2014). The Act prohibits the clearing of native vegetation if it is likely to cause deterioration in the quality of surface or underground water if clearing is likely to cause, or exacerbate, the incidence or intensity of flooding.

***Metropolitan Water Supply, Sewerage, and Drainage Act 1909* (WA)**

This Act provides for the creation of “Water Reserves” and “Underground Water Pollution Control Areas” for which specific by-laws pertaining to activities affecting water quality in these regions apply. No such reserves are currently present in the City of Melville.

***Swan and Canning Rivers Management Act 2006* (WA)**

This Act makes provisions for the protection and management of the Swan Canning Rivers and associated land. This includes the Swan Canning Riverpark (the river waterbody area itself as well as associated shoreline areas), the Development Control Area (an area including and surrounding the Riverpark for which special development conditions apply) and the catchment area, all of which have areas within the City. Under this Act, a River Protection notice can be issued by DBCA to owners of land within the catchment area if any action is required, or refraining from any action is required, in order to protect or enhance the Swan Canning Riverpark. Infringement notices can be issued if a River Protection notice is not followed.

***Biodiversity Conservation Act 2016* (WA)**

This Act provides for the conservation and protection of biodiversity and biodiversity components. The Act allows for the listing of protected or threatened species, threatened ecological communities and critical habitats and provides certain protections for these. In respect to critical habitats, a habitat conservation notice can be issued, which may require a person to repair habitat damage, reestablish and maintain critical habitat in any area affected by habitat damage or prevent the erosion, drift or movement of sand, soil, dust or water, to ensure that specified land, watercourse or wetland where critical habitat is or was located will not be damaged or further damaged. The Act also provides for the creation of biodiversity management programmes and recovery plans. Public authorities must have regard to these programmes when performing functions relating to these programmes. The Minister can also, on behalf of the State, enter into an agreement (a biodiversity conservation agreement) with an owner or occupier of land in relation to land specified in the agreement.

Waterways Conservation Act 1976 **(WA)**

This Act provides for the conservation and management of certain waters and of their associated land and environment. No such areas are currently present in the City.

Metropolitan Arterial Drainage Act 1982 **(WA)**

This Act provides for the Arterial Drainage Scheme and its planning, maintenance and improvement. While the relevant Minister responsible is responsible for the overall administration of the Scheme, the control or management of particular drains may be vested in other individuals or bodies. The Minister can declare a drainage asset or proposed drainage asset to be an arterial drain.

Rights in Water and Irrigation Act 1914 **(WA)**

This Act provides for the regulation, management, use and protection of water resources and governs the allocation and management of water resources for consumption. Under this Act, obstructing or destroying watercourses or discharging any sediment or other material likely to obstruct flow of a watercourse is an offence.

Conservation and Land Management Act 1984 **(WA)**

This Act provides for the use, protection and management of certain public lands, including State forest, timber reserves, national parks, conservation parks, nature reserves, marine nature reserves, marine parks, marine management areas and other land reserved by the Minister for Lands under the Land Administration Act 1997. An area of the Alfred Cove foreshore is considered part of the Swan Estuary Marine Park, with the purpose of this area to provide for the conservation and restoration of the natural environment, the protection of indigenous flora and fauna, and preservation of features of archaeological, historic or scientific interest.

Soil and Land Conservation Act 1945 **(WA)**

This Act controls the degradation of land, which includes groundwater beneath land and surface water on land. If, as a result of certain activities including failure to prevent soil erosion, salinity or flooding, land degradation (which includes salinity, eutrophication or flooding) is occurring or likely to occur, a soil conservation notice can be issued to the land owner. This notice can require the land owner to refrain from certain activities or take action to prevent the erosion, drift or movement of sand, soil, dust or water on or from any land specified in the notice.

Aboriginal Heritage Act 1972 **(WA)**

This Act provides for the protection of Aboriginal cultural heritage. Under the Act it is an offence for anyone to excavate, damage, destroy, conceal or in any way alter an Aboriginal Site without the Minister's permission. A Register of Aboriginal Sites is maintained by the Department of Indigenous

Affairs (DIA) and is available online. Registered Aboriginal Sites within the City of Melville include North Lake (North), Booragoon Lake Reserve and the Swan River.

Contaminated Sites Act 2003 **(WA)**

Under this Act, contaminated or suspected contaminated sites must be reported to DWER. Contaminated sites are placed on a publicly available register with details of the contamination and whether there are any restrictions on the use of that land. Contaminated sites can be sources of groundwater or stormwater pollution.

5.2. Australian legislative requirements

Environment Protection and Biodiversity Conservation Act 1999 **(Cth)**

Matters of national environmental significance are protected under this Act, including Ramsar Wetlands (which includes the Swan River), nationally recognised threatened species and ecological communities (including Banksia woodlands of the Swan Coastal Plain and subtropical and temperate coastal saltmarsh) and migratory species protected under international agreements. Any proposals which may have a significant impact on any of these matters require referral and assessment under this Act.

5.3. Policies and guideline documents

Stormwater Management Manual for Western Australia and Decision Process for Stormwater Management in WA

The Stormwater Management Manual for Western Australia is a comprehensive guide to best practice stormwater management in a Western Australian context, prepared through collaboration with multiple government stakeholders. It includes an explanation of the context of stormwater management in WA (DoE 2004b), and provides guidance regarding preparation of stormwater management plans (DoW and SRT 2007a), retrofitting existing infrastructure (DoW and SRT 2006), non-structural stormwater controls (DoE and SRT 2005) education and awareness (DoE 2004c), structural controls (DoW and SRT 2007b) and performance management and evaluation (DoW and SRT 2007c).

The Stormwater Management Manual for Western Australia also includes the Decision Process for Stormwater Management in WA (DWER 2017b), which details a step by step process for planning and designing stormwater management systems for new developments and existing stormwater management system retrofits. It includes the following four main objectives for stormwater projects:

- Manage stormwater quantity,
- Manage water quality,
- Protect and manage water resources, and
- Achieve good urban amenity.

To achieve each of these objectives, the document contains criteria to be followed when designing and planning stormwater project stages.

State Planning Policy 2 - Environment and Natural Resources **(Western Australian Planning Commission [WAPC] 2003) and *State Planning Policy 2.9 - Water Resources* (WAPC 2006)**

State Planning Policy 2 outlines broad measures to be considered undertaking land use planning in regards to water resources, with the overarching objectives of:

- Integrating environment and natural resource management with broader land use planning and decision-making;
- Protecting, conserving and enhancing the natural environment; and
- Promoting and assisting in the wise and sustainable use and management of natural resources.

State Planning Policy 2.9 provides more specific guidance for the consideration of water resources in land use planning processes. This includes guidance for incorporation of policy measures into planning mechanisms and decision-making, guidance for the determination of appropriate buffering of waterways and estuaries and principles of total water cycle management and water sensitive urban design. This policy does not impose changes to existing land use activities.

***Better Urban Water Management* (WAPC 2008)**

This document provides guidance on the implementation of State Planning Policy 2.9 for new greenfield and urban renewal projects where residential, commercial, industrial and rural residential uses and development are proposed. It provides a framework for applying water sensitive urban design at each stage of the land use planning process by identifying the various actions and investigations required. It also identifies the agencies responsible for providing the required information to inform planning.

***Environmental Guidance for Planning and Development (Guidance Statement 33)* (EPA 2008)**

This guidance statement provides an overview of environmental protection processes and information relevant to the *Environment Protection Act 1986* (WA) and provides advice from the EPA on a range of environmental factors in order to assist participants in land use planning and development to protect, conserve and enhance the environment. This includes a chapter about planning and decision making for the protection of wetlands, which includes measures for stormwater management.

***Planning for stormwater management affecting the Swan Canning Development Control Area (Corporate policy statement no. 49)* (Department of Parks and Wildlife (DPAW) and SRT 2016)**

This policy document provides guidance regarding how DBCA assess development and permit applications involving stormwater management in accordance with the *Swan and Canning Rivers Management Act 2006* (WA) and the *Swan and Canning Rivers Management Regulations 2007* (WA). It outlines the requirements, including requirements for stormwater quality, which development proposals need to address in order to be accepted.

***Swan Canning River Protection Strategy* (SRT 2015a)**

This is a strategic document is produced in accordance with the *Swan and Canning Rivers Management Act 2006* (WA). Along with actions pertaining to management of the Riverpark itself, the following actions pertaining to stormwater management to be undertaken by Local Government Authorities (including the City of Melville) are specified in this document:

- Identify the levels and sources of nutrients, organic material and sediment entering the Swan and Canning rivers (support organisation);
- Develop and implement Swan Canning and local Water Quality Improvement Plans to achieve nutrient load reduction targets (support organisation);
- Prescribe and apply intervention techniques to either trap nutrients, organic material and sediments in drains and tributaries, or to achieve source control of these contaminants (lead organisation);

- Improve management of fertiliser use to reduce nutrient loss from urban and rural land in the Swan Canning catchment (support organisation);
- Implement actions arising from the urban water drainage partnership addressing strategic issues in the Swan Canning catchment (support organisation);
- Improve planning schemes and policies to achieve a net decrease in nutrient inputs from future land development (lead organisation);
- Maintain an inventory of sources of pollution incidents (support organisation);
- Undertake river and catchment-based water quality monitoring program to measure compliance against management targets (support organisation);
- Establish a program to monitor non-nutrient contaminants entering, and in, the river system (support organisation);
- Coordinate the management of declared plant species (support organisation).

***Local Water Quality Improvement Plan - Bull Creek Catchment* (SRT 2012)**

This plan provides local government authorities (including the City of Melville) and communities with a mechanism to prioritise recommendations and resources and seek funding to improve water quality in the Bull Creek catchment. Actions within WQIPs address nutrient and pollutant pathways through catchments from their source to the discharge point. This document followed the *Swan Canning Water Quality Improvement Plan* (SRT 2009), which describes the Bull Creek Catchment as having "unacceptable water quality" in regards to the nitrogen loads it contributes to the Swan Canning River.

***Western Australian environmental guidelines for the establishment and maintenance of turf grass areas* (SRT 2015b)**

These guidelines outline best management practices for turf maintenance in Western Australia with an aim to reduce nutrient loss from fertilisers.

***Guidelines for district water management strategies* (DoW 2013)**

This document guides planners of district structure plans or region scheme amendments on the preparation of a District Water Management Strategy.

***Interim: Developing a local water management strategy* (DoW 2008)**

This document guides planners of local planning scheme amendments or local structure plans on the preparation of a Local Water Management Strategy.

***Wetlands of the Swan Coastal Plain* (Hill et al 1996)**

This document contains a map of all the significant wetlands in the Swan Coastal Plain and ascribes management categories to the most significant of these wetlands, providing guidance on how the wetlands should be managed and protected. These management categories are referenced in many other policies and guideline documents, including WAPC (2003), EPA (2008) and DWER (2017b). The categories are as follows:

- Conservation category:
    - Wetlands that support a high level of attributes and functions;
    - Objective is to preserve and protect existing conservation values;
- Resource enhancement:
    - Wetlands which may have been partially modified but still support substantial ecological attributes and functions;

    - Objective is to manage, restore and protect these wetlands towards improving their conservation value.
- Multiple use:
    - Wetlands with few remaining important attributes and functions;
    - Management should be considered in the context of ecologically sustainable development and best management practice catchment planning through landcare.

See **Table 1** for the management categories assigned to the priority stormwater receptors in the City of Melville.

***Wetlands of National Importance* (Commonwealth Department of the Environment and Heritage, Canberra 2001)**

Booragoon Lake and the Swan Canning Estuary are defined as Wetlands of National Importance in this document.

Vegetation guidelines for stormwater biofilters in the south-west of Western Australia (Monash University 2014)

This document outlines an approach to choosing, establishing and maintaining vegetation in order to maximise the effectiveness of stormwater biofilters. It includes a table with Western Australian plants proven and likely to be effective at removing nutrients from stormwater.

6. Stormwater quality management approach

The receiving environments are intimately linked to the health of the catchment via the flow of water and nutrients through the catchment. Stormwater quality should therefore be managed using a holistic "treatment train" approach that incorporates various management strategies along pollutant pathways to maximise water quality improvements. The treatment train approach for the Swan Canning River outlined in the *Swan Canning Water Quality Improvement Plan* (SRT 2009) (**Figure 2**) and for the Bull Creek Catchment outlined in the *Local Water Quality Improvement Plan: Bull Creek Catchment* (SRT 2012) can be adapted for the management of entire City's stormwater quality. The following management strategies form this treatment train approach:

- **Prevention**: Strategies aimed at preventing stormwater pollution by employing water sensitive planning methodology. Principles to assist with planning and designing stormwater management systems are outlined in **Section 7** of this document.
- **Minimisation**: Strategies aimed at minimising the generation of pollutants that could potentially enter stormwater by increasing the efficiency of both water use and practices with the potential to cause stormwater pollution (e.g. such as industrial processes, cleaning and fertiliser use). This includes education regarding best practices to maximise efficiency. Minimisation measures are outlined in **Sections 10.1, 10.3 and 10.4** of this document;
- **Reduction**: Strategies aimed at reducing the amount of pollution entering the stormwater network by implementing controls at the pollution source. Controls could be physical, (e.g. silt fences on construction sites or pervious paving) or involve education (e.g. raising public awareness of the connection of the urban drainage system to the River to encourage them not to discharge car washing water into stormwater). Reduction measures are outlined in **Sections 10.1, 10.2, 10.3 and 10.4** of this document;
- **Amelioration:** Strategies aimed at improving stormwater conveyance structures such that they facilitate reduced pollutant transport. This can be achieved by maximising biofiltration, incorporating buffers to prevent pollution entry, and facilitate nutrient cycling to promote nutrient loss. Amelioration measures are outlined in **Sections 8.4 and 10.5** of this document.

- **Treatment, reuse and disposal:** Strategies aimed at treating or reusing water before it enters the stormwater network. This can include structural interventions such as constructed wetlands, gross pollutant traps and chemical dosing of water, as well as the reuse of wastewater. Treatment and discharge measures are outlined in **Section 8.4** and **Section 10.6** of this document.

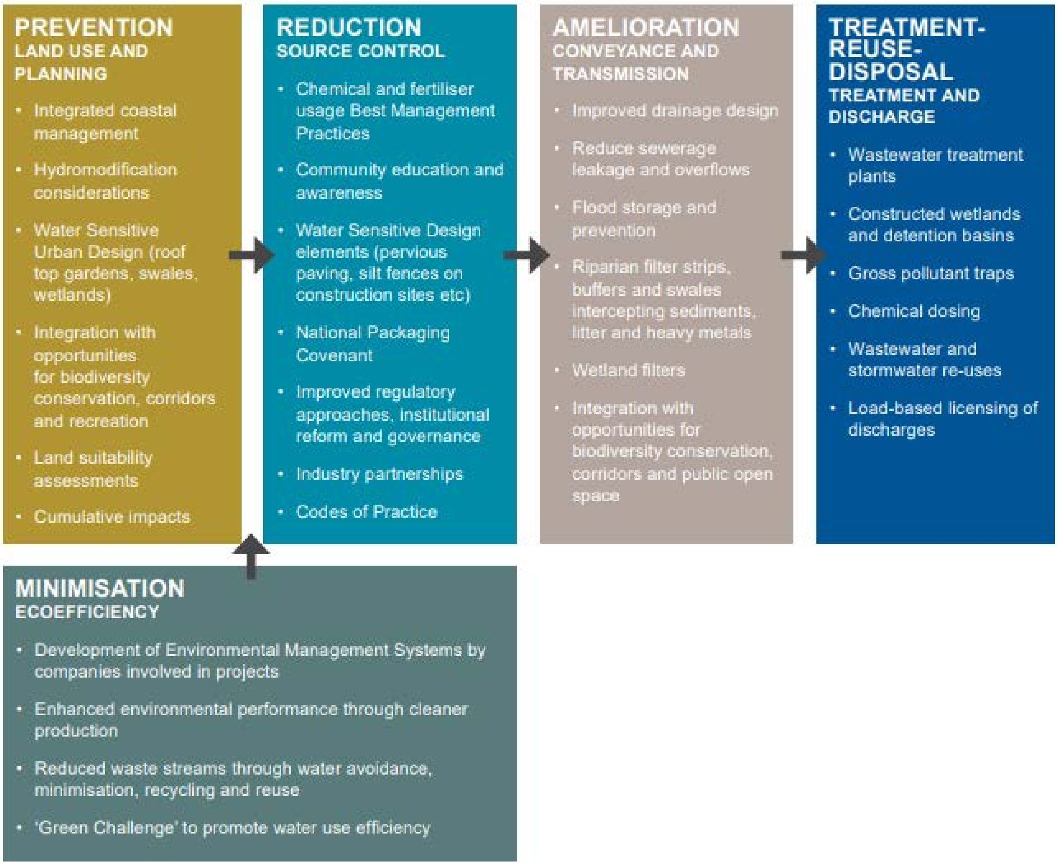

Figure 2: Treatment train approach for water quality improvement in the Swan Canning River (SRT 2009)

7. Planning principles for water sensitive stormwater management

7.1. Water Sensitive Urban Design (WSUD) overview

Urban development has necessitated a stormwater network that can protect property and other assets from flooding resulting from high rainfall events. As such, the primary function of a traditional "pit and pipe" stormwater network is conveyance and flood mitigation, with drainage designs catering for the 100-year flood event. However, traditional stormwater networks do not have much capability to improve the quality of the water moving through them, and in some cases can exacerbate poor water quality. Water sensitive urban design (WSUD) offers an alternative to this traditional approach by attempting to replicate the natural water cycle to minimise the impacts of urbanisation on the natural water cycle, including the following:

- Decreased tree canopy: It is now recognised that urban catchments can be several degrees hotter than surrounding areas due to the lack of urban tree canopy. This has significant implications for the health of residents within the catchment;
- Decreased green spaces and natural areas: An increasing number of studies link green space and nature to health and wellbeing of people within urban environments;
- Increased nutrient and non-nutrient pollutants entering receiving environments (i.e. the Swan Canning River and the natural wetlands present in the City).

WSUD accomplishes this via the following objectives (WAPC 2008):

- Maintain a water regime;
- Maintain and, where possible, enhance water quality;
- Encourage water conservation;
- Maintain and, where possible, enhance water-related environmental values; and
- Enhance water-related recreational and cultural values.

While these Stormwater Quality Management Guidelines are focussed on the improvement of stormwater quality and the improvement of water related environmental values, all the above WSUD objectives should be considered when planning stormwater management systems.

7.2. Incorporating WSUD principles in stormwater planning

The *Decision process for stormwater management in Western Australia* (DWER 2017b) provides an approach to achieve water sensitive urban design outcomes when planning stormwater management systems for new urban developments and when planning and designing stormwater management system retrofits. These guidelines stipulate that the below principles should be considered when planning and designing stormwater management systems.

Mimic natural hydrological processes to achieve best economic, social and environmental outcomes

This should be done by:

- Retaining and protecting water bodies with environmental and social values:
    - To achieve this, all wetlands within the City, and particularly conservation category and resource management wetlands, should be retained and protected. The City has management plans for many of its wetlands of high conservation value that will facilitate this.
- Retaining and planting vegetation wherever possible:
    - Vegetation reduces stormwater volume and peak flow rates and should therefore be maximised. The City's *Urban Forest Strategic Plan 2017-2036, Part A: City Controlled Land* (2017) provides a strategy to help achieve this.
- Minimising 'effective imperviousness':
    - Pervious surfaces (e.g. gardens, turf, and pervious pavement) that allow infiltration should be retained and installed in preference to impervious surfaces (e.g. hard pavement, roads).
- Managing small rainfall event runoff at-source:
    - DWER (2017b) stipulates that stormwater runoff from constructed impervious surfaces generated by the first 15 mm of rainfall should be managed (retained and/or detained and treated (if required)) at-source. As infiltration would have been the primary pathway for rainfall prior to urbanisation due to the City's permeable soils, infiltration at source is the ideal management method. This can be achieved through structural

controls such as tree pits and biofilters (see **Section 8.4.1**). As well as improving water quality, studies undertaken by the CRC for Water Sensitive Cities have demonstrated that significant attenuation of peak flow events can be achieved by the implementation of stormwater biofiltration WSUD measures (e.g. rain gardens and biofilters) within the stormwater network (Payne et al 2015).

- Providing overland flow paths wherever practical:
  - Vegetated overland flow paths, such as swales, living streams and vegetated buffers (see **Section 8.4.3** and **Section 8.4.4**), should be used to convey stormwater instead of pipes or drains wherever practical, as they slow down and reduce the volume of runoff, improving water quality.
- Incorporating the forms and processes of natural water bodies within stormwater management systems:
  - Incorporating waterbodies with a more natural form, such as living streams, vegetated swales and constructed wetlands (see **Section 8.4.3**, **Section 8.4.4** and **Section 8.4.1**), into the stormwater network will improve biodiversity and amenity, as well as provide opportunities for water quality improvement.

Prevent and reduce stormwater pollution through the application of structural and non-structural controls

As mentioned in **Section 6**, it is important to consider both structural and non-structural stormwater controls when planning stormwater management systems. **Sections 8 and 10** of these guidelines describe structural and non-structural stormwater controls that should be considered at the planning stage.

Integrate stormwater management systems in the urban form to enhance urban amenity

The amenity of WSUD stormwater assets can be enhanced by:

- Integrating stormwater management systems within the design of road reserves, public spaces and public open space;
- Retaining and planting vegetation throughout the urban landscape
- Establishing a connection between people, water and nature in the urban landscape. This could be achieved through the use of media, artwork, public events or other cultural works/activities.

Integrate stormwater management in the land and water planning process

Stormwater management system design should be included as part of other land and water planning processes to ensure integration. Further guidance regarding the integration of stormwater planning into land and/or water planning pertinent to the City can be found in the following guidance documents:

- *Better Urban Water Management* (WAPC 2008);
- *Guidelines for district water management strategies* (DoW 2013); and
- *Interim: Developing a local water management strategy* (DoW 2008).

Design site-responsive stormwater management systems based on local site parameters

The design of stormwater management systems should take into account local site conditions and constraints, desired outcomes, stormwater threats from upstream catchments and values in receiving waterbodies. See **Section 8.3** for more details.

8. WSUD stormwater structural controls

8.1. Overview

WSUD utilises various stormwater structural controls, which are engineered devices that improve water quality and in some cases enhance water-related environmental, recreational and cultural values. Stormwater structural controls have different functions, including:

- Infiltration: aim to utilise or infiltrate the 1-year event;
- Conveyance: move the water across the landscape in larger events;
- Detention: provide capacity within the network to enable infiltration for larger events and for these events to be conveyed through the network, within the design conveyance capacity of the network; and
- Discharge: aim to mitigate the negative impacts of stormwater discharge to the receiving environment.

As is considered best practice in water sensitive urban design, stormwater structural controls should be implemented parallel and/or in sequence as part of a treatment train approach to maximise water quality improvement and to sufficiently mitigate flood risk during larger rainfall events. This treatment train approach was utilised by GHD (2015) when devising their capital works plan for treatment measures for stormwater in the City.

These Stormwater Quality Management Guidelines have focussed on implementation considerations for stormwater structural controls that have environmental values (referred to henceforth as “WSUD assets”), as these controls largely comprise the recommendations made by GHD (2015) for the City, and will be managed by the City’s Parks and Environment Unit. Many of the treatment measures recommended by GHD (2015) involve upgrades of existing stormwater assets to WSUD assets. However, it is important to realise that there are many other stormwater structural controls (e.g. soakwells, gross pollutant traps and oil/water separators) and traditional stormwater assets (e.g. open drains, pits and sumps) that form an important part of the City’s stormwater network. This includes detention sumps or basins that contain permanent water, which DWER currently does not recommend the new construction of as best practice (see *Interim Drainage and Water Management Position Statement: Constructed Lakes* (Department of Water 2007)). Further information regarding the design and maintenance of these assets can be found in:

- Stormwater structural control design and maintenance: *Stormwater Management Manual for Western Australia, Chapter 9, Structural Controls* (DoW and SRT 2007b);
- Maintenance of traditional stormwater assets: *Stormwater Management Manual for Western Australia, Chapter 7, Non Structural Controls* (DoE and SRT 2005).

It is important to distinguish between each phase in the life cycle of WSUD assets: design, construction, establishment, handover, general maintenance and major maintenance. Design and vegetation considerations for WSUD assets, as well as maintenance requirements, are included in **Section 8.2** and **Section 8.4**, with references provided containing more detailed information for specific assets. Indicative costs for maintenance of WSUD assets are included in **Appendix B** Construction and establishment of these assets will largely depend on the individual asset, with detailed information available in *Construction and establishment guidelines: Swales, bioretention systems and wetlands* (Water by Design 2010). The asset handover process is summarised in **Section 8.5.**

8.2. Understanding peak flow

The following general principles of peak flow should be considered when designing all stormwater structural control assets:

- Within a pre urban catchment, flow paths for water moving across the landscape were often long with many barriers to slow the flow. The most significant changes to stormwater flow in the urban landscape are:
    - the increase in hard surfaces that will not allow infiltration, and
    - the speed at which the drainage allows water to move across the landscape;
- The peak flow of any stormwater flow event is the point at which the potential for damage to occur within the system is the greatest. Designing stormwater assets to accommodate peak flows will significantly reduce potential damaging impacts within the system and to the receiving environment. There are three variables that determine the peak flow for any stormwater event:
    - The amount of rainfall in the catchment,
    - The size and shape of the catchment (a larger catchment will result in a larger total flow through the system), and
    - The flow velocity (the quicker the floodwater runs off the catchment the higher the peak flow event will be);
- Water will move from the highest to the lowest point via the path of least resistance. As such, when establishing vegetation in a stormwater asset it is important to consider where the water will flow during peak flows if blockage occurs, and whether there is sufficient space for the water to move through the site. If vegetation does create a blockage water may preferentially flow through soil, which can result in erosion and creation of a new flow path;
- Erosion in waterways is a balance of the energy of the water moving through the site, and:
    - Vegetation colonisation – binding of the soil,
    - Soil structure – the soil's ability to hold together,
    - Groundwater levels – dry soils are more erodible than moist soil,
    - Land use – determines runoff volumes and velocities.

8.3. Site specific considerations

When designing WSUD assets for a site, the following site specific considerations should be factored into the design:

- Local site conditions and constraints. This should include:
    - Land area and shape;
    - Surrounding infrastructure, including underground assets;
    - Water resources;
    - Groundwater levels, direction of flow and quality;
    - Existing surface water pathways and quality,
    - Soil characteristics (e.g. soils type, infiltration rates, presence of acid sulfate soils (see DER 2015b), capacity to retain nutrients);
    - Social characteristics, such as current and historical land use, Aboriginal heritage values, public perception of the site;
    - Economic constraints;
- Desired economic, social and environmental outcomes sought for the site;
- The threats, and resultant stormwater impacts and pollutants requiring management, posed by upstream catchment(s). The City of Melville catchment mapping and estimated pollutant loads modelled in GHD (2015), as well as catchment water quality monitoring data

(e.g. SERCUL 2019) can be utilised for this purpose. **Appendix A** outlines management strategies and controls for common urban pollutants;

- The environmental and social values of downstream receptors:
    - Assess the environmental (flora, fauna, and ecosystems), social and aesthetic values present in the receptors;
    - Assess the conditions necessary to sustain these values. This could include water quality, hydrological, sediment or vegetation condition. The City has management plans for many of the priority receptors in the City that should be consulted to obtain this information;
    - Assess if and how the construction, implementation and maintenance of the new asset could impact these values and/or conditions. This could be by introducing sediment during construction, changing the water regime or water quality, introducing a source of vegetation foreign to the receptor or introducing excess organic material (see **Section 3**).

8.4. Summary of WSUD assets

It should be noted that the maintenance requirements below are a suggested guide, and should be adjusted as needed. As stormwater assets are linked to and respond to the activities within the catchment, catchment activities influence the management requirements of these assets and maintenance frequency and timing may need to be adjusted accordingly.

8.4.1. Biofiltration basins, rain gardens and tree pits

Description

Biofiltration basins, rain gardens, and tree pits are type of biofilters designed primarily to infiltrate stormwater to the underlying soils. They consist of basins filled with porous media and planted with vegetation. Stormwater enters these systems via either a pipe or over the ground surface, and slowly filters through the filter media. Treated flows can either be infiltrated to underlying soils (a suitable approach within many areas of the City due to the permeable soils present, see **Figure 3** for example) or collected in an underdrain system for conveyance to the downstream stormwater network; designs would need to consider the constraints and the opportunities of each location. Rain gardens tend to refer to biofiltration basins implemented on a smaller scale. Tree pits are smaller, generally containing only one tree with or without some small understorey vegetation, and are often used in hard landscapes (e.g. along footpaths) (see **Figure 4**).

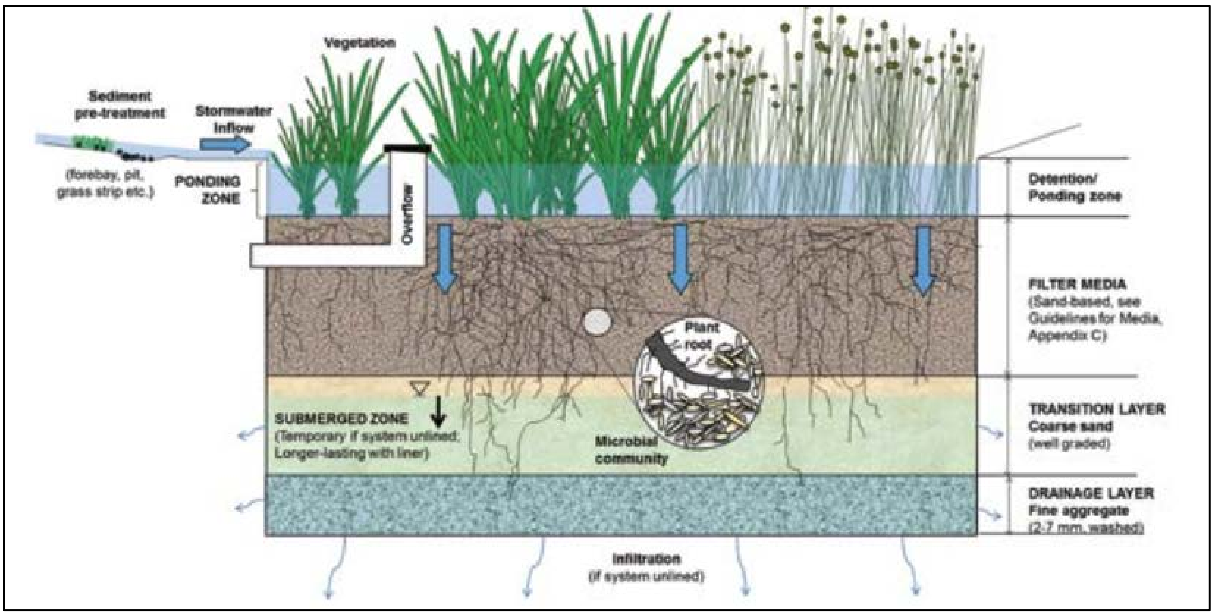

Figure 3: Example cross sectional illustration of a biofilter without an underdrain system (Source: Payne et al 2015, p 51).

Figure 4: Example illustration of a tree pit (Source: Melbourne Water 2013, p 26)

Function

Infiltration (up to the 1 year event)

Round one capital works program locations (GHD 2015)

- Sump to biofilter conversion at:
  - Aulberry Parade sump
  - Laughton Way sump
  - Ernest Wild Park
  - Cedric Smith Park
  - Dudley Hartree Park
  - Douglas Freeman Park sump
  - Harry Baker Park

    - Winnacott Reserve
    - Blue Gum Reserve
    - George Welby Park
    - Gemmel Park
- Rain gardens in opportunistic locations in the Marmion Reserve Lake catchment;
- Tree pits in:
    - Future trees in the APP23 (Applecross) and BIC09 (Bicton) catchments of the Swan River Estuary;
    - Opportunistic locations in the Marmion Reserve Lake catchment.

Target pollutants

- coarse sediment
- suspended solids
- phosphorus
- nitrogen
- heavy metals

Design considerations

- Assess the site specific conditions as per **Section 8.3**;
- Given the porous soils and high infiltration rates within the City, may be able to design these assets without a direct connection into the piped stormwater network - design should consider site specific conditions;
- Mitigate acid sulfate soils as necessary (DER 2015a);
- Ensure integration into landscape design;
- Consider location during planning of roads and lots – infiltration assets should be placed as close to run-off sources as possible;
- Surface area should be at least 2% of the constructed, directly connected impervious catchment for water quality treatment (DoW 2011a);
- Incorporate a submerged zone and carbon source to promote vegetation health and resilience during dry periods and aid nitrogen removal;
- Ensure design includes access for maintenance and litter removal, including vehicle access for large biofilters, to improve maintenance efficiency;
- Consider placing flush kerbing between roads/footpaths and biofilters where applicable to allow water ingress;
- Prevent mosquito breeding by adequate design – no water ponding after 96 hours between November and May;
- Mulch should not be used in vegetated assets where it can be mobilised.

Vegetation considerations

- All plants chosen must be able to tolerate periods of inundation and/or waterlogging;
- All plants chosen should tolerate the soil, salinity, and water regime conditions present in the biofilter;
- Species that remove nutrients should be prioritised, with at least 50% of plants comprised of species shown to be effective for nutrient removal (Monash University 2014). These species tend to have extensive and fine roots, fast growth rates and a large total mass. Refer to **Table C-1, Appendix C** for a list of such species;
- Consider target pollutants– certain plants have been shown to be taken up certain pollutants more effectively than others (see Table 4 of Payne et al 2015);

- Choose a diverse range of species to improve resilience;
- Choose species local to the City, as these are more likely to be adapted to local conditions (see Appendix 3 in Woodgis 2011);
- Choose plants to enhance biodiversity and create habitat;
- Plants must be able to tolerate long periods of drought;
- Avoid the use of nitrogen fixing plants (Monash University 2014);
- Avoid deciduous species;
- Avoid species that drop large amounts of leaves, fruit or branches;
- For tree pits:
    - Consider impacts of tree height and width on surrounding infrastructure (e.g. powerlines);
    - Consider the impact of shade produced by trees;
    - Consider the impact of roots – physical barriers may be required for root control
- Avoid the use of pesticides/herbicides.

Maintenance

Issue/activity	Frequency/ timing
Filter media: Remove sediment, infill holes/scoured areas, and ensure adequate filtration	Quarterly after rain
Litter control: check for and remove rubbish and plant material	Quarterly after rain
Vegetation: • Check for pests and disease – treat if required • Check plant density – remove/add plants if required • Remove weeds • Provide water if required • Pruning (trees) • For tree pits without understorey vegetation, any accumulation of leaf litter should be removed	Quarterly, vegetation may require more regular watering in dry months (e.g. summer and autumn)
Check underdrain pipes, raised outlet and sediment forebay (if present) and unclog if required.	Twice a year after rain
Check inlet pits, overflow pits and other stormwater junction pits	Monthly, or twice yearly if no current construction in catchment
Mosquito management: should not hold water for more than 96 hours between November and May. If extended water pooling is occurring, this needs to be rectified	Check during summer/ autumn site inspections
Public perception: community should understand the value and role of these assets. Maintain aesthetics to ensure their acceptance, and educate community.	Periodically

Further information

- *Stormwater Management Manual for Western Australia, Chapter 9, Structural Controls* (DoW and SRT 2007b) pp 103-122
- *Water sensitive urban design: Biofilters* (Department of Water 2011a)
- *Adoption guidelines for stormwater biofiltration systems (Version 2)* (Payne et al 2015)
- *Vegetation guidelines for stormwater biofilters in the south-west of Western Australia* (Monash University 2014)
- *Bioretention technical design guidelines* (Water by Design 2014)
- *Tree pit design principles* (Clearwater 2014)
- Melbourne Water (2013) *WSUD maintenance guidelines: Inspection and maintenance activities*.

8.4.2. Infiltration basins

Description

Infiltration basins are depressions designed to capture, store and infiltrate stormwater to underlying soils, and include sumps that are “dry” (i.e. those that do not intersect the maximum groundwater table) but not those which intersect groundwater or hold water for significant periods. While many such basins may have been installed primarily to detain water and mitigate flood risk, as they facilitate infiltration they can afford significant water quality improvements if maintained correctly. These systems are often incorporated within parks or natural areas but many are also fenced. They often incorporate some form of vegetation, and are often turfed.

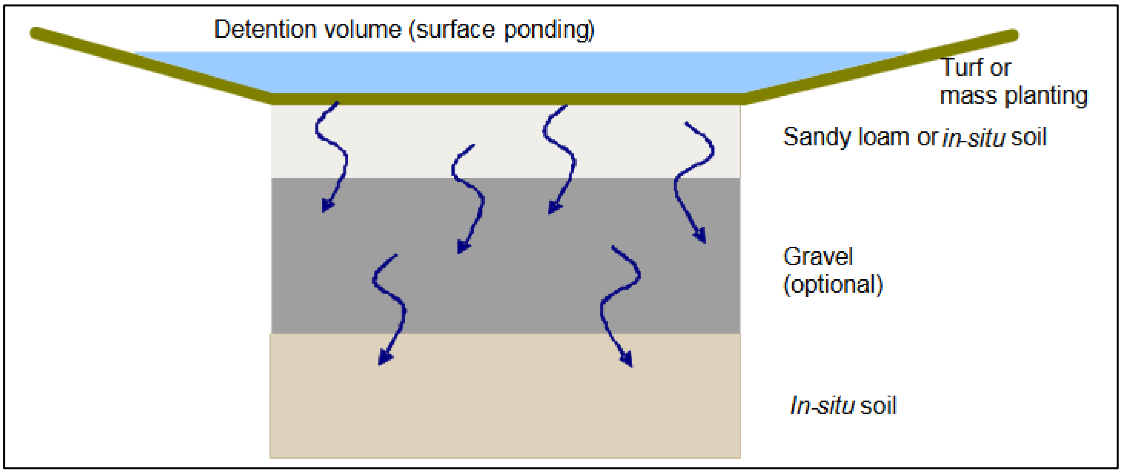

Figure 5: Schematic cross-sectional diagram of an example infiltration basin (Source: City of Gold Coast 2007, p5)

Function

- Infiltration (1 year event or larger with appropriate design)
- Detention

Target pollutants

- litter and organic matter
- coarse sediment
- suspended solids
- nitrogen
- phosphorus
- heavy metals

Round one capital works program locations (GHD 2015)

NA

Design considerations

- Assess the site specific conditions as per **Section 8.3**. Infiltration basins should not be employed in loose aeolian (i.e. windblown dunal) sands (not generally present within the City);
- Mitigate acid sulfate soils as necessary (DER 2015a);
- Can be vegetated or turfed. The pollutant removal effectiveness depends on the vegetation type and cover and phosphorus retention index of the soil;

- Base should be at least 300mm above the maximum or controlled groundwater level;
- Prevent mosquito breeding by adequate design – no water ponding after 96 hours between November and May;
- Where stormwater is conveyed via pipes into these systems, pre-treatment (e.g. via litter traps or other WSUD assets) is recommended;
- Ensure they are integrated with the landscape design of public open space.

Vegetation considerations

Usually incorporate turf or other vegetation. Vegetation can provide some water quality treatment and the root network assists in preventing the basin floor from clogging. When choosing vegetation species other than turf, consider similar plant species as for biofilters.

Maintenance

Issue/activity	Frequency/timing
Pre-treatment devices, inlets and outlets (if present): Check and remove blockages	Biannually and after major storm events
Surface ponding, sediment accumulation and erosion: Check for and rectify	Check biannually and after major storm events. If sediment requires removal, do in summer when sediment is dry enough to remove from basin floor

Further information regarding maintenance of sumps can be found in *Stormwater management manual for Western Australia, Chapter 7, Non structural controls* (DoE and SRT 2005).

Further information

- *Stormwater Management Manual for Western Australia, Chapter 9, Structural Controls* (DoW and SRT 2007b) pp 63-74
- *Water sensitive urban design: Infiltration basins and trenches* (DoW 2011b)

8.4.3. Swales and buffer strips

Description

Swales and buffer strips are biofilters consisting of grassed or vegetated channels overlaying a porous filter medium. Due to their linear shape, they have a conveyance function as well as facilitating infiltration. They often run alongside to roads to collect and convey road runoff. Swales are usually aligned in the direction of flow whereas buffer strips are aligned perpendicular to flow. Swales can be combined with a bioretention trench to provide further treatment (known as bioretention swales, see **Figure 6**).

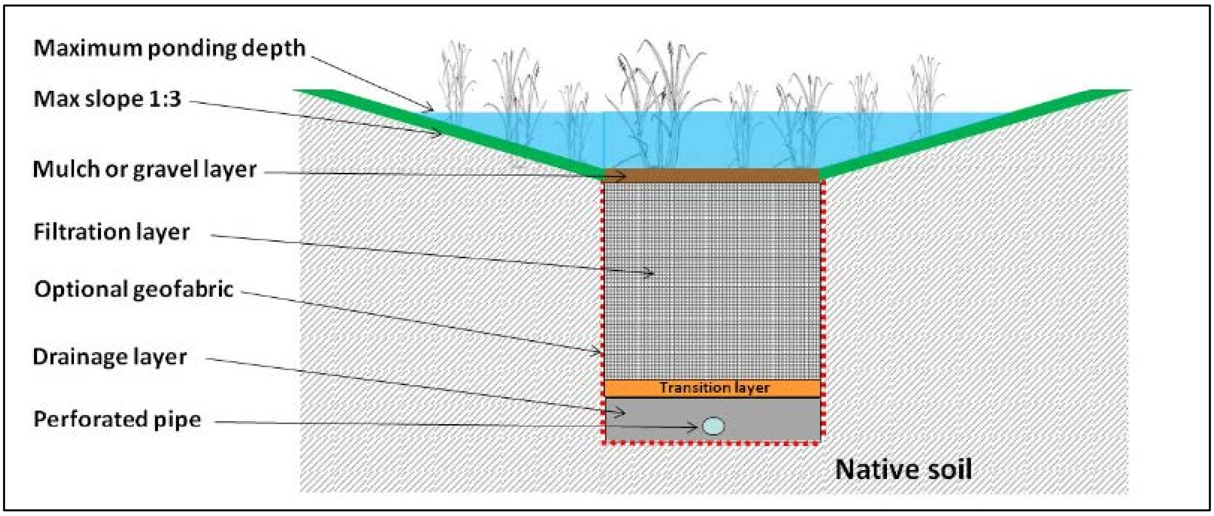

Figure 6: Cross sectional diagram of an example bioretention swale (Source: Department of Planning and Local Government (SA) 2010, p2)

Function

- Conveyance
- Infiltration

Round one capital works program locations (GHD 2015)

- Swale recommended for the conversion of the outlet at Attadale Reserve
- Buffer strip recommended at Booragoon Lake Reserve along Aldridge Road and Lang St

Target pollutants

- litter
- coarse sediment
- suspended solids

Design considerations

- Assess the site specific conditions as per **Section 8.3**;
- Mitigate acid sulfate soils as necessary (DER 2015a);
- Given the porous soils and high infiltration rates within the City, may be able to design these assets without a direct connection into the piped stormwater network - design should consider site specific conditions;
- Design longitudinal slope to avoid scouring, protect public safety and prevent stagnant water. The slope is considered to be most efficient between 1% and 4% (DoW and SRT 2007b);
- Consideration must be given to bank stabilisation to ensure bank erosion does not occur;
- Should not intersect the groundwater table in dry season to avoid the creation of warm stagnant water;
- Give attention to road crossovers;
- Consider location relative to underground services;
- Prevent mosquito breeding by adequate design – no water ponding after 96 hours between November and May.

Vegetation considerations

- Can be turfed or vegetated with species such as tufted grasses, sedges or groundcovers. Turf swales will require regular maintenance and mowing. All vegetation other than turf will require a greater area to convey flows (DoW and SRT 2007b);
- Species in vegetated swales should be chosen to ensure that conveyance is facilitated during high flow periods. A list of suitable sedge and rush species for conveyance is present in **Table C-2, Appendix C**.
- In vegetated swales, aim to choose species shown to be effective for nutrient removal (see **Table C-1, Appendix C**);
- Consider target pollutants– certain plants have been shown to be taken up certain pollutants more effectively than others (see Table 4 of Payne et al 2015);
- In turfed swales, a fine, close growing, water resistant grass species should be chosen (DoW and SRT 2007b);
- All plants chosen must be able to tolerate periods of inundation and/or waterlogging;
- All plants chosen should tolerate the soil, salinity, and water regime conditions present;
- Choose a diverse range of species to improve resilience;
- Choose species local to the City, as these are more likely to be adapted to local conditions (see Appendix 3 in Woodgis 2011);
- Plants must be able to tolerate long periods of drought;
- Avoid the use of nitrogen fixing plants (Monash University 2014);
- Consider the effect of plants on driver visibility for swales installed in road reserves;
- Grass swales should be mowed no shorter than the design flow levels;
- Avoid species that drop large amounts of leaves, fruit or branches;
- Avoid the use of pesticides/herbicides.

Maintenance

Issue/activity	**Frequency/timing**
Erosion: check for erosion/scouring and preferential flow paths, fill, replant or stabilise eroded areas as required	Monthly or following major storm events during first winter, then quarterly or following major storm events
Inlets and outlets: Check for blockages and for erosion around these structures	Monthly or following major storm events during first winter, then quarterly or following major storm events
Vegetation: • Check for pests and disease – treat if required • Check plant density – remove/add plants if required • Remove weeds • Provide water if required • Mow (grass)	Quarterly or biannually checks. Complete vegetation management activities in summer (or for weed control, depending on target species)
Design capacity: check for and remove excess sediment or vegetation as required to maintain	Annually before winter
Ponding: stagnant water should not occur for prolonged periods to prevent mosquito breeding, check and rectify if required	Monthly during low flow period (i.e. summer/ autumn) or following summer/autumn storm events

Further information

- *Stormwater Management Manual for Western Australia, Chapter 9, Structural Controls* (DoW and SRT 2007b) pp 89-102
- *Water sensitive urban design: Swales and buffer strips* (DoW 2011c)
- *Adoption guidelines for stormwater biofiltration systems (Version 2)* (Payne et al 2015)

- Melbourne Water (2013) *WSUD maintenance guidelines: Inspection and maintenance activities*.

8.4.4. Living streams

Description

Living streams are stormwater conveyance channels that mimic the characteristics of a natural stream (**Figure 7**). Living streams can support diverse habitats for wildlife and improve water quality. They generally have stabilised vegetated banks and a more natural morphology than traditional trapezoidal stormwater drains.

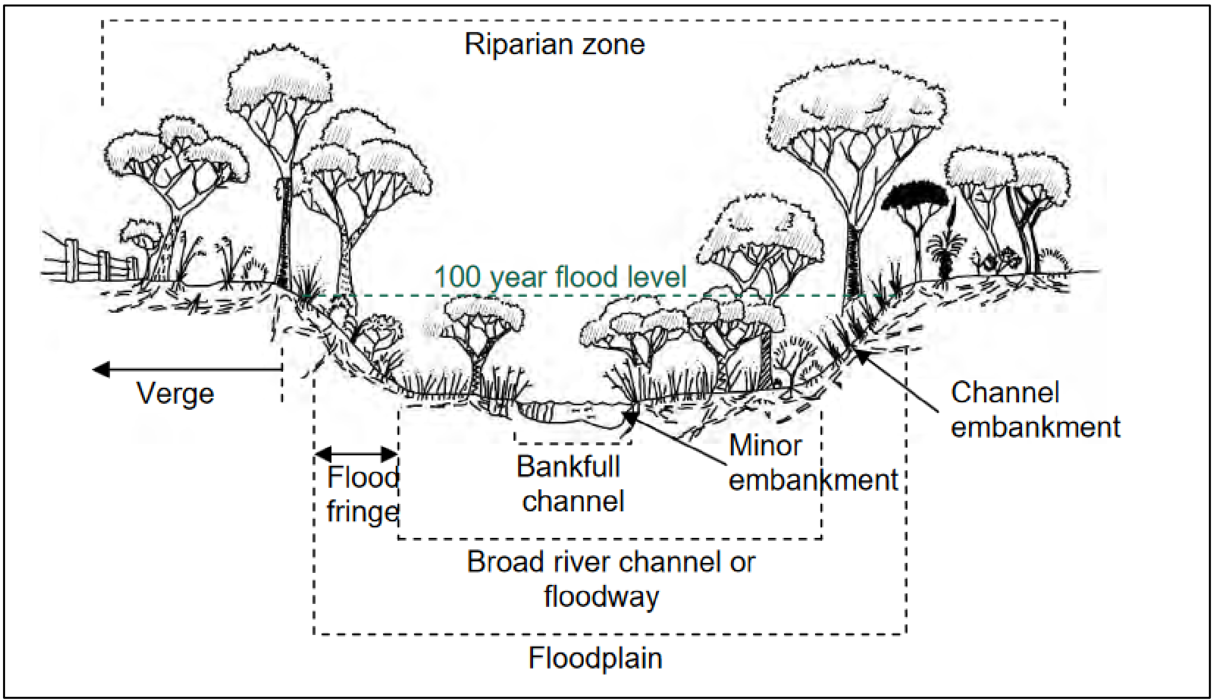

Figure 7: Cross sectional diagram of an example living stream (Source: Water and Rivers Commission and Department of Environment 1999-2003)

Function

- Conveyance
- Infiltration (in areas with permeable soils i.e. most areas within the City)

Round one capital works program locations (GHD 2015)

NA

Target pollutants

- suspended solids
- nitrogen
- phosphorus
- heavy metals
- hydrocarbons

Design considerations

- Assess the site specific conditions as per **Section 8.3**;
- Mitigate acid sulfate soils as necessary (DER 2015a) if excavating new ground during implementation;
- Ensure integration with landscape design components of public open space;
- Consider terrain and geology when selecting placement and alignment;
- Where possible, living streams should be designed not to intersect the groundwater table and the channel invert should be dry during summer to avoid the creation of warm stagnant water (DoW and SRT 2007b). However this may not always be possible, particularly when retrofitting existing systems;
- When retrofitting existing open drains in urban areas, designs should be hydraulically assessed to ensure the existing flood capacity of the drain is maintained;
- When designing living streams in Water Corporation drainage assets, specific guidelines (DoW and Water Corporation 2016) need to be followed;
- Buffer zones for natural stream assets are recommended to be a minimum of 30m where possible;
- Incorporate features such as riffles, woody debris, pools and meanders to provide varied habitats. Riffles and other grade control structures will also improve oxygenation;
- To prevent erosion of the channel banks and bed, measures such as detention areas, grade control structures (e.g. riffles), organic matting, brush mattressing, geotextiles and use of intensive planting can be used in high velocity areas to increase hydraulic roughness and slow flows.

Vegetation considerations

- Consider vegetation to suit each of the different hydrological zones that may be present, including:
  - Permanent inundation (or long periods of permanent inundation). This would include the in-stream areas in permanently flowing (or at least permanently moist) living streams;
  - Seasonal/temporary inundation. This would include in-stream areas in seasonally flowing streams, and flood plain/lower bank areas in permanently flowing streams;
  - Irregular inundation i.e. surrounding dryland areas that may be inundated in very large events;
- Species from **Table C-2, Appendix C** can be chosen for in-stream areas of various depths as they can tolerate inundation and maintain conveyance. However, in some living streams a flow path clear of vegetation may need to be maintained to ensure adequate conveyance. To achieve this, the invert level of this flow path needs to be low enough such that the expected water depth is greater than the tolerance of the vegetation species planted adjacent to it. If this water depth cannot be achieved, then consider planting species with a lower tolerance for inundation;
- A flood plain or bench can be set at a specific level to create the conditions suitable for a specific suite of vegetation, such as species effective at removing nutrients (e.g. those in **Table C-1, Appendix C**). The bench should have a gentle grade back to the main channel to prevent pooling of water within the system;
- Choose plants that have hard leaves that decompose slowly;
- Include fringing trees to provide shade. Shade lowers water temperatures, leading to higher dissolved oxygen concentrations, less aquatic weed and algal growth and conditions more conducive to nutrient processing
- Retain existing native plants where possible and use local species (see Woodgis 2011) as they are better adapted to local conditions;

- Choose a diverse range of species to improve resilience;
- Choose plants to enhance biodiversity and create habitat;
- Avoid the use of pesticides/herbicides.

Maintenance

Issue/activity	Frequency/timing
Erosion: check for erosion/scouring and preferential flow paths, fill, replant or stabilise eroded areas as required	Monthly during winter, otherwise quarterly or following heavy rain events
Inlets and outlets: Check for blockages and for erosion around these structures	Monthly during winter, otherwise quarterly or following heavy rain events
Vegetation: • Check for pests and disease – treat if required • Check plant density – remove/add plants if required • Remove weeds • Provide water to establishing vegetation if required	Quarterly checks, vegetation management activities ideally done in summer (or for weed control, dependent on the target species)
Design capacity: check for and remove excess sediment or vegetation as required to maintain	Annually before winter
Ponding: pools of stagnant water should not form, check and rectify if required	Monthly during low flow period (i.e. summer/ autumn) or following summer/ autumn storm events
Public perception: community should understand the value and role of these assets. Maintain aesthetics to ensure their acceptance, and educate community.	Periodically

Further information

- *Stormwater Management Manual for Western Australia, Chapter 9, Structural Controls* (DoW and SRT 2007b) pp 123-136
- *Water sensitive urban design: Living streams* (DoW 2011d)
- *Drainage for Liveability Fact Sheet: Living streams in Water Corporation assets* (DoW and Water Corporation 2016)

8.4.1. Constructed wetlands

Description

Constructed wetlands are extensively vegetated water bodies that are specifically designed to remove pollutants whilst supporting other environmental values. They usually have multiple zones which support different functions and processes to improve water quality, including sedimentation, filtration and biological uptake of pollutants.

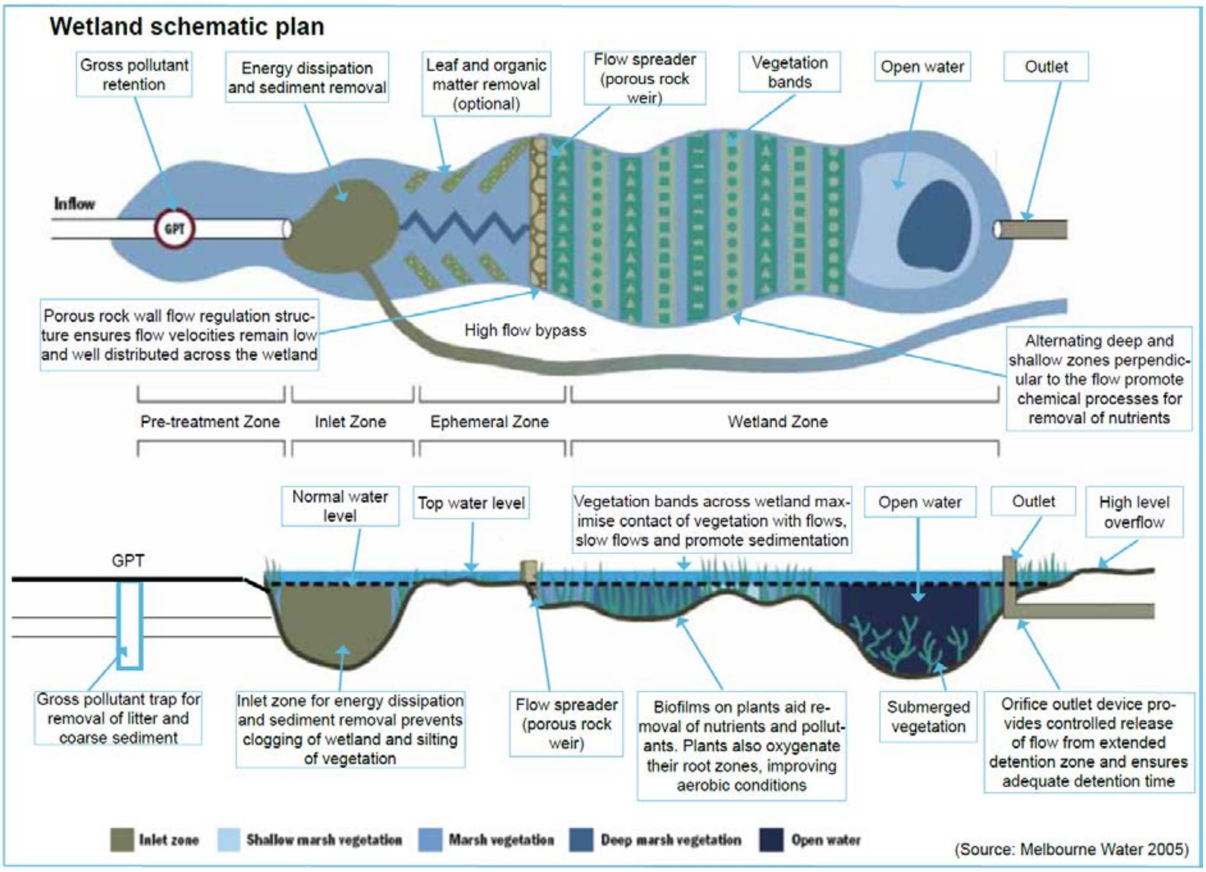

Figure 8: Schematic representation of an example constructed wetland design (Melbourne Water 2005). Note that not all constructed wetlands will incorporate the same components.

Function

Often have multiple functions, including:

- Treatment of water before discharge into other waterbodies;
- Detention;
- Conveyance;
- Infiltration.

Round one capital works program locations (GHD 2015)

- Ephemeral constructed wetland at Bob Gordon Reserve

Target pollutants

- coarse sediment
- suspended solids
- phosphorus
- nitrogen
- heavy metals

Design considerations

- Assess the site specific conditions as per **Section 8.3**.
- Very important to consider the possible impacts of discharge from these assets into these receiving environments, particularly sensitive environments (such as salt marshes), the Swan Canning Estuary, or wetlands with high conservation value (see **Section 3**);
- Mitigate acid sulfate soils as necessary (DER 2015a)
- Design should consider the low flow (1-year event) and the larger irregular events (100-year event) - the asset may be designed to manage the low flow events and allow the larger flow events to bypass;
- Ensure the wetland is separated from groundwater where possible, as contaminated or nutrient rich groundwater can result in water quality problems in the wetland. This may mean that constructed wetlands implemented in the permeable soils present in the City may be ephemeral rather than permanently wet (similarly to many natural wetlands in the Swan Coastal Plain). However, this may not be possible in some situations (e.g. when retrofitting existing systems);
- Area should be about 1 to 2% of the total catchment area (DoW 2011e);
- A vegetated buffer, separate to the wetland area, should be included in the design (refer to **Section 10.5** for more details);
- Design should facilitate alternating water depths and niches for different aquatic vegetation and to allow different nutrient cycling processes to occur. Dry and shallow zones promote oxygenated water and sediment, that allows for mineralisation and nitrification to occur whereas deep zones promote anoxic conditions that allow denitrification and loss of nitrogen gas to the atmosphere to occur (see **Appendix A**);
- Design should consider other pollutants entering the wetland and appropriate treatment methods (see **Appendix A** for suitable approaches to management of specific pollutants);
- Incorporate a deep inlet zone to provide an area for sediment entering the wetland to settle and be removed if required;
- Constructed wetlands that contain permanent, still water will need to be managed for mosquitoes and chironomid midges. Refer to *Mosquito Management Manual* (Department of Health 2015) for more information;
- Ensure design includes vehicle access for maintenance.

Vegetation considerations

- Consider vegetation to suit each of the different hydrological zones that may be present, including:
    - Permanent inundation (or long periods of permanent inundation);
    - Seasonal/temporary inundation i.e. flood plain/lower banks;
    - Irregular inundation i.e. dryland areas that may be inundated in very large events;
- In areas where water is expected to infiltrate, consider the species in **Table C-1, Appendix C**;
- In areas where conveyance needs to be maintained, consider the species in **Table C-2, Appendix C**;
- A general density of 4 plants/m^2 is recommended for channel and basin areas, with plants planted in rows perpendicular to flow paths with each row offset from the previous. An average density of 3 plants/m^2 is recommended for floodplain areas (DoW and SRT 2007b);
- Retain/restore remnant vegetation areas where possible;
- Choose plants that have hard leaves that decompose slowly;
- Include fringing trees to provide shade. Shade lowers water temperatures, leading to higher dissolved oxygen concentrations, less aquatic weed and algal growth and conditions more conducive to nutrient processing;

- Retain existing native plants where possible and use local species (see Woodgis 2011) as they are better adapted to local conditions;
- Choose a diverse range of species to improve resilience;
- Choose plants to enhance biodiversity and create habitat;
- Avoid the use of pesticides/herbicides.

Maintenance

- As constructed wetland designs vary, maintenance requirements of constructed wetlands are dependent on the design components, which are likely to be a combination of the above structural controls;
- It is particularly important to prevent channelization of flow through the constructed wetlands as they function most effectively with a high level of interaction with all parts of the wetland;
- Over time vegetation is likely to grow in areas designated for maintenance access and therefore pruning or removal of native vegetation may be required. The germination of larger species in the access area should be recognised and removed before becoming established.

Further information

- *Stormwater Management Manual for Western Australia, Chapter 9, Structural Controls* (DoW and SRT 2007b, pp 145-159)
- *Water sensitive urban design: Constructed wetlands for stormwater management* (DoW 2011e)

8.5. WSUD asset handover

Due to the vegetation present, WSUD assets require different handover processes from traditional stormwater infrastructure. Once a WSUD asset is established a handover should be conducted between the asset designer and the team in charge of its maintenance. This may involve handover between a private developer and the City, or between different teams within the City. The handover process may vary in structure or complexity depending on the parties involved in the handover. A summary of the handover process required is detailed below.

- Following practical completion of a project, there will often an on-maintenance period when the team constructing the asset will continue maintenance works, including rectifying any defects, allowing the ultimate asset manager to verify that the asset is performing normally before taking final responsibility.
- Following this on-maintenance period, the team ultimately taking over the maintenance of the asset should complete an off-maintenance inspection prior to final handover to ensure it is healthy, stable and functioning.
- Following the off-maintenance inspection a checklist should be completed and the asset should not be handed over unless the inspection is completed. Example checklists for swales, biofilters and constructed wetlands can be found in Sections 4, 5 and 6 respectively of *Transferring ownership of vegetated stormwater assets* (Water by Design 2012), as well as in Section 4 of Payne et al (2015). Checklists should include considerations such as:
    - The system is performing as designed. There may be several performance indicators relevant to assessing this depending on the type of asset;
    - There are no maintenance issues or defects in the asset, such as poor plant health, bare zones, inappropriate hydraulics or excessive sediment accumulation;
    - All relevant documentation has been provided. This should include:

- As constructed plans of the assets;
- A description of the asset function, including its purpose/role in the stormwater network, downstream receptors, flow paths, hydraulic requirements and critical flow points (pinch points);
- As constructed photos of the asset;
- Details of any rectification and maintenance activities undertaken in the on maintenance period;
- Vegetation and other maintenance requirements, including frequency and timing of maintenance; and
- Any performance or management performance indicators specific to the asset.

For further information refer to Water by Design (2012) and Payne et al (2015).

8.6. WSUD asset register

A register of the City's WSUD assets should be maintained including the following information:

- Asset name and location;
- Asset type;
- Who designed and constructed the asset;
- Size and dimensions;
- Year constructed;
- Maintenance requirements (what, how often, when and who is responsible);
- Maintenance costs;
- Photographs.

This information will allow the City to keep asset maintenance consistent during staff changeovers and departmental changes, assist with financial reporting, tracking KPIs, and catchment modelling, and allow staff to make informed decisions for implementation of future stormwater assets. The asset register can be updated with changes to maintenance requirements as they occur. The register could take the form of a spreadsheet, database or GIS layer/map.

New Water Ways (2019) have developed a nationwide interactive WSUD Asset Map that includes locations and details of various WSUD projects (https://www.newwaterways.org.au/map/). This can be employed to find examples of similar projects when planning and designing WSUD assets. The City should consider submitting some examples of implemented WSUD projects to contribute to this worthwhile database.

9. Retrofitting the stormwater network

Alongside the installation of new WSUD assets and conversion of old stormwater assets to WSUD assets, improvements can be made within the City to enhance water quality and other environmental values. Many of the recommendations made in the stormwater capital works program recommended by GHD (2015) can be considered retrofitting projects. The following are examples of improvements that can be made:

- Replacement of impervious surfaces with pervious surfaces (such as pervious paving (see DoW and SRT 2007b), turf or gardens);

- Replacement of raised road kerbing with flush kerbing next to public open spaces, vegetated road reserves and WSUD assets to allow stormwater to interact with these areas rather than enter stormwater drains;
- Planting (preferably native) vegetation around existing stormwater drains and waterbodies;
- Replacing exotic species (particularly those that drop a lot of organic material) with native vegetation around existing stormwater drains and waterbodies;
- Retrofitting existing basins (e.g. by reshaping banks to a gentle slope, planting native vegetation, removing weeds);
- Upgrading inlets to basins and other stormwater to incorporate water quality treatment (e.g. by installing gross pollutant traps, litter nets).

For more information and examples of such projects, refer to *Stormwater management manual for Western Australia, Chapter 6, Retrofitting* (DoE and SRT 2006).

10. Non structural stormwater controls

10.1. Management of parks, gardens and reserves

As a Local Government Authority (LGA), the City is responsible for the design and maintenance of parks, gardens and reserves within the Melville catchment. The City has the opportunity to lead the community by setting examples in best practice and ensuring stormwater, and in turn the Swan and Canning River systems and other receiving wetlands, are not adversely affected by management of these areas. The following general park, garden and reserve management principles should be followed to reduce impacts to stormwater:

- Minimise fertiliser use: fertilisers contain high levels of nutrients, much of which are not absorbed by the soils which they are applied to, particularly in the sandy soils present in the City. These nutrients are therefore eventually transported by stormwater or groundwater away from parks and reserves and into the stormwater network;
- Minimise water use: reducing the amount of water used in gardens and reserves, will reduce the transport of nutrients and sediments from these areas into stormwater;
- Minimise production of organic matter: Organic matter can enter the stormwater network and be decomposed to produce nutrients, consuming oxygen in the process;
- Minimise pesticide and herbicide use: These chemicals can be transported by runoff into the stormwater network and eventually into receiving waterbodies, where they may have a negative impact upon fauna;
- Control weeds, particularly close to stormwater structures: Weeds can easily be spread throughout the stormwater network.

These principles can be followed by adhering to the recommendations in the sections below. These recommendations should be followed for all of the City's parks, gardens and reserves, but particularly areas close to waterbodies or stormwater drains, steep areas and areas subject to erosion.

10.1.1. Nutrient monitoring and fertiliser use

- Conduct soil tests and/or leaf tissue analysis before applying fertiliser to sports fields (including its public golf course at Point Walter), irrigated parks, dry grass areas and foreshore reserves to determine if nutrients are required, and if required, the application

rate and type of nutrients needed. This testing will result in unnecessary fertiliser applications being avoided.
- Use Australasian Soil and Plant Analysis Council (ASPAC) verified laboratories for these analyses so that accurate information is received.
- Leaf tissue should be analysed for nitrogen and phosphorus. Leaf tissue nitrogen content should be maintained between 1.5% - 2% for passive turf and 2% - 3% for sports fields (Ruscoe, Johnston & McKenzie, 2004) and phosphorus content should be maintained between 0.2% - 0.4% (Ruscoe, Johnston & McKenzie, 2004).
- Soil should be analysed for available phosphorus using the Colwell (1963) method, the standard method for Western Australian conditions, and Phosphorus Retention Index (PRI) according to the Allen & Jeffery (1990) method to determine the capacity of the soil to hold on to phosphorus.
- The City should apply the method described in Ruscoe et al (2004) to determine if phosphorus applications are necessary based upon soil phosphorus (Colwell 1963 method) results and PRI (Allen & Jeffery 1990 method) (**Table 2**). As a minimum, these tests should be conducted every second year.

Table 2: Phosphorus application recommendations based upon soil analysis results

Phosphorus Recommendations		
PRI (Allen & Jeffery (1990) method)	**Soil Test P (Colwell (1963) test)**	**Recommendations**
0 or negative		Do not apply P
0.1 - 0.5	< 5 ppm > 5 ppm	Apply up to 5 kg P/ha Do not apply P
0.5 - 2	< 7 ppm > 7 ppm	Apply up to 5 kg P/ha Do not apply P
3 - 5	< 10 ppm > 10 ppm	Apply up to 10 kg P/ha Do not apply P
> 5	< 10 ppm	Apply up to 20 kg P/ha

Source: Ruscoe, Johnston & McKenzie (2004)

- Only apply phosphorus and nitrogen when testing indicates it is required;
- Use specific fertilisers according to the soil and leaf tissue analyses for each site rather than using the same fertiliser for all sites;
- Consult experts (i.e. independent turf consultant and laboratory interpretation) if necessary, in addition to City's own employees, to determine application rates and types of fertiliser, to ensure appropriate fertiliser regimes are being conducted;
- If nutrients are required, then controlled release or low water soluble fertilisers should be applied to reduce leaching;
- Determine the rate of each nutrient of the fertiliser required before application to ensure that over application of phosphorus and nitrogen does not occur. To determine the rate of nutrient application, multiply the amount of fertiliser to be applied per hectare by the percentage of that nutrient (either N% or P%) in the fertiliser, divided by 100. The maximum nitrogen rate for a single application to established turf is 40 kg nitrogen/hectare (Ruscoe, Johnston & McKenzie, 2004) though 30 kg nitrogen/hectare is usually sufficient. The maximum phosphorus rate for a single application to established turf is 5 kg phosphorus/hectare (J. Forrest, pers. comm). High maintenance active turf should not exceed applications of 100-200 kg/ha/year for nitrogen and 0-50 kg/ha/year of phosphorus. Passive turf and foreshore area applications should not exceed 0-50 kg/ha/year for nitrogen and 0-5 kg/ha/year for phosphorus;

- If fertiliser is required, it should be applied in spring or early autumn (September, October, November, March and April) when grass grows rapidly. Apply the fertiliser in small amounts and often over these months instead of in a single application. This will ensure all nutrients can be utilised by the turf;
- Do not fertilise in summer or winter. Fertiliser should not be applied in the winter months or at any time before heavy rainfall as such events can wash nutrients into waterways via stormwater drains or leaching into groundwater. Summer fertilising encourages over use of water and turf may grow excessively.
- If the City has any areas containing couch and buffalo grass types they should not fertilise this turf in the winter months as it could be in its dormant phase;
- Keep a log book to record details of fertiliser and nutrient applications over the year for each application area including details such as weather conditions and monitoring information;
- Ensure all City employees involved in the monitoring, management and application of fertiliser attend the Fertilise Wise Fertiliser Training course that is hosted by the Phosphorus Awareness Project. The course trains turf managers and local government officers in fertiliser best management practices;
- Promote soil and leaf tissue testing in privately owned golf courses (i.e. Melville Glades Golf Club) in the City area, as they can be a significant source of nutrients to waterways;
- Conduct regular moisture testing of all fertilised areas to avoid overwatering and the potential leaching of nutrients from these areas;
- Irrigation needs to be carefully monitored so that overwatering does not wash fertilisers into waterways;
- Do not apply fertiliser too close to hard surfaces such as roads. Fertiliser on hard surfaces will be washed into stormwater drains and end up in waterways;
- Refer to the following publications (see Reference section for full publication details) to obtain more information on fertiliser and irrigation best management practices:
    - *Turf Sustain – A guide to turf management in Western Australia* (Ruscoe, Johnston & McKenzie 2004);
    - *Western Australian environmental guidelines for the establishment and maintenance of turf grass areas* (SRT 2014);
    - *Stormwater management manual for Western Australia, Chapter 7, Non structural controls* (DoE and SRT 2005);
    - *Fertiliser application on pasture or turf near sensitive water resources* (Department of Water [DoW] 2010a).

10.1.2. Maintenance considerations

The below recommendations for maintenance are based upon those in DoE and SRT (2005).

Irrigation

- Ensure that the irrigation system and watering schedule is as water efficient as possible. Rain sensors should be employed to prevent irrigation after summer rain storms. For more information on irrigation best practices see *A guide to water efficient landscape and irrigation for non residential facilities* (Josh Byrne and Associates 2013);
- Ensure the that irrigation does not produce surface runoff from the area being watered;
- Check irrigation systems weekly to identify maintenance needs (e.g. the repair of leaks), or, for major irrigation systems, install an automated warning system to identify malfunctions;
- Apply mulch to garden beds where possible. Mulch can to improve water retention (thereby lessening water requirements), smother weeds and prevent erosion;

- Where required, apply soil wetting agents to improve water infiltration into soils and/or soil amendments to improve the water retention capacities of soils.

Pest control

- Before spraying herbicides in or near aquatic areas, consult the Cooperative Research Centre for Australian Weed Management factsheet: *Herbicides: guidelines for use in and around water* (2005) and the Waters and Rivers commission factsheet *Herbicide use in wetlands* (2001) Many herbicides and surfactants should not be used around aquatic areas as they can harm aquatic fauna;
- Aim to minimise the use of herbicides and insecticides, which can be toxic to some fauna, by employing integrated pest management (IPM). IPM is a holistic approach to pest (i.e. weed and insect) control that incorporates preventative practices in combination with chemical and non-chemical pest control methods to minimise the use of traditional pesticides. Non-chemical pest control methods include biological (e.g. predation of pest species by other organisms), and manual methods (e.g. weeding, slashing, use of black plastic to cover weeds). The City of Melville Environmental weed management guidelines (Natural Area Consulting 2013) contains details of all weed control methodologies suitable for the City's natural areas;
- Where chemical pest control methods need to be used, use the least hazardous product available and ensure that it is applied according to the instructions on the label;
- Do not apply pesticides when rain is occurring or imminent (to avoid pesticides washing off) or on windy days (to avoid spray drift);
- Where possible, use more targeted methods of pesticide application than spraying (e.g. wiping or injecting) to avoid spray drift ;
- When spraying herbicides, mix in a coloured (non-toxic) dye to ensure that sprayed areas are clearly visible and unnecessary excess spraying is avoided.

Garden maintenance

- Turf should not be mown too short, as this is conducive to erosion occurring;
- Where there is not a risk of cuttings entering adjacent water bodies, grass cuttings should be left on the lawn after mowing, or if collected should be composted and reused as fertiliser;
- Avoid getting grass clippings on hard surfaces or in adjacent water bodies, and if grass clippings or pruning debris do get onto hard surfaces remove them using dry methods (e.g. sweeping);
- When mowing turf or pruning adjacent to roads, where possible time these activities with street sweeping;
- Water used to clean gardening equipment should not be allowed to enter the stormwater system;
- Ensure a vegetated buffer is maintained between a turf area to which top dressing is applied, and stormwater drains or water bodies.

10.1.3. Planning and design considerations

- Aim to plant local native species in City's management areas as they require low levels of water and fertiliser and once established may require no further applications. Information on local native plant policies and using local native species is available from: *Local Government Natural Resources Management Policy Manual* (Eastern Metropolitan Regional Council 2008) Section 2.3.2. Landscaping with Local Plants;
- When planting exotic species particularly minimise the use of:
    - Deciduous plants, as leaves dropped from deciduous plants can clog waterways and decompose quickly, resulting in nutrient release into water bodies;

    - Grassed/lawn areas, as these tend to require fertilisers, plentiful water and produce grass clippings;
    - Other plants which require heavy watering;
- Use kikuyu as the first choice for turfed areas as it has low fertiliser requirements, requires a medium water usage and is drought and wear tolerant;
- Employ hydro-zoning (grouping plants on the basis of having similar water requirements) principles to planting design to minimise water use;
- Maximise the use of water conserving elements and techniques, such as mulches, ground covers and porous paving;
- Revegetate and restore existing waterbodies and stormwater drains to help attenuate stormwater flows and nutrient pollutants. Further information regarding revegetation of streams and wetlands can be found in the *River Restoration Manual* (Waters and Rivers Commission and Department of Environment 1999-2003) and Chapter 3 of *A guide to managing and restoring wetlands in Western Australia* (Department of Environment and Conservation 2012a) respectively.

10.2. Catchment hygiene

10.2.1. Street sweeping

Street sweeping should be undertaken by the City to reduce the accumulation of litter, leaves and coarse sediments from roads, carparks and footpaths to prevent these materials from entering the stormwater network. In general, if resources are limited, the greatest water quality improvements from street sweeping can be had when it is targeted towards high risk areas or done under specific circumstances, for example (adapted from DoE and SRT 2005):

- Focussing on pollution 'hot spots' such as commercial or shopping centre precincts;
- Street sweeping should be coordinated with other maintenance activities and events e.g. after construction activities or public events. Planning of these activities and events should include provisions for street sweeping;
- Street sweeping should be conducted as soon as possible before 'first-flush' runoff events;
- Street sweeping should be conducted in areas with deciduous trees during autumn;
- Sweeping frequency should be increased during the wet season to prevent rainfall runoff transporting pollutants;
- Developers of construction sites and owners of large commercial or industrial premises should be encouraged to conduct their own street sweeping.

Further considerations for street sweeping include (adapted from DoE and SRT 2005):

- Conduct street sweeping at a time when vehicles are less likely to block kerb access, as particulates tend to accumulate along the kerb line. To further prevent this problem, the community should be advised of street sweeping schedules and encouraged to ensure their vehicles will not obstruct the sweeping process;
- Inspect the area swept pre and post sweeping to evaluate its effectiveness;
- Keep records of street sweeping to help improve efficiency;
- Keep up to date with new sweeping technology;
- Ensure street sweepers do not discharge any collected waste to the drainage system. This waste should instead be disposed of in a landfill (consult DWER (2018b) for more information);
- Where mechanical sweeping equipment cannot sufficiently access an area, hand sweeping is recommended.

10.2.2. Litter management

Managing litter to ensure it does not enter the stormwater network will help to improve water quality and aesthetic values in receiving waterbodies. The following recommendations for litter management are recommended (adapted from DoE and SRT 2005):

- Keep observable litter to a minimum (e.g. through manual collection and street sweeping). Littering rates have been shown to be lower in areas that are regularly cleaned;
- When undertaking manual litter collection, focus on ‘hot spots’ where litter tends to accumulate or where there is a high risk of litter entering the stormwater management system or receiving water bodies;
- Organise litter clean-up days where the general public or corporate groups can be involved and use these opportunities to raise awareness of stormwater pollution and littering e.g. through signage at the event or social media;
- Ensure that high safety standards are employed when undertaking manual litter collection, including the use of sharps containers;
- Place litter and recycling bins in locations where litter is most likely to be generated (i.e. close to fast food outlets, ATMs, shopping centres) or near heavily used spaces (e.g. parks, sporting venues). Involve the community in bin placement decisions. Bins should be easily accessible;
- Ensure that bins are easily identifiable. Being consistent with the colours and shapes of recycling and general waste bins will help the public to use bins correctly;
- Bins should be of an adequate size and have an adequately sized opening. Both the bin and bin opening should be large enough to accommodate rubbish but no so large as to encourage illegal dumping;
- Site assessments should be undertaken to identify heavily used bins. These bins should be more inspected and maintained (if required) more often;
- Aim to empty bins before they reach 75 - 80% full;
- Place signage close to litter hot spots to discourage littering. Signage may include reminders that littering is an offence.

For more details refer to DoE and SRT (2005).

10.3. Light industry audits

Audits of light industrial premises in the Myaree area should be conducted by City environmental health officers with the aim of reducing contaminants being released into groundwater and stormwater drainage. Audits should be consistent with those conducted for the Light Industry Program (LIP), a joint initiative between DWER, DBCA and local governments (including the City of Melville).

Audits should aim to ensure that premises are compliant with the *Environmental Protection Act 1986* (WA) and the *Environmental Protection (Unauthorised Discharges) Regulations 2004* (WA). Under these regulations, the discharge of scheduled materials into the environment, which includes stormwater drainage, is prohibited. The regulations also contain a list of materials that cannot be discharged into the environment (including stormwater drains). When conducting an audit, officers should assess whether premises are storing and disposing of liquid wastes (including washing water) correctly, and that liquids are not inappropriately entering the stormwater or groundwater (e.g. via infiltration through unsealed ground). Officers should also assess whether other discharges (i.e. dust, odour, smoke, vapour and noise) are being appropriately managed.

The audits should be considered an opportunity to educate businesses in the connection between stormwater drains and their receiving environments, and the importance of not discharging wastes into stormwater drains. Officers should provide advice and suggestions for improved processes and safety measures to achieve environmental compliance and where environmental issues are identified, a follow-up inspection should be scheduled.

Officers should prioritise auditing of new premises and premises that have not been inspected before. A register should be maintained of all inspected premises, which should include a risk rating of the premises likelihood to discharge scheduled materials to the environment. This risk rating should be based on the type of activities conducted (e.g. wreckers could be considered a high risk premises) and the quality of procedures and equipment in place to manage discharges. Aim to inspect high risk premises on at least an annual basis, medium risk premises every two years, and low risk premises every three to five years (Lara Saunders (DWER) pers. comm.).

Where a collaborative approach has not succeeded in addressing any issues identified, local government can take enforcement action to achieve environmental compliance. Where serious pollution issues are identified, the issue can be escalated to DWER specialist pollution and enforcement groups. For more information about regarding industry audits contact DWER's Pollution Response Unit.

10.4. Community Education

Raising community awareness of the link between stormwater drains and natural waterways is vital in managing stormwater quality and protecting receiving water bodies from harm. Stormwater can be impacted by pollutants produced in the home including litter, 'natural' pollution such as leaves, garden clippings, food waste, animal faeces and discarded aquarium plants, and chemical pollution such as fertilisers, oil or detergents, and therefore residents have a large role to play in reducing stormwater pollution. There are a number of ways in which to educate the public on issues relating to stormwater management, which are outlined below.

10.4.1. Signage

Signage can be placed around open or closed stormwater drains and waterbodies to educate the public in the following topics:

- The link between stormwater drains and natural waterbodies (i.e. that anything that enters stormwater drains will ultimately end up in the nearest river or wetland);
- Native flora, fauna and ecosystems that can be found in waterbodies;
- The role of living streams, constructed wetlands and other stormwater structural interventions in water quality improvement and habitat creation; and
- The consequences of the following actions on waterbodies:
    - Littering;
    - Irresponsible fertiliser use;
    - Feeding birds;
    - Dumping of feral fish, aquatic plants and green waste in to waterbodies.

Signage can involve words and/or art depending on the context and location of the sign. Some examples of different types of signage projects include:

- The "Clean Drains, River Gains" drain stencilling project (https://www.sercul.org.au/our-projects/clean-drains-river-gains/), coordinated by SERCUL's Phosphorus Awareness Project and previously implemented by City of Melville, is an example of a relatively cheap signage project that raises awareness of the link between drains and natural waterways whilst engaging the community.

- The large, aesthetically pleasing sign placed at the Brentwood Living Stream with text and a diagram illustrating the function of the living stream in improving the water quality entering the Canning River. As the public are expected to spend longer periods of time at the site enjoying the area, a larger sign at this location is more likely to be read.
- Near inlet structures incorporating visible litter catching structures such as gross pollutant traps or litter nets, signage can be placed drawing attention to the amount of litter present, highlighting the impact that littering can have.

10.4.2. Media

Media, including print media, social media, newsletters, websites, should be utilised to educate the general public about the functions of the stormwater network, the consequences of stormwater pollution on the health of receiving water bodies and how to prevent stormwater pollution. The following different media types can be used to capture the attention of different sections of the community:

- Website: The City's own website can be utilised to provide information on stormwater and nutrient management practices to everyone in the City. This can include:
    - Advertisement of water quality improvement projects undertaken by the City, such as the conversion of the Brentwood Main Drain into a Living Stream;
    - Reporting the results of the City's water quality monitoring. This demonstrates the City's commitment to the environment and provides important information to community catchment and environment groups to enable them to determine where rehabilitation of waterways and education of general community members needs to occur;
    - Information regarding appropriate nutrient management practices, such as the effective use of fertiliser, not feeding the birds, picking up of dog poo, correct disposal of grass clippings and leaves, and planting according to your soil type could also be disseminated to the City's residents through their website.
    - Links to other topic specific websites such as Fertilise Wise (www.fertilisewise.org.au), Home River Ocean (www.homeriverocean.com.au), Your Home: Stormwater (http://yourhome.gov.au/water/stormwater) and The Dirty Truth (www.thedirtytruth.com.au).
- Social media: The City should consider using platforms such as Facebook and Instagram for educational purposes. As of March 2019, in Australia, approximately 60% of the population uses Facebook (with the largest numbers of users in the 25-39, 40-55 and 18-25 age brackets respectively), half of the population uses YouTube, and a third of the population uses Instagram (with a slightly younger audience than Facebook) (Vivid Social 2019). Information on similar topics to those listed above can be shared on these platforms, with the following points of difference to take into account:
    - Due to the broad user base of social media platforms, it is a good way of broadcasting information to those that may not necessarily go looking for it otherwise;
    - Social media is a great way of disseminating information quickly, and as such can be beneficial for publicising public health information e.g. the presence of an algal bloom;
    - Content shared on these platforms is best presented in a short, lively and engaging format to attract attention (Howard 2013);

- Facebook is a particularly good platform for promoting events, such as workshops and clean-up days;
- Facebook "Groups" can also be created, which can bring people with similar interests together. For example, groups could be created for environmental community groups who work around waterbodies to facilitate the sharing of ideas and information.

For more information pertaining to local government use of social media, refer to Howard (2013).

- Newsletters and newspaper articles: This media can disseminate the same information as above, but is particularly useful for educating those in the community, such as older people, who do not engage with the internet or social media.

10.4.3. Workshops

Workshops are an effective way of educating interested people on topics that have relevance to stormwater quality. Workshops could be held on such topics including the benefits of native gardens; importance of not feeding birds, nutrient management, and mosquitos and their link to the quality of stormwater and the health of receiving waterbodies. Workshops do not need to be held as stand-alone events but can take place during other City-run or private community events. Alternatively, there are a number of organisations running workshops on topics related to stormwater quality including SERCUL's Phosphorus Awareness Project (https://www.sercul.org.au/our-projects/pap/) and Mozzie Wise Education Program (https://www.sercul.org.au/our-projects/mozzie-wise/), Great Gardens (https://theforeverproject.com.au/page/about-great-gardens) and Beyond Gardens (www.beyondgardens.com.au) that could be utilised to educate the City's residents.

10.4.4. Brochures

Brochures can be utilised alone or, more effectively, in conjunction with other education campaigns to increase community awareness about issues directly or indirectly affecting stormwater quality and/or the health of waterways. Brochures could be produced by the City to target particular areas of concern or the City could utilise brochures produced by other organisations and government departments such as:

- Water Corporation:
  - Installing and caring for your low maintenance lawn (Water Corporation 2017a)
  - Your guide to a waterwise garden (Water Corporation 2017b)
- Department of Primary Industries and Regional Development:
  - Don't dump that fish (Department of Fisheries 2016))
- SERCUL:
  - Clean Drains River Gains: Practical steps you can take to prevent stormwater pollution (SERCUL 2011)
  - Phosphorus Awareness Project: Improving the health of wetlands and the Swan and Canning Rivers (SERCUL 2018)
  - Mozzie Wise: How to protect yourself and your home from mosquitoes (SERCUL 2015)
  - Grow local plants' and 'Fertilise Wise' (see SERCUL's (2019b) Fertilise Wise website http://www.fertilisewise.com.au/for-gardeners.html for links).

10.4.5. School education programs

Educating school aged children about the link between what we do in our homes, gardens, workplaces and schools and stormwater quality and the health of our waterways is vital to ensuring behavioural change now and into the future. Piney Lakes Environmental Education Centre plays an important role in educating children on these topics. There are a number of other organisations providing school educational experiences relating to stormwater quality including SERCUL's Phosphorus Awareness Program (https://www.sercul.org.au/our-projects/pap/), Department of Biodiversity, Conservation and Attractions' Nearer to Nature Schools Program (https://www.dpaw.wa.gov.au/get-involved/nearer-to-nature) and Water Corporation's Waterwise Schools Program (https://www.watercorporation.com.au/home/education/waterwise-schools-program).

10.4.6. Lead by example

The City needs to lead by example by adopting policies that encourage the use of native plants, appropriate fertiliser and water use and the correct disposal of green waste (such as those outlined in **Sections 10.1 and 10.2**). The City could demonstrate their leadership in these areas by:

- Promoting park maintenance teams following the correct procedures regarding fertiliser use and disposal of grass clippings and other green waste (i.e. using the Food Organic Green Organic (FOGO) bin for green waste disposal).
- Demonstration gardens containing native plants incorporating signage explaining their low water and fertiliser requirements.
- Incorporating water sensitive urban design into council buildings and landscaping. This could include initiatives such as installing tree pits and rain gardens in council building car parks, or collecting stormwater from building roofs and re-using it for irrigation.

10.4.1. Community based social marketing

Community based social marketing is a new approach to sustainability education that promotes the adoption of a particular methodology to change community behaviours for environmental benefit. Research has shown that if your goal is to change people's behaviour then a purely information based campaign has very little chance of substantively doing this (Steg and Vlek 2009). As such, in order to instigate behaviour changes, along with providing people with information to the community people about what they can do to help the environment, measures should be taken to ensure they actively engage in the behaviour change. Community-based social marketing includes a five step approach to fostering sustainable behaviour that involves selecting the behaviours that you want to target, identifying the barriers and benefits, developing strategies to achieve your programs goals, piloting your program, implementing the program on a broad scale and evaluating its effectiveness. More information on Community-based social marketing can be found on websites such as http://www.cbsm.com/pages/guide/preface/.

10.5. Wetland buffers

Wetland buffers encompass both the distance and type of separation between a wetland and adjacent land uses. They often comprise of a band of vegetation surrounding a wetland, but can also include fencing, paths and Wetland buffers play an important role in protecting wetland values from threats posed by stormwater, such as eutrophication, toxicity to biota, sedimentation and the spread of weeds. Incorporating appropriate wetland buffers should therefore be essential consideration of planners when planning development around wetland areas.

The most current guidance for wetland buffers is set out in Environmental Protection Authority's (EPA) Guidance Statement No. 33 Environmental Guidance for Planning and Development (2008). This guidance states prescribes a minimum 50 m buffer distance for wetlands that are to be protected, or that a site-specific buffer distance may be determined. In the City, wetlands to be protected should include at least all conservation and resource management category wetlands as defined by Hill et al (1996), which encompasses all the wetlands in Table 12 (Very high value wetlands) of the City's *Natural Areas Asset Management Plan* (Woodgis 2011). The guidelines recommend following the methodology provided in the *Guideline for the Determination of Wetland Buffer Requirements* [*for public comment (December 2005)]* (Essential Environmental 2005) to determine site specific wetland buffers for an individual wetland. These guidelines are currently in draft form, with document finalisation in process. The draft guidelines outline the following process to determine wetland buffers for an individual wetland:

1. Acknowledge the existence of a wetland.
2. Identify wetland attributes specific to the wetland (e.g. "presence of rare flora species" or "turtle habitat"), the wetland management category assigned to that wetland (Hill et al 1996) and the management objective(s) for that wetland (see Table 4).
3. The above inputs are used to define the wetland function area: the area which needs to be protected to ensure that the functions and values of all wetland attributes can be maintained (see Table 5). The wetland function area would usually include the wetland waterbody, the wetland vegetation and any directly associated dependent terrestrial habitat.
4. Identify threatening processes for that wetland e.g. "poor water quality" or "alterations to water regime" (see Table 6).
5. Identify the role of the separation requirement for each wetland attribute to ensure the separation will meet the wetland's management objective (see Table 7).
6. Identify the separation requirement (distance and type of separation) from the wetland function area for each wetland threatening process. These vary depending on the management category of the wetland (see Tables 8, 9 and 10). The separation distances for each threatening process can be combined to give an overall separation requirement all around the wetland (**Figure 9**). This can mean that the separation distance may vary around the perimeter of the wetland.

- Determine whether the separation requirement for the wetland is achievable. Guidance is provided for situations where the separation requirement is not achievable.

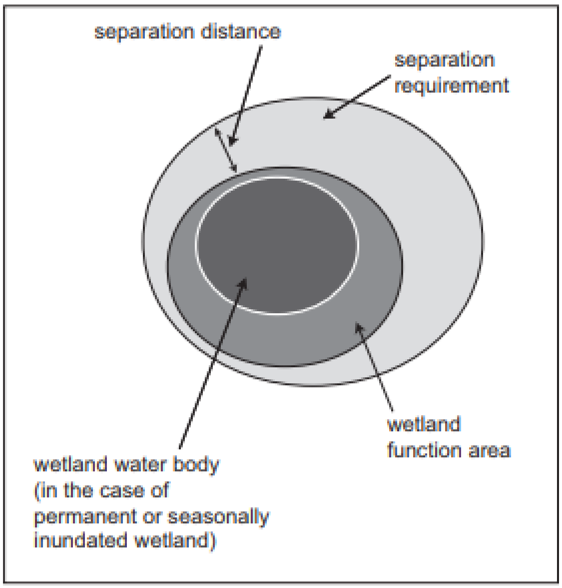

Figure 9: Generalised wetland buffering concept (Welker Environmental Consultancy 2002)

The EPA (2008) guidance statement also encourages the following in regard to wetland buffers:

- Retain all remnant vegetation in the buffer;
- No fill, no fertiliser or chemical application, no drainage into or out of (other than natural or approved stormwater management), no groundwater or wetland water abstraction, no liquid or solid waste disposal, and no excavation is permitted in the wetland or the buffer;
- Repair degraded/eroded portions of the buffer;
- Rehabilitate the wetland vegetation and the adjoining dryland zones using indigenous species of local provenance;
- Remove inappropriate infrastructure;
- Install fencing, paths and gates to control access;

- Replace inappropriate drainage facilities.

As stated in DWER (2017b), stormwater management systems (including pipes, constructed drains, detention areas and vegetated swales) should be located outside the buffers (as well as the wetlands themselves) of conservation category wetlands, resource enhancement category wetlands, other wetlands of high conservation significance.

10.6. Alternative management options

10.6.1. Phoslock®

Phoslock®, or Lanthanum Modified Clay, is a product that has been utilised to control soluble phosphate concentrations in water bodies susceptible to algal blooms. The product is the reaction of bentonite clay and lanthanum chloride. Phoslock® is commonly applied as a slurry, with a recommended dose rate of 100:1 Phoslock® to filterable reactive phosphorus (FRP). As the product moves through the water column, the lanthanum binds phosphate in the water column and eventually settles to the bottom sediment. Once settled, the phosphate is "locked" into the sediment as inorganic lanthanum phosphate particles (Meis et al 2012) that are unavailable to phytoplankton. Following initial assessment in 2001 under the National Industrial Chemicals Notification and Assessment Scheme (NICNAS 2001), the product was used within Australia with varying outcomes. It has been used successfully to reduce phytoplankton levels in both lakes and rivers in the Swan Coastal Plain (Bronwyn Rennie (DWER) pers. comm.). In flowing waters, the product may be transported downstream (National Industrial Chemicals Notification and Assessment Scheme [NICNAS] 2014) and as such it may not be suitable for usage in fast flowing drainage channels.

Phoslock® has shown to perform best in wetlands from pH 5 to 7 (with the capacity of the product to adsorb phosphate shown to decrease above pH 7) and performs well in anoxic conditions (Ross et al 2008). Toxicology of the product relates to the proportion of the total lanthanum in the product that becomes soluble, and therefore bioavailable, in the water. An *Existing Chemical Secondary Notification Assessment Report* (NICNAS 2014) advises that the following conditions can result in excess lanthanum bioavailability and/or toxicity:

- "soft" or low alkalinity waters (<60 mg/L $CaCO_3$);
- In soft waters with very low FRP concentrations, as ionic lanthanum is more likely to remain in solution as there is a lack of anions to bind with;
- Water bodies with high salinity waters, increasing release of lanthanum from Phoslock™.

As it an offence to discharge substances into the environment that cause environmental harm, a site specific risk assessment should be undertaken prior to applying Phoslock® to ensure it does not result in environmental harm to biota in the waterbody. NICNAS (2014) has identified the following risk matrix for Phoslock® application:

- High risk applications:
  - Alkalinity <60 mg/L CaCO3 and FRP < 0.1 mg/L; or
  - Alkalinity <60 mg/L CaCO3 and FRP ≥0.1 mg/L.
- Low risk applications:
  - Alkalinity >60 mg/L $CaCO_3$ regardless of FRP concentration.

For waterbodies meeting either of these high risk criteria, it is presumed that Phoslock® should not be used to mitigate FRP, unless justified with further testing, including direct toxicity assessment (DCA) on species of aquatic biota. Tables 11.2 and 11.3 of NICNAS (2014) outline the DCA testing requirements for these high risk Phoslock® applications when FRP is less than and greater than 0.1mg/L respectively. For low risk applications, DCA testing is still required but to a less stringent degree (NICNAS 2014, Table 11.4). A suitably qualified consultant should be engaged to conduct DCAs. For further information and expertise in this area, DWER should be consulted.

If Phoslock® to be used in any waterbodies within the Swan Canning Development Control Area, or in any waterbodies that drain to the Swan Canning Estuary (either directly or indirectly through stormwater drainage), approval is required from the Department of Biodiversity Conservation and Attractions. This would entail submitting an application to DBCA, which should include details about the waterbody to be treated and its connection to the Swan Canning Estuary and the proposed methodology, dose rate and volume of Phoslock® to be used. For a map of the Development Control Area and further information regarding this approvals process see the DBCA website (https://www.dpaw.wa.gov.au/management/swan-canning-riverpark/planning-development-and-permits).

10.6.2. Agricultural lime

Agricultural lime (aglime or agrilime) is considered the most suitable material available for neutralising acidic lakes (DER 2015), such as those affected by oxidation of acid sulfate soils. This is due to several factors:

- It is relatively inexpensive;
- It will not make water excessively alkaline if applied in excess;
- It will increase the acid-base buffering capacity of the water; and
- It is considered generally not to be harmful to plants, livestock, humans and most aquatic species.

However, aglime has limited solubility in water and as such will need to be applied in a slurry (DER 2015). Using aglime to increase the pH of water can therefore be slow and costly, and repeated applications will usually be required. The procedure for determining liming rates to neutralise acidic lakes is described in Appendix A, and methods of aglime application described in Section 5.3.2 of DER (2015a).

It is important to note that prevention of the oxidation of potential acid sulfate soils is the most important feature of acid sulfate soil management. Any activity with the potential to disturb acid sulfate soils requires a specific investigation, assessment and development of an acid sulfate soils management plan according to DER (2015b). Refer to the *City of Melville acid sulfate soil guidelines* (City of Melville 2016) for more information regarding acid sulfate soil management.

11. Performance monitoring

11.1. Overview

Monitoring and evaluation of stormwater management actions is essential to assess their effectiveness to inform future management. Monitoring programs should observe the following generic process (from Department of Water and Swan River Trust 2007c):

1. Ascertain the purpose of the monitoring;
2. Develop monitoring objectives;
3. Devise evaluation questions and indicators;
4. Plan the monitoring process;
5. Implement the monitoring;
6. Analyse and interpret monitoring results; and
7. Prepare a report with monitoring results and recommendations.

An overview of several types of monitoring programs to evaluate stormwater management actions is provided below.

11.2. Water quality

11.2.1. Monitoring program types

Surface water quality monitoring is one of the most effective ways to evaluate the performance of stormwater structural controls and prioritise future stormwater management. It is recommended that two types of surface water quality monitoring programs be conducted:

- **Routine monitoring program:** To be conducted on an annual basis at key sites (within both stormwater drainage channels and stormwater receptors) within the City with the purposes of:
  - Locating "hot spots" of poor water quality within the City in order to allow for the prioritisation of management strategies;
  - Assessing the health of priority stormwater receptor wetlands;
  - Assessing the effectiveness of ongoing non structural controls (i.e. education) in improving water quality;
  - Contributing to the State Water Information (WIN) Database to inform state government management decisions and provide data for other interested parties;
- **Structural stormwater control monitoring:** To be conducted before (baseline) and after, and upstream and downstream (if relevant) of structural stormwater controls in order to assess their effectiveness both immediately and over time with the purposes of:
  - Determining whether and what modifications to the control may be required;
  - Creating knowledge to optimise the implementation of future projects both within and outside the City.

11.2.2. Monitoring locations

Monitoring sites should be selected to represent the following:

- **Routine monitoring program:**
  - Main drainage channels representative of large segments of the catchment and/or with higher flows. Such drainage may often be a Water Corporation asset;
  - Drainage entering high priority receptors (i.e. the Swan Canning River);
  - Drainage upstream and downstream of proposed land-use changes (alterations and or developments);
  - Drainage upstream and downstream of likely contaminant sources;
  - Priority receptors of stormwater;
  - Previously sampled sites to allow for continuity of data;
- **Structural control monitoring:**
  - Upstream (if relevant) and downstream of the structural control location. There may be multiple inlet or outlets sites requiring monitoring.

11.2.3. Parameters

Appendix A contains a list of the common pollutants that are present in urban catchments and their sources to assist with selecting parameters for monitoring, and **Appendix D** lists the commonly monitored water quality parameters, how they can be monitored, in which circumstances monitoring may be required and what guidelines results can be compared to. When assessing stormwater quality, it is recommended that the following parameters be monitored at a minimum:

- pH;
- Electrical conductivity;
- Dissolved oxygen;
- Temperature;
- Total nitrogen and individual nitrogen species (total oxidised nitrogen, nitrogen and ammonia/ammonium, total organic nitrogen, dissolved organic nitrogen) concentrations;
- Total phosphorus and filterable reactive phosphorus concentrations;
- Total suspended solids concentrations and/or turbidity.

It should be noted that concentration data alone may not provide a complete picture of water quality. For example, nitrogen concentrations may be the same in water sampled before and after the implementation of a BMP, but if the water volume is lower after implementation then the volume of nitrogen delivered by that water will actually be lower than previously. However, while concentrations are relatively easily measured by a laboratory, measuring the loads or volumes of pollutants is more difficult and requires an assessment of flow. To quantify flow rates, construction of a flow control structure (e.g. a weir) is generally required, either continuous or discrete measurements of water level and/or water velocity must be collected, and calculations of flow performed by an appropriately experienced professional based on these measurements. If quantitative flow rates are not calculated, flow should at least be qualitatively described when sampling. For further details regarding flow calculation, refer to DoW and SRT (2007c).

11.2.4. Monitoring timing and frequency

As monitoring frequency increases, so does the amount of data generated and therefore the level of confidence in this data. DoW and SRT (2007c) suggest monthly or preferably fortnightly monitoring to capture seasonal variation. However, given the expenses associated with monitoring, the following more conservative approaches for the timing and frequency of monitoring is recommended:

- **Routine monitoring program:**
  - After the “first flush” rainfall event (i.e. the first heavy rainfall event of the season that mobilises pollutants on the ground surface);
  - On several occasions during the high flow season (i.e. winter/spring);
  - Following other particularly large rainfall events;
  - At least once within the summer at sites that intercept groundwater in summer or have significant flow/water level in summer.
- **Structural control monitoring**
  - Both for one year before and three years after BMP implementation:
    - After the “first flush” rainfall event (i.e. the first heavy rainfall event of the season that mobilises pollutants on the ground surface);
    - On several occasions during the high flow season (i.e. winter/spring);
    - Following other particularly large rainfall events;
    - At least once within the summer at sites that intercept groundwater in summer or have significant flow/water level in summer.

In general, if costs are prohibitive and sampling frequency is limited, monitoring should be targeted towards the periods of highest stormwater flow possible i.e. first flush and winter.

11.2.5. Sampling methodology

Manual field sampling, including both usage of a water quality meter and grab sampling procedures for common water quality parameters, should be conducted in accordance with DoW (2009) guidelines and relevant Australian/New Zealand Standards for surface water quality sampling (AS/NZS 1998a, 1998b, 1998c).

11.2.6. Assessment guidelines

Water quality data can be compared to several different guidelines for assessment depending on type of waterbody (i.e. stream or wetland) the habitat value of the waterbody, whether the waterbody has recreational value and if the waterbody is likely to discharge into the Swan Canning River. For more information refer to **Appendix D**. The following guideline documents contain relevant trigger values for data comparison:

- Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*:
    - These guidelines contain the most up to date trigger values for stressors (i.e. nutrients and physicochemical parameters) in slightly disturbed aquatic ecosystems (both wetlands and rivers) and for toxicants for protection of aquatic biota.
- SRT (2008) *Healthy Rivers Action Plan*:
    - These guidelines contain short term and long term trigger values for nitrogen and phosphorus in catchment tributaries of the Swan Canning river system.
- National Health and Medical Research Council [NHMRC] (2008) *Guidelines for managing risks in recreational water*:
    - These guidelines specify trigger values for waterbodies used for recreation, with separate trigger values specified for health and aesthetic value for some parameters. As specified in the guidelines, trigger values for health and aesthetic value should be calculated by multiplying values in the Australian Drinking Water Guidelines (National Health and Medical Research Council 2018) by 10.

11.3. Sediment quality

Sediments can store nutrients and other pollutants, which can be released back into the water column under certain conditions and can also be harmful to organisms that live in the sediment. As such, sediment sampling data can complement water quality data in both routine and structural BMP monitoring programs to provide a more complete understanding of the impacts of stormwater on waterbodies. Sediments can be sampled for:

- Nitrogen and phosphorus: to obtain a greater understanding of nutrient cycling;
- Metals: if metals are detected in water and/or if waterbody is downstream of metal sources;
- Organic compounds, including:
    - Total recoverable hydrocarbons (TRH);
    - Polycyclic Aromatic Hydrocarbons (PAH);
    - BTEX (Benzene, Toluene, Ethylbenzene, Xylene);
    - Polychlorinated biphenyls;
    - Pesticides;
    - Herbicides:

  If the above are detected in water and/or if waterbody is downstream of sources;
- Total organic content (TOC): always sample when sampling organic compounds as trigger values are adjusted by TOC;

- Particle size analysis: always sample when analysing sediments to obtain an understanding of a sediment's potential to store pollutants (sediments comprised smaller particles generally have a greater capacity to store pollutants);
- Chromium reducible suite: if acid sulfate soils are suspected.

In routine monitoring programs, annual sediment sampling is usually sufficient as in most waterbodies sediment composition would not change significantly in the short term. More frequent sediment sampling may be warranted if sediment is being deposited at a high rate, if water is contributing a lot of pollutants to a system over a short period of time, or after pollution events. In structural BMP monitoring programs, at least one baseline sediment sample should be taken and at least annually after implementation.

Sediments should be sampled in accordance with AS/NZS (1999). If sampling water and sediment at the same site on the same day, water should be sampled before sediment to ensure that disturbed sediment is not captured in the water sample.

As well as comparing results between sites and over different sampling occasions, sediment results should be compared to trigger values in Table 3.5.1 of ANZECC & ARMCANZ (2000) to determine whether these pollutants may result in negative impacts. It should be noted that no trigger values guidelines are available for nitrogen and phosphorus and this data can only be compared over time or between sites.

11.4. Aquatic invertebrates

Aquatic invertebrates (often known as macroinvertebrates, but can also include microinvertebrates) are often sampled as part of a wetland health assessment as they are easy to sample, and are vital to the presence of other fauna due to their importance in aquatic food webs. Furthermore, certain aquatic invertebrate taxa can also be good indicators of wetland condition. As such, aquatic invertebrate sampling may be conducted in stormwater receptors with high conservation value in conjunction with water quality sampling. This can be either be conducted on a regular basis (to assess the effectiveness of ongoing non structural BMPs), or before and after the implementation of structural BMPs (to assess their effectiveness). Comparing aquatic invertebrate data over time, as well as comparing data between waterbodies, can provide useful information for the assessment of BMP effectiveness.

In the south-west of Western Australia, mid spring (around October) is the ideal sampling time for aquatic invertebrates in most wetlands (DEC 2012b). Aquatic invertebrates should be sampled from the variety of different habitat types present in that wetland (i.e. sedge areas, deep open water areas, shallow open water areas, grassed areas, areas with copious leaf litter). For further information regarding aquatic invertebrate sampling protocols see Davis et al (1999) and DEC (2012b).

When assessing aquatic invertebrates, the following data assessment methods can be used:

- SWAMPS (Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity) Biotic Index – An index developed for wetlands on the Swan Coastal Plain, which assigns numerical values to invertebrate taxa (Chessman, Trayler and Davis 2002). SWAMPS indices can be calculated for families (SWAMPS-F) or species (SWAMPS-S) according to the process outlined in Chessman, Trayler and Davis (2002). A SWAMPS-S score of <46, or SWAMPS-F score of <42 indicates that cultural eutrophication or other human impact is likely, whereas a SWAMPS-S score of

>49, or SWAMPS-F score of >44 indicates that cultural eutrophication is unlikely. The index can be used as an absolute assessment of individual wetland condition;
- Taxa richness – Useful to compare between wetlands and within a wetland over time, but one measurement cannot be used as an absolute measure of wetland condition (Davis et al 1999);
- Functional feeding groups: Invertebrate ecosystems with a diversity of functional feeding groups (e.g. filter feeders, shredders, predators, collectors) are considered to be healthier (Cummins et al 1995);
- Presence/absence of certain taxa: Certain invertebrate taxa are sensitive to pollution (e.g. stonefly nymphs, mayfly nymphs, caddisfly larvae) and may be indicative of less pollution (NRM Education 2011), although their absence does not necessarily indicate poor water quality. However, large numbers of tolerant taxa (e.g. Daphniidae, Cypridopsidae (Davis et al 1999)) combined with a lack of sensitive taxa may indicate poor water quality.
- Mosquito larvae numbers – as well as being present in wetlands with poor water quality, due to human health risks posed by adult mosquitoes, mosquito larval counts are conducted, often independently from other invertebrate monitoring, to assist with mosquito control measures. This is particularly relevant when implementing stormwater BMPs where previously open water is planted or when flow rates in a channel are reduced, as this may enable increased mosquito breeding. For more information regarding mosquito monitoring, see *Mosquito Management Manual* (Department of Health 2015).

11.5. Visual inspections

While conducting water quality monitoring or other works at a waterbody, it is always helpful to conduct a visual inspection. Indicators that may be assessed visually that may be relevant to stormwater include:

- Presence of litter or other gross pollutants (i.e. leaves);
- Volume of sediment;
- Presence of bank erosion;
- Volume of aquatic or terrestrial weeds;
- Abundance, diversity and health of vegetation;
- Abundance and diversity of fauna;
- Presence of deaths of fish or other fauna;
- Volume and species of macroalgae;
- Presence and intensity of green or unusually coloured water (indicative of phytoplankton);
- Water levels.

11.6. Education indicators

Monitoring and evaluation of educational programs should also be performed to assess their effectiveness. The CRC for Catchment Hydrology (Taylor and Wong, 2003) has recently developed monitoring and evaluation guidelines aimed specifically at non-structural measures (such as education) for stormwater management, which specify the following seven types of monitoring "styles":

1. Implementation of management actions (i.e. whether the management action has been fully implemented and the quality of that implementation).

2. Changes in people's awareness and/or knowledge (e.g. awareness of stormwater issues);

3. Changes in people's self-reported attitude;

4. Changes in people's self-reported behaviour;

5. Changes in people's actual behaviour;

6. Changes in stormwater quality; and

7. Changes in waterway health.

Monitoring styles 6 and 7 are covered in **Section 12.1 and Section 12.2** above. Style 1 could involve collecting information about the number of training sessions delivered, number of people trained and trainees' ratings on the quality of the course's content and its delivery. Styles 2, 3 and 4 could include surveys, questionnaires or interviews conducted before and after the education is received. Style 5 could consist of direct observations of behaviour (e.g. littering studies, car washing) or audits (e.g. of industrial premises). For further information regarding the implementation of monitoring the effectiveness of education programs using monitoring styles 1 to 5, refer to Taylor and Wong (2003).

12. Key performance indicators

12.1. Surface water quality

- Regular monitoring should be conducted of all main stormwater drains discharging to the Swan Canning Estuary during high-flow months (i.e. winter and spring) at a minimum, according to **Section 11.2**;
- Regular monitoring should be conducted of all stormwater drains entering conservation category (and preferably resource enhancement) priority receptor wetlands/and or the wetlands themselves, where practicable (i.e. water quantity/depth is sufficient) during high-flow months (i.e. winter and spring) at a minimum, according to **Section 11.2**;
- In main stormwater drains sites close to the river outlet:
    - Total nitrogen and total phosphorus concentrations be below meet HRAP long term targets;
    - Concentrations of all nutrient parameters (total, nitrogen as ammonia/ ammonium and total oxidised nitrogen) should be less than ANZECC and ARMCANZ trigger values for lowland rivers;
    - pH and dissolved oxygen values should be within ANZECC and ARMCANZ acceptable ranges for lowland rivers
    - concentrations of all toxicant parameters (metals and any other relevant toxicants analysed) should be less than ANZECC and ARMCANZ trigger values for 95% protection of freshwater biota;
    - Total suspended solids concentrations should be less than the DWER interim value;
- In upstream portions of main stormwater drains:
    - Concentrations of all nutrient and toxicant parameters and total suspended solids should decrease over time (where they are greater than HRAP, ANZECC and ARMCANZ or DWER interim trigger values);
    - Where pH or dissolved oxygen values are outside acceptable ranges, values should become closer to acceptable ranges over time;
- In stormwater drains discharging to wetlands or in wetlands:
    - Concentrations of all nutrient parameters should meet ARMCANZ trigger values for wetlands;

  - pH and dissolved oxygen values should be within ANZECC and ARMCANZ acceptable ranges for wetlands;
  - Concentrations of all toxicant parameters (metals and any other relevant toxicants analysed) should be less than ANZECC and ARMCANZ trigger values for 95% protection of freshwater biota;
  - Total suspended solids concentrations should be less than the DWER interim value;
  - No avian botulism outbreaks should occur in wetlands;
  - No significant algal blooms should occur in wetlands;
  - No visible sedimentation should be present in wetlands (as a result of bank erosion or from settling of suspended solids from stormwater);
  - No litter or coarse sediment discharged into resource management and conservation wetlands.
- For newly implemented major stormwater structural controls (i.e. new biofilters, constructed wetlands or large swales);
  - Monitoring upstream and downstream of major stormwater interventions should occur (where practicable) for at least one year before and three years after their implementation;
  - Concentrations and/or loads of relevant parameters should be lower downstream than upstream of the intervention;
  - Concentrations and/or loads of relevant parameters should be lower after than before implementation in sites downstream from the intervention;
  - For larger stormwater interventions, consider calculating the removal efficiency for relevant parameters (see DoW and SRT 2007c, Section 4.6.1). The removal efficiency of the intervention should be greater after implementation than before.

12.2. Aquatic invertebrates

- Aquatic invertebrate sampling conducted at least every five years in conservation category (and preferably resource enhancement) wetlands;
- In conservation category wetlands, aim for a SWAMPS-S score 46-49 or SWAMPS-S score 42-44 (or at least an improvement in SWAMPS scores over time);
- Taxa richness should increase over time in conservation category and resource enhancement wetlands;
- Mosquito larval counts and adult mosquito numbers from waterbodies should not increase over time;
- Nuisance and disease from adult mosquitoes should be minimal to none;
- Mosquito control chemicals should be kept to a minimum.

12.3. Maintenance of stormwater network

- Hydraulic function is maintained (includes the management of sediment, native vegetation, weeds and litter);
- Vegetation in stormwater assets is healthy;
- Maintenance access is maintained (as per the design);
- Develop and maintain a WSUD asset register with maintenance responsibilities, maintenance requirements, costs involved in maintenance etc. as per **Section 8.6**;
- Submit at least one of the City's WSUD projects to the New Water Ways (2019) *WSUD Asset Map* per year.

12.4. Implementation of new WSUD assets

- Implement the stormwater capital works program (round one) proposed in Table 9 of GHD;
- Stormwater asset designs are a collaboration of disciplines within the City and involve both the implementation and maintenance teams;
- Designs consider the opportunities, constraints, desired outcomes, upstream catchment and stormwater receptors of each site;
- Designs consider both the individual asset and the potential interrelation of surrounding assets;
- Designs allows for regular maintenance access and consider long term management requirements;
- Hard engineering components in WSUD assets are designed to allow optimum vegetation establishment and health;
- Handovers between asset designers and ultimate asset managers are conducted within 3 months of stormwater project completion according to the process in **Section 8.5**.

12.5. Retrofitting the stormwater network

- Implement the stormwater capital works program (round one) proposed in Table 9 of GHD;
- In addition to this:
    - Continue to support drain restoration projects (such as the restoration Bull Creek Reserve around Bull Creek Main Drain);
    - Undertake at least one new revegetation project around a stormwater asset (sump or drain) each year, with priority given to stormwater assets with drainage discharging to priority receptors;
    - Complete at least two upgrade projects to inlets entering priority receptors each year.

12.6. Reserve management

- All City employees involved in the monitoring, management and application of fertiliser have attended the Fertilise Wise Fertiliser Training course that is hosted by the Phosphorus Awareness Project (or similar training);
- Soil tests and leaf tissue analysis conducted prior to fertilising (and fertiliser rates calculated accordingly) at all City managed reserves where fertilising occurs at least every second year;
- No “regular” fertilisers used, or at least a decrease in the amount used. These are to be replaced with controlled release or low water soluble fertiliser;
- Log book maintained for each fertiliser application area to record details of applications;
- No significant surface runoff from irrigated areas in the City onto adjacent hardstand areas observed;
- No signs of erosion/degradation from City managed gardens and reserves during storms;
- No garden waste from council gardens discharged into waterbodies.

12.7. Catchment hygiene

- Investigate street sweeping data to evaluate the effectiveness of keeping the drains clear and determine whether changes are required;
- Street sweeping conducted in relevant areas after every major event held in the City;

- Street sweeping conducted regularly in pollution 'hot spots' such as commercial or shopping centre precincts such that large amounts of rubbish do not accumulate;
- Street sweeping conducted regularly (ideally fortnightly) in streets that drop significant organic matter (e.g. deciduous trees, jacaranda flowers) during relevant times of the year such that large amounts of organic debris do not accumulate;
- Street sweeping conducted regularly (ideally fortnightly) during winter in streets with drains discharging to priority stormwater receptors (including the Swan Canning Estuary);
- Bins present near all reserves, parks, public facilities, all commercial areas and areas of high foot traffic;
- Sufficient bin numbers in public areas a and bins emptied frequently enough such that no rubbish is placed around bins;
- At least two litter clean up days involving the community are organised by the City each year (for example on "Clean up Australia Day" and "World Oceans Day").

12.8. Light industry audits

- Audits of light industrial premises should be conducted at the following frequency:
    - High risk premises: annually;
    - Medium risk premises: every two years;
    - Low risk premises: every three to five years;
- Non-compliances of the *Environmental Protection (Unauthorised Discharge) Regulations 2004* (WA) should be greatly reduced or absent in follow-up inspections at the same premises.

12.9. Community education

- Two signs developed and placed around different open or closed stormwater drains and waterbodies each year;
- Two articles included on the City of Melville website on water quality; improvement projects undertaken by the City or the City's water quality monitoring results each year;
- The City of Melville website to include links to one of the topic specific websites mentioned in **Section 10.4.2**;
- Social media platforms utilised once a month to promote water quality topics;
- Two articles included in either the City's newsletter or a local newspaper about water quality projects or education about water quality topics each year.
- Two workshops on topics that have relevance to stormwater quality for the City's residents to be held each year;
- Distribution of two of the brochures mentioned in **Section 10.4.4** at City events and at the Piney Lakes Eco Education Centre and/or City of Melville Civic Centre Reception each year;
- Schools in the City's area have been provided with information about organisations that provide school educational experiences relating to stormwater quality.
- Twenty school classes have participated in an educational experience related to stormwater quality each year;
- Park maintenance teams followed the correct procedures regarding fertiliser use (i.e. follow Fertilise Wise Best Management Practices - http://www.fertilisewise.org.au/for-turf-managers.html) and disposal of grass clippings and other green waste (i.e. using the Food Organic Green Organic (FOGO) bin for green waste disposal);
- One demonstration garden installed containing native plants and signage explaining their low water and fertiliser requirements;

- Community Based Social Marketing investigated as an option that would benefit the City in promoting stormwater quality actions and improvement;
- Surveys conducted both before and after all relevant workshops, large media campaigns (if undertaken) and at least one relevant school activity per year group;
- Surveys should demonstrate an improvement after the event in the following:
    - Awareness and/or knowledge (e.g. awareness of stormwater issues);
    - Self-reported attitude;
    - Self-reported behaviour.

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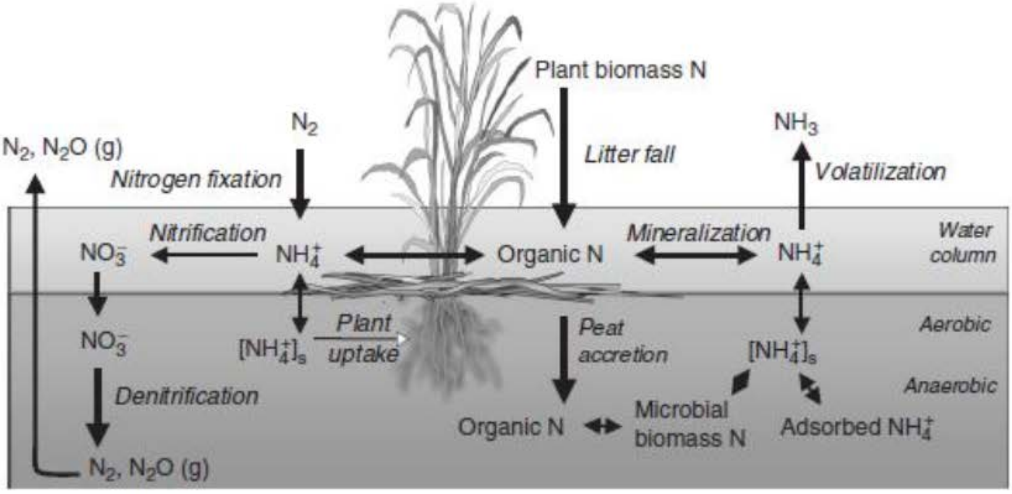
Appendix A Sources and management of common urban stormwater pollutants

Pollutant	Anthropogenic sources	Management strategies to reduce impacts	Suitable structural and non-structural stormwater controls
Phosphorus	• Fertiliser • Soil erosion • Pet wastes • Bird faeces • Detergents (e.g. from car washing) • Septic overflows/leaks	• Reduce discharges • Promote assimilation by plants and soil microbes • Often bound to soil, therefore: o Limit transport of soil o Provide opportunities for further binding to soil or other phosphorus binding media • Prevent release of phosphorus from anoxic sediment by promoting oxygenation of surface sediments	• Biofilters and rain gardens • Tree pits • Infiltration basins • Living streams • Constructed wetlands • Optimal fertiliser and gardening practices • Limiting soil transport • Education • Light industry audits • Phoslock ® (for wetlands)
Nitrogen	• Fertiliser • Organic material • Pet wastes • Bird faeces • Detergents (e.g. from car washing) • Septic overflows/leaks	• Reduce discharges • Reduce sources of organic material (e.g. deciduous trees, aquatic weeds) • Assist nitrogen cycle processes in to allow denitrification (loss of nitrogen gas to the atmosphere) to occur (see figure below) o Requires microbes operating in alternating oxic and anoxic conditions • Promote assimilation by plants (and biofilms on plants) and soil microbes	• Biofilters and rain gardens • Tree pits • Infiltration basins • Living streams (esp. incorporating oxic and anoxic zones) • Constructed wetlands (esp. incorporating oxic and anoxic zones) • Optimal fertiliser and gardening practices • Light industry audits • Education
Sediment	• Exposed soil (e.g. gardens and construction sites) • Erosion of banks and scouring of bottom sediments in waterbodies	• Reduce soil movement from gardens, construction sites etc. • Remove loose sediment before it enters waterbodies • Prevent erosion and scour in waterbodies: o Bank stabilisation (e.g. vegetation, rocks, geofabrics) o Reduce speed and volume of stormwater flowing over banks and within waterbodies • Trap or filter sediment through structural controls • Remove accumulated sediment from waterbodies and structural controls	• Biofilters and rain gardens • Tree pits • Infiltration basins • Pervious paving • Soakwells • Living streams (incorporating slow areas to allow sediment to settle) • Swales and buffer strips (incorporating slow areas) • Constructed wetlands (incorporating slow areas) • Optimal gardening practices • Optimal street sweeping • Light industry audits • Education (esp. of construction industry)
Gross pollutants (debris larger than 5mm)	• Litter • Organic material (e.g. deciduous trees, aquatic weeds, lawn clippings)	• Reduce littering • Clean up litter • Reduce sources of organic material • Trap gross pollutants through structural controls	• Litter and sediment traps • Soakwells • Infiltration basins • Swales and buffer strips • Optimal bin management • Litter cleanup • Optimal street sweeping • Light industry audits • Education

Pollutant	Anthropogenic sources	Management strategies to reduce impacts	Suitable structural and non-structural stormwater controls
Heavy metals	• Vehicle wear • Weathering of materials (e.g. metal roofs and pipes) • Industrial sources	• Reduce discharges • Often bound to particles and litter therefore: o Clean up and trapping of these sediment and gross pollutants o Filtration of sediment in structural controls • Promote assimilation by plants	• Biofilters and rain gardens • Tree pits • Infiltration basins • Pervious/ permeable/ porous paving • Soakwells • Living streams • Constructed wetlands • Litter and sediment traps • Catchment hygiene • Light industry audits • Education
Other organic pollutants (e.g. hydrocarbons, pesticides and herbicides)	• Industrial sources • Excessive/inappropriate herbicide or pesticide use • Vehicle wear	• Reduce discharges • Filtration in structural controls • Containment of spills • Treatment of polluted water	• Biofilters and rain gardens • Tree pits • Infiltration basins • Pervious/ permeable/ porous paving • Oil/water separators for hydrocarbons • Light industry audits • Collaboration with DWER • Education
Acidity	• Mobilisation of acid from acid sulfate soil oxidation • Industrial sources	• Reduce discharges • Prevent acid sulfate soil oxidation • Neutralise acid	• Light industry audits • Education • Plan for and manage if necessary acid sulfate soils during development • Aglime
Saline water (pollutant to fresh wetlands) or fresh water (pollutant to saline wetlands)	• Industrial sources	• Reduce discharges • Design stormwater network such that freshwater drains do not discharge into sensitive saline environments (e.g. salt marsh)	• Light industry audits • Education



Schematic illustration of the nitrogen cycle in a wetland (Source: Reddy and Delaune 2008)

Appendix B Indicative costs of maintaining WSUD assets

The following costs have been provided from published information to provide a guide to the indicative costs of maintaining WSUD assets. It should be noted that the design of WSUD assets can vary significantly depending on local conditions and their catchments, thus costs may differ to the published information below.

Summary of the costs and activities in maintaining a variety of different types of bioretention systems (Water by Design (2015) *Guide to the cost of maintaining bioretention systems*)

Bioretention System Type	Vegetation type	Cost [1]	Activities	Frequency
Streetscape / Car Park systems	Understorey only (grasses & sedges)	\$20-\$30/m^2fm/yr (isolated systems[2]) \$10-\$15/m^2fm/yr (grouped systems[2])	Weed control Litter removal Replanting Scour control Sediment removal from coarse sediment forebay of filter media	4-6 weeks 4-6 weeks Irregular – complete if required Rare – complete if required Irregular – complete if required
Precinct scale systems	Understorey only (grasses & sedges)	\$5/m^2fm/yr	Weed control Litter removal Replanting Scour control Sediment removal from coarse sediment forebay of filter media	4-6 weeks 4-6 weeks Rare – complete if required Rare – complete if required Rare – complete if required
	Canopy and understorey (grass, sedges, shrubs & trees)	\$1/m^2fm/yr	Weed control Litter removal Replanting Scour control Sediment removal from coarse sediment forebay of filter media	Rare – complete if required Rare – complete if required Rare – complete if required Rare – complete if required Rare – complete if required

Summary of the costs and activities in maintaining a variety of different types of bioretention systems (Water by Design (2015) *Guide to the cost of maintaining bioretention systems*)

Bioretention System Type	Vegetation type	Cost [1]	Activities	Frequency
Large systems	Understorey only (grasses & sedges)	$5/m^2fm/yr	Weed control Litter removal Replanting Scour control Sediment removal from coarse sediment forebay of filter media Sediment removal from sediment basin	4-6 weeks 4-6 weeks Rare – complete if required Rare – complete if required If sediment pond is present then not applicable, rare otherwise. If sediment pond is present, every 5 years, otherwise not required.
	Canopy and understorey (grass, sedges, shrubs & trees)	$1/m^2fm/yr	Weed control Litter removal Replanting Scour control Sediment removal from coarse sediment forebay of filter media Sediment removal from sediment basin	4-6 weeks 4-6 weeks Rare – complete if required Rare – complete if required If sediment pond is present then not applicable, rare otherwise If sediment pond is present, every 5 years, otherwise not required.

Definitions

Rare – maintenance activity unlikely to be required in any given year if the asset is appropriately designed, constructed and maintained.

Irregular – maintenance activities may occur or more in any given year, but not on a regular basis

Notes

[1]all costs are presented a $X per square meter of filter media and in 2014 Australian Dollars

[2]Streetscape / carpark bioretention system maintenance costs are strongly related to traffic control requirements. Individual systems are likely to need traffic control for maintenance. Systems located in close proximity may be able to share traffic control, dramatically reducing costs.

Maintenance costs for WSUD assets (EPA Victoria (2008) *Maintaining Water Sensitive Urban Design Elements*)

Asset type	**Description**	**Cost**	**Comment**
Sediment Basin	Ponds, sediment traps and sediment basins	typically 3-6% of the construction cost.	Low cost in most years but higher cost when desilting or aquatic weed management is required
Wetlands	Includes an inlet zone sediment basin/pond and a machrophyte zone without a GPT	typically 2-6% of the construction cost annually	Costs increase where; - there are introduced weeds - sediments are contaminated -upstream control of sediment is poor -access is difficult dewatering areas are limited
Vegetated swales		$9/m2/year	
Bioretention systems (rain gardens, biofilters)		typically, 5-7% of the cost of construction annually.	
Street tree pits		typically, 5-7% of the cost of construction annually.	
Infiltration		Ranges from 5-20% of the construction costs	

Appendix C Recommended plant species for WSUD assets

Recommended species for biofilters

The species in the table below are those that have been proven to remove nitrogen in biofilters (Payne 2013; Payne et. al. 2014; Zhang et al 2011). At least 50% of vegetation in biofilters should comprise at least 50% of these species (Monash University 2014). Other species suitable for use in biofilters implemented in the City (i.e. species native to Western Australia that prefer sandy or loamy soil and can tolerate regular or temporary inundation) can be found in Table 5, Part B in Monash University (2014).

Table C-1: Recommended species (shown to effectively remove nitrogen) for biofilters (adapted from Monash University 2014)

Genus	Species	Common Name	Habit	Inundation tolerance	Drought tolerant	Salinity tolerance	Height	Native to City of Melville (Woodgis 2011)
Baumea	*juncea*	Bare twig rush	sedge	RTD	N	F, B	1	Y
Baumea	*rubiginosa*	River twig sedge	sedge	RT	N	F, B	1	N
Carex	*appressa*	Tussock sedge	sedge	RTD	Y	F	1.8	N
Cyperus	*gymnocaulus*	Spiny flat sedge	sedge	RT	N	F, B	1	Y
Juncus	*pallidus*	Pale rush	rush	TD	Y	F, B	1.5	Y
Juncus	*kraussii*	Shore rush	rush	RT	N	F, B, S	1.2	Y
Juncus	*subsecundus*	Finger rush	rush	RTD	Y	F	1	N
Melaleuca	*incana*	Grey honey myrtle	shrub	T	N		3	N
Melaleuca	*lateritia*	Robin redbreast bush	shrub	RTD	N	F, B	2.5	Y
Poa	*poiformis*	Coastal Poa	grass	TD	Y	F	0.9	N
Sporobolus	*virginicus*	Marine couch	grass	TD	N	F, B, S	0.5	Y

Inundation tolerance: R=regular
T=temporary
D=dry

Salinity tolerance: F=fresh
B=brackish
S=saline

Recommended species for conveyance assets

The species in the table below are those that have been found suitable to be placed in conveyance assets to provide some water quality improvement while still facilitating flow.

Table C-2: Recommended species for conveyance assets

Genus	Species	Common Name	Habit	Maximum tolerated depth	Drought tolerant (Monash University 2014)	Salinity tolerance (Monash University 2014)	Height (Monash University 2014)	Native to City of Melville (Woodgis 2011)
Baumea	*vaginalis*	sheath twig sedge	sedge	20cm	N	F, B	1.2	N
Baumea	*preissi*	broad twig sedge	sedge	20cm	N	F, B	1	Y
Baumea	*juncea*	bare twig rush	sedge	30cm	N	F, B	1	Y
Carex	*inversa*	knob sedge	sedge	20cm		F	0.5	N
Carex	*fascicularis*	tassel sedge	sedge	20cm	N	F	1	N
Carex	*appressa*	tussock sedge	sedge	20cm	Y	F	1.8	N
Ficinia	*nodosa*	knotted club rush	sedge	Saturated	Y	F, B	1	Y
Isolepis	*cernua*	nodding club rush	Sedge	Saturated	N	F, B, S	0.4	Y
Juncus	*holoschoenus*	jointleaf rush	Rush	Saturated		F	1	N
Juncus	*pallidus*	pale rush	rush	Moist	Y	F, B	1.5	Y
Juncus	*kraussii*	shore rush	rush	20cm	N	F, B, S	1.2	Y
Juncus	*subsecundus*	finger rush	rush	Saturated	Y	F	1	N
Lepidosperma	*gladiatum*	sword sedge	sedge	Saturated	Y	F, B		Y
Lepidosperma	*angustatum*		sedge	Saturated			0.5	Y

Salinity tolerance: F=fresh
B=brackish
S=saline

Appendix D Summary of water quality monitoring parameters

Parameter	How to monitor		Description	Factors affecting this parameter	When/why to monitor	Guidelines for comparison
	In situ*	Laboratory analysis				
pH	X	X	Hydrogen concentration measured on a logarithmic scale. High pH indicates alkaline water, low pH indicates acidic water	Natural: rainfall (↓), soil type (↓↑), algal/plant growth (photosynthesis ↑, respiration ↓) presence of tannins (↓), groundwater influence (↓↑) Anthropogenic: Oxidation of acid sulfate soils (↓), industrial discharge (↓↑), acid rain (↓)	Always measure when monitoring stormwater. Changes in pH can cause stress to aquatic biota and may indicate pollution or oxidation of acid sulfate soils	SW Aust. TV: • Wetlands (i.e. wetlands or stormwater rains discharging into wetlands): 7-8.5 • Lowland Rivers (i.e. stormwater drains discharging into the Swan River): 6.5-8 Recreational: 6.5-8.5
Dissolved oxygen saturation/ concentration	X		Amount of oxygen dissolved in the water.	Natural: time of day (↓↑), water temperature (↓), salinity, algal/plant growth (photosynthesis/respiration), water velocity (↑), weather (windy ↑, calm ↓), water depth (↓), decomposing material (↓) Anthropogenic: Decomposing organic material from eutrophication or disposal of organic materials (e.g. grass clippings or hydrocarbons) (↓), excess algal growth (↑)	Always measure when monitoring stormwater. Oxygen is necessary for life for aquatic biota. Low oxygen is a common consequence of eutrophication	SW Aust. TV: • Wetlands (i.e. wetlands or stormwater rains discharging into wetlands): 90-120% • Lowland Rivers (i.e. stormwater drains discharging into the Swan River): 80-120% Rec: >80%
Electrical Conductivity	X	X	Different measures of the ion (i.e. salt) content in water. Different wetlands and waterways will have naturally different values	Natural: rainfall (↓), evaporation (↑), soil type (↓↑), groundwater influence (↓↑), tidal influence (↑) Anthropogenic: Discharge of water from industry (hypersaline (↑), hyposaline (↓)), sewerage or agriculture into stormwater (↑)	Always measure when monitoring stormwater (at least one of these parameters). Changes in electrical conductivity can cause stress to aquatic biota and may indicate pollution	SW Aust. TV range: • Lakes reservoirs & wetlands (i.e. wetlands or stormwater rains discharging into wetlands): 300-1500 µS/cm • Upland & lowland rivers (i.e. stormwater drains discharging into the Swan River): 120-300 µS/cm
Salinity	X	X				NA
Total dissolved solids	X	X				NA
Temperature	X		Water temperature	Natural: air temperature (↑), shade (↓), water colour (↑) Anthropogenic: Discharge of hot (↑) or cold (↓) water from industry into stormwater	Always measure when monitoring stormwater. Changes in temperature can cause stress to aquatic biota and may indicate pollution	NA
Total Nitrogen		X	Sum of all forms (organic + inorganic, soluble + particulate) of nitrogen in water	Natural: soil type (↓↑) and weathering of rocks/soil (↑), surrounding vegetation type and volume (e.g. deciduous trees (↑)), plant and animal decomposition (↑), faecal material (↑), lightning and volcanic activity (↑) Anthropogenic ↑: Fertilisers, sewerage, feed lots, pet droppings, exogenous plant debris, cleaning products, industrial processes	Always measure when monitoring stormwater. Important indicator of eutrophication	FW biota prot.: • Wetlands (i.e wetlands or stormwater rains discharging into wetlands): 1.5 mg/L • Lowland Rivers (i.e. stormwater drains discharging into the Swan River): 1.2 mg/L HRAP: • short term target: 2 mg/L • long term target: 1 mg/L
Total oxidised nitrogen		X	Sum of oxidised dissolved nitrogen forms nitrate (NO_3^-, usually more prevalent) and nitrite (NO_2^-, usually less prevalent).	See above. Converted from organic forms of nitrogen as part of the nitrogen cycle, or input into water directly from fertilisers, sewerage or industrial waste	Always measure when monitoring stormwater. Important indicator of eutrophication as these forms of nitrogen are readily available for plant and algal uptake	SW Aust. TV: • Wetlands (i.e wetlands or stormwater rains discharging into wetlands): 0.10 mg/L • Lowland Rivers (i.e. stormwater drains discharging into the Swan River): 0.15 mg/L

Parameter	How to monitor		Description	Factors affecting this parameter	When/why to monitor	Guidelines for comparison
	In situ	Laboratory analysis				
Nitrogen as ammonia		X	Sum of dissolved nitrogen forms ammonium (NH^{4+}, usually more prevalent) and ammonia (NH_3, usually less prevalent)	See above. Converted from organic forms of nitrogen as part of the nitrogen cycle, or input into water directly from fertilisers, sewerage, cleaning products or industrial waste	Always measure when monitoring stormwater. Important indicator of eutrophication as these forms of nitrogen are readily available for plant and algal uptake	SW Aust. TV: • Wetlands (i.e wetlands or stormwater rains discharging into wetlands): 0.10 mg/L • Lowland Rivers (i.e. stormwater drains discharging into the Swan River): 0.15 mg/L FW biota prot: 0.9 mg/L
Total/dissolved organic nitrogen		X	Total and dissolved organic forms of nitrogen	See above	Always measure when monitoring stormwater. Important to understand nitrogen balance	NA
Total phosphorus		X	Sum of all forms (organic + inorganic, soluble + particulate) of nitrogen in water	Natural: soil type (↓↑) and weathering of rocks/soil (↑), surrounding vegetation type and volume (e.g. deciduous trees (↑)), plant and animal decomposition (↑), faecal material (↑), oxygen levels (↓) Anthropogenic ↑ : Fertilisers, sewerage, feed lots, pet droppings, exogenous plant debris, cleaning products, industrial processes	Always measure when monitoring stormwater. Important indicator of eutrophication	HRAP: • short term target: 0.2 mg/L • long term target: 0.1 mg/L SW Aust. TV: • Wetlands (i.e wetlands or stormwater rains discharging into wetlands): 0.06 mg/L • Lowland Rivers (i.e. stormwater drains discharging into the Swan River): 0.065 mg/L
Filterable reactive phosphorus		X	Portion of phosphorus that passes through a 0.45 µm filter, considered to be chemically indicative of the inorganic orthophosphate (PO_4^{3-}) ion	See above	Always measure when monitoring stormwater. Important indicator of eutrophication as readily available for plant and algal uptake	SW Aust. TV: • Wetlands (i.e wetlands or stormwater rains discharging into wetlands): 0.03 mg/L • Lowland Rivers (i.e. stormwater drains discharging into the Swan River): 0.04 mg/L
Total suspended solids		X	Concentration of suspended materials in water	Natural/anthropogenic ↑: soil particles, organic material (e.g. algae, microorganisms, decaying plant and animal matter), iron floc.	Always measure one of these when monitoring stormwater. Can indicate the transport of sediments (in flowing waters). High levels can negatively impact biota by blocking light or smothering	DWER interim value: 6 mg/L
Turbidity	X	X	The cloudiness of the water due to light scattering by suspended particles			SW Aust. TV range: • Lakes reservoirs & wetlands (i.e. wetlands or stormwater rains discharging into wetlands): 2-200 NTU • Upland & lowland rivers (i.e. stormwater drains discharging into the Swan River): 20-250 NTU
Total metals		X	Metal concentration, including dissolved and particulate forms. Common metals ins stormwater include aluminium, chromium, copper, iron, lead and zinc, other metals include arsenic, cadmium, chromium, cobalt, mercury, nickel	Natural: soil type (↓↑) and weathering of rocks/soil (↑), groundwater influence (↓↑), pH (↓↑ depending on metal) Anthropogenic ↑ : Various industrial/manufacturing processes, dissolution of metals in structures, vehicle sources, oxidation of acid sulfate soils, fertilisers, sewerage	Analyse common metals as a baseline and continue to monitor if high concentrations are found. Analyse less common metals if warranted (e.g. source of these metals from industry or contaminated site upstream). Total metals useful to show metals able to be transported in stormwater	FW biota prot: see table, varies depending on metal. Some metals only have moderate or low reliability trigger values, see ANZECC & ARMCANZ (2000) Chapter 8 for more details.

Parameter	How to monitor		Description	Factors affecting this parameter	When/why to monitor	Guidelines for comparison
	In situ	Laboratory analysis				
Soluble metals		X	Concentration of soluble (or dissolved) portions of metals that are soluble. Common metals in stormwater include aluminium, chromium, copper, iron, lead and zinc, other metals include arsenic, cadmium, chromium, cobalt, mercury, nickel	See above	See above. Soluble metals are more readily bioavailable to biota than particulate metals and therefore a better indication than total metals of toxicity to biota	FW biota prot: see table, varies depending on metal. Some metals only have moderate or low reliability trigger values, see ANZECC & ARMCANZ (2000) Chapter 8 for more details. Rec health/aesthetic: see table, varies depending on metal.
Hardness		X	The combined concentration of earth-alkali metals, predominantly magnesium (Mg2+) and calcium (Ca2+), and some strontium (Sr2+)	Natural: Underlying geology (e.g. wetlands over limestone ↑) Anthropogenic: Discharges from industry (↓↑)	Monitor whenever monitoring metals, as the toxicity of some metals is reduced in harder water and therefore trigger values for these metals can be adjusted	NA
Acid sulfate soil (ASS) suite		X	A suite of parameters** to monitor to assess impacts of ASS oxidation on waterbodies	ASS, or potential ASS, are naturally occurring soils or sediments which contain iron sulfides and/or other sulfidic minerals that have been, or potentially can be, oxidised (through contact with air) to cause acid release. Such oxidation can result from excavation or dredging, dewatering of groundwater or surface water, or lowering of the groundwater table from drought or abstraction	Monitor when oxidation of ASS is suspected to have impacted surface water (i.e. low pH plus high iron and aluminium, or visual evidence present). Consult DWER (2015a) prior to any earthworks or dewatering to check full monitoring requirements.	Data can be compared to trigger values outlined above. Also see DWER (2015b) Table 10 for minimum trigger/action levels to be used where dewatering effluent is to be discharged to a sensitive wetland or waterway
Various organic compounds from human activities		X	Includes polycyclic aromatic hydrocarbons, total recoverable hydrocarbons, BTEX (Benzene, toluene, ethylbenzene, xylenes), polychlorinated biphenyls, pesticides, herbicides	Not naturally occurring substances, only from anthropogenic sources. See ANZECC & ARMCANZ Chapter 8 for more details for each	Expensive so analyse only if warranted (e.g. source of these metals from industry or contaminated site upstream) or if problems observed (e.g. hydrocarbon slick present)	FW biota prot: see table, varies depending on parameter. Some parameters only have moderate or low reliability trigger values, see ANZECC & ARMCANZ (2000) Chapter 8 for more details. Rec health/aesthetic: see table, varies depending on parameter.
Total organic carbon		X	Non specific measurement of all organics (e.g. organic material, hydrocarbons etc) present in a sample	Any organic material both from anthropogenic (i.e. pet droppings, grass clippings, sewerage) and natural sources (leaves, algae, bird droppings), as well other contaminating organic compounds from anthropogenic sources (see above) will contribute to total organic carbon.	Indicator of the degree of organic pollution in water without analysing more expensive individual parameters.	NA
Biochemical (or biological) oxygen demand		X	The amount of oxygen required by microbes to decompose organic matter in a sample over a five day period	Any organic material, both from anthropogenic (i.e. pet droppings, grass clippings, sewerage) and natural sources (leaves, algae, bird droppings) will contribute to total organic carbon	Indicator of the degree of organic pollution in water. High BOD indicates the potential for anoxic conditions, as more oxygen will be used for decomposing the organic waste.	NA
Redox potential/ oxidisation reduction potential (ORP)	X	X	A non-specific measure of the potential of a sample to take electrons (i.e. oxidise) or donate electrons (i.e. reduce) from another substance. It is usually measured compared to a standard reference solution.	Oxidising samples will have a positive ORP value and reducing solutions will have a negative ORP value. Common oxidising agents that will increase ORP values of a waterbody include oxygen, chlorine, hydrogen peroxide, and sulphuric acid. As pH decreases, ORP increases. reducing. Common reducing agents include nitrates, ferrous ions and hydrogen sulphite. As pH increases, ORP decreases. ORP can change considerably during the day depending on temperature and oxygen saturation.	Used to make a broad distinction between oxic, anoxic and reducing conditions, which can result in the alteration of other substances in the water. Can be used to track certain kinds of strongly oxidising or reducing pollutants,	NA

Parameter	How to monitor		Description	Factors affecting this parameter	When/why to monitor	Guidelines for comparison
	In situ	Laboratory analysis				
Chlorophyll α	X	X	The concentration of chlorophyll α, a green pigment produced by algae for photosynthesis	Is an indirect measure of phytoplankton volume and as such concentrations increase with increasing phytoplankton volume, however concentrations can vary between phytoplankton species. Phytoplankton growth is enhanced with increased nutrient concentrations, and is hindered by turbidity, colour and water depth (i.e. light availability).	Used as a relatively inexpensive, nonspecific measure of phytoplankton concentrations. High values may warrant more specific tests of microalgal concentrations, speciation and toxins	SW Aust. TV: • Wetlands (i.e wetlands or stormwater rains discharging into wetlands): 30 µg/L • Lowland Rivers (i.e. stormwater drains discharging into the Swan River): 3-5 µg/L
Phytoplankton amount and speciation		X	Phytoplankton density (cells/mL) or biovolume (mm^3/L) per individual phytoplankton taxa	Phytoplankton growth is enhanced with increased nutrient concentrations, and is hindered by turbidity, colour and water depth (i.e. light availability). Different species of phytoplankton can proliferate depending on a combination of biotic and abiotic factors	Used mainly for evaluating human health risk in recreational waters with human contact, and relevant for monitoring the Swan River and any waterbody from which irrigation water is abstracted. Different phytoplankton species can be more harmful than others. Can help determine treatment options	Rec: Fresh recreational water bodies should not contain: • ≥10 µg/L total microcystins; or > 50 000 cells/mL toxic Microcystis aeruginosa; or biovolume equivalent of > 4 mm3/L for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume; or • ≥ 10 mm^3/L for total biovolume of all cyanobacterial material where known toxins are not present; or • cyanobacterial scums consistently present.
Microalgal toxins		X	Tests for a specified suite of toxins produced by blue green algae	Some species of blue green algae can produce harmful toxins, the most common of which include *Cylindrospermopsis raciborskii, Raphidiopsis mediterranea, Chrysosporum ovalisporum, Microseira wollei, Dolichospermum circinale, Microcystis aeruginosa and Nodularia spumigena*	Expensive analysis. Used mainly for evaluating human health risk in recreational waters with human contact, and relevant for monitoring the Swan River and any waterbody from which irrigation water is abstracted. Different phytoplankton species can be produce different toxins with varying pathologies	NA
Enterococci		X	A group of bacteria, normal inhabitants of the intestinal tract of humans and other animals. Used as an indicator faecal contamination, although not necessarily a health risk themselves (NHMRC 2008)	Sewerage leaks, septic tank failure, direct human or animal contact and/or fouling of waterbodies	Measurement may be warranted in recreational bodies with human contact (i.e. Swan River), in waterbodies from which irrigation water is abstracted, or to track suspected sewerage leaks into stormwater	NA for freshwater

* Note not all water quality meters or loggers can measure all of these parameters

** Includes : total acidity, total alkalinity, sulfate, chloride, dissolved aluminium, total aluminium, dissolved arsenic, dissolved chromium, dissolved cadmium, total iron, dissolved iron, dissolved manganese, dissolved nickel, dissolved zinc and dissolved selenium (DWER 2015)

SW Aust. TV: Trigger values for slightly disturbed ecosystems: A&A (2000) Table 3.3.6

SW Aust. TV range: Ranges of trigger values for slightly disturbed ecosystems: A&A (2000) Table 3.3.7

FW biota prot.: ANZECC & ARMCANZ (2000) Table 3.3.6, 95% level of protection (Note 95% level of protection is generally used – can decrease the level of protection in wetlands where ecological value is not a priority)

HRAP: Target for catchment tributaries of the Swan Canning River System: Healthy Rivers Action Plan (SRT 2008)

Rec: NHMRC (2008) Table 1.5

Rec health/aesthetic: As specified in NHMRC (2008), multiply values in Table 10.6 in the *Australian Drinking Water Guidelines* (NHMRC 2018) by 10.