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EVALUATION OF CONSTRUCTED WETLANDS IN PERTH

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EVALUATION OF CONSTRUCTED WETLANDS IN PERTH

Prepared for
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Contents

Executive summary

Evangelisti & Associates, in association with the Department of Civil Engineering at Monash University and Alan Tingay & Associates, were commissioned in early 1996 to prepare a Water Quality Management Manual which would involve the development, promotion and application of compliance techniques and processes to enable the achievement of the more rigorous Water Quality targets envisaged in the Swan and Canning Estuary Environmental Protection Policy (EPP). This report is intended to compliment the manual. The effectiveness of existing Best Management Practices (BMPs) was reviewed, and monitoring strategies recommended that will effectively assess the performance of BMPs.

A limited number of stormwater BMPs have been used in Perth, and to date only a small selection of these have been monitored. Monitoring data were reviewed to determine the effectiveness of some existing BMPs in Western Australia. The focus of the review was on wet detention basins and constructed wetlands since these were the BMPs most frequently used and monitored in Perth.

Most of the wetland BMPs were designed as bottom end retrofits to existing drainage systems rather than as integrated stormwater management systems distributed throughout the catchment. As expected for bottom end retrofits, the majority of the constructed wetlands reviewed were observed to be poor at removing nutrients entering the wetland. The Bartram Road system was effective in nitrogen removal (30%) but yielded a net export of total phosphorus. Insufficient data were available to determine the effectiveness of the Woodlake Village Lake. Constructed wetlands in the Peel-Harvey catchment were able to remove significant amounts of phosphorus (71%) at moderate to high flow rates.

The poor performance of the constructed wetlands in urban catchments was attributed to non compliance with design specifications. Residence times were lower than designed for all three wetlands, notably by a factor of four for the Bartram Road and Hird Road wetlands and basins. The contribution of groundwater to each of the wetland sites was not quantified in the design. It was therefore not possible to determine whether the groundwater diluted or concentrated surface flows, which in turn made accurate performance evaluation difficult.

In contrast, the Spectacles, a natural wetland was highly efficient at removing both nitrogen and phosphorus. This efficiency was attributed to the wetlands low rate of flow, large area relative to its catchment and dense fringing vegetation. Natural wetlands in the Peel-Harvey Estuary act as sinks for phosphorus from surrounding farmlands, in low to moderate flow years. Some resuspension of accumulated phosphorus may occur in very high flow years but these were not observed.

To be effective at nutrient removal, constructed wetlands and detention basins should:

- Meet design specifications for area, hydraulic retention time, flow patterns and hydraulic outflow control as detailed in the Urban Stormwater Quality Management manual for Western Australia
- Utilise vegetation for controlling flow, reducing short circuiting and aiding in nutrient uptake and transformation.

Performance Monitoring

The limited data available for evaluation of existing BMPs in Perth emphasise the need for reliable monitoring programmes to be implemented to test BMPs. A number of factors must be considered when developing a monitoring programme. These include:

- Observed or predicted hydraulic loads and pollutant concentrations
- Likely impact of seasons on loads and concentrations
- Flow/discharge relationships
- Ensure that careful analysis and correlation between inflow and outflow monitoring data

Monitoring programmes widely used in Australia have been based on fixed frequency sampling. This form of sampling frequently fails to sample individual flood events and concentration changes. It is important to have a sampling frequency that matches discharge as the concentration of solutes and particulates changes.

Constructed Wetland and Detention Basin Design

This document is intended to compliment the Urban Stormwater Quality Management Manual recently published for the Water & Rivers Commission. While the effectiveness of selected constructed wetlands and wet detention basins for nutrient removal has been discussed in the report, the manual should be referred to where detailed design criteria are required for the construction of these systems. This manual provides guidance on the implementation of a range of stormwater BMPs. Specifications and compliance mechanisms have been included for use in the practical application of the BMPs.

1. Introduction

1.1 General

Of the limited number of stormwater Best Management Practices (BMPs) implemented in Perth, the most frequently used examples are constructed wetlands and wet detention basins. Many of these have not been designed for the sole purpose of contaminant removal, but are also associated with an amenity value or for wetland re-creation or restoration of lost wetlands. While the intended purpose of these wetlands needs be acknowledged, the evaluation of the performance of these systems for pollution removal can assist in determining appropriate design for future use of the BMPs.

1.2 Aims

This report compliments the Urban Stormwater Quality Management Manual recently prepared for the Water & Rivers Commission. The Manual provides practical advice to developers, planners and engineers on the implementation of a range of stormwater BMPs. The aim of this report was to evaluate the effectiveness of existing examples of BMPs for pollutant removal in Perth. The focus of the report was on constructed wetlands and wet detention basins as these were the most frequently used and most monitored BMPs in Perth.

The use of constructed wetlands for nutrient removal from stormwater is considered a fledgling treatment technique in Perth. The high cost and variable success of this approach in Perth has raised considerable debate with regard to the suitability of future applications. While it is acknowledged that some existing examples of these BMPs do not appear to be performing well in Perth, their relative success needs to be viewed in context with the availability of design information at the time of their construction; their intended purpose; the extent to which they meet more recently developed design criteria; and the level of maintenance which they have received since construction.

The examples of constructed wetlands discussed in this report appear to be achieving a lower Contaminant Removal Efficiency (CRE) than some natural wetlands in Perth. Experience overseas and interstate has indicated that this should not be the case. Continued evaluation of these structures is needed in order to identify factors which may constrain CRE within constructed wetlands in Perth, and to refine designs for future constructions.

1.3 Monitoring of stormwater BMPs

The evaluations in this report have necessarily been based on a limited suite of monitoring data which has precluded the ability to make definitive statements about their performance. This limitation emphasises the need for reliable monitoring programmes to be implemented along with BMPs.

Monitoring programmes widely used in Australia have been based on fixed frequency sampling. This form of sampling frequently fails to sample individual flood events and concentration changes. It is important to have a sampling frequency that matches discharge concentration changes of solutes and particulates.

Existing monitoring programmes were reviewed and monitoring strategies recommended that will effectively assess the performance of BMPs.

2. Stormwater pollutants

2.1 General

Pollutant concentrations in stormwater are generally extremely variable over time. This is due to the large number of factors contributing to stormwater flows. Among other influences, stormwater pollutant loads vary with land use, soil type and climatic influences, such as rainfall intensity, duration and time between rainfall events. When combined with historical fertiliser applications, possible water table interactions with septic tanks and subsurface drainage systems, the concentrations of contaminants can vary dramatically (Hale, 1995).

2.2 Issues of concern of Perth

Loss of fertilisers used for agricultural and domestic purposes has stressed receiving water bodies throughout the southwest of Western Australia. Many of these have exceeded their assimilative capacity with eutrophication becoming a major problem. Many local waterbodies and drainage discharge outlets in Perth have experienced regular algal blooms. Algal blooms are of particular concern for managers of stormwater discharges as they are not aesthetically pleasing and some species have potential human health implications (Hosja & Deeley, 1994).

Nutrient enrichment is the cause of dramatic increases in plant biomass, or algal blooms, associated with eutrophication (McComb & Lukatelich, 1986). Urban runoff is an often underestimated source of nutrients which can lead to increased phytoplankton populations in receiving waters (Hamilton, 1992) Nutrients assimilated by these blooms contribute to the enrichment of sediments when the blooms collapse and decompose. Nutrient regeneration mechanisms in sediments again support nuisance algal blooms later in the year (Douglas et al, 1996; McAuliffe et al, 1993).

As a result of the Mediterranean climate in Perth, little or no runoff is generated from summer storm in rural areas, but runoff is usually associated with these storm events in urban areas. The nutrient inputs from summer urban runoff may be more concentrated than large winter runoff events from rural land. Algal assimilation is also generally greater in summer because of the high temperatures and light availability.

Phosphorus has been identified as the limiting nutrient for algal growth in many Australian inland waters, although many coastal waterbodies and the upper Swan River may be limited by nitrogen (Thompson & Hosja, 1996). The relative importance of nitrogen or phosphorus may be determined by examining the N:P ratios during the growing period (Fosberg, 1978).

Henderson and Jarvis (1995) found that many urban drains contain high enough concentrations of total phosphorus to cause algal blooms given optimum conditions for algal growth in the receiving waterbodies. The use of BMPs such as wet detention basins and constructed wetlands can assist in reducing the nutrient load to receiving waters, thereby reducing the potential for algal blooms.

2.3 First flush.

For a mediterranean climate, pollutant concentrations and loads are generally greatest, both spatially and temporally, in the early stages of winter runoff. This is caused by runoff flushing accumulated contaminants from the ground surface. The first flush effect is particularly noticeable after the extended dry weather periods over summer due to the accumulation of contaminants (Urbonas & Stahre, 1993). In Perth, the first flush effect is often compounded by soil with non wetting properties, which may behave like an impermeable surface during the first flush.

Optimal stormwater treatment should focus on removing the high pollutant concentrations and loads from the first flush (Livingston, 1993; Livingston, et al, 1994). Quantification of the first flush effect needs to be carried out by an intense sampling programme to asses spatial and temporal heterogeneity (Ellis, 1989). Defining the seasonality of event response of non point-source pollution is an important first step.

Wet detention basins and constructed wetlands behave in a similar manner to conventional detention basins. They can be used to manage stormwater peak flows and to enhance stormwater quality. In recent years, wetlands and wet detention basins have been widely used as BMPs for improving stormwater quality in many countries. When properly designed, constructed and maintained, wet detention basins and constructed wetlands can be effective tools for removing stormwater pollutants. There has been considerable debate in the literature over their ability to remove nutrients, heavy metals, organics and suspended solids. What constitutes optimal design and maintenance for nutrient removal has not been determined in many cases. Caution should be used when designing these BMPs as it is still an evolving field (Urbonas & Stahre, 1993). There are, however, several characteristics common to successful application of these stormwater treatment facilities.

3. Wet detention basins and constructed wetlands

3.1 General

The use of constructed wetlands and wet detention basins is considered to be a developing and experiment approach for stormwater treatment. A number of design aspects which may optimise the Contaminant Removal Efficiency (CRE) of these systems are outlined below. A percentage concentration CRE represents the percentage reduction in outflow concentration of an element compared with inflow concentrations, this is used when concentration limits are of concern. In cases where the protection of a receiving environment from chronic, long term loading is the objective, percentage load CRE is more appropriate.

3.2 Design aspects

3.2.1 Hydraulic requirements

BMP design constraints generally include the physical size of the available site, the desired minimum period of stormwater detention and the overall proportion of stormwater volume subjected to the prescribed minimum period of detention, defined as the hydraulic effectiveness (HE).

Control of the hydraulic regime involves providing adequate detention time for processes such as sedimentation and infiltration to be effective, and draining the detention facility at a rate which results in sufficient storage available to treat at least the first flush of the next runoff event.

3.2.2 Vegetation

Vegetation plays an important role in constructed wetlands. Vegetation contributes to water quality enhancement by a number of physical, chemical and biological processes. The relative importance of each of these factors is determined by the stormwater flow conditions. Biological and chemical treatment processes may be more effective during baseflow conditions compared to eventflows because of longer detention times. Under eventflow conditions, wetland vegetation mainly performs the physical functions of distributing and retarding flows and trapping gross pollution.

Vegetation layout has a strong influence on the flow regime in the wetland. Short circuiting can be reduced by appropriately placed vegetation forcing the flow to take a longer route, thus increasing the hydraulic residence time (HRT). Vegetation can also minimise channelling when placed as transverse barriers to the direction of flow (Urbonas & Stahre, 1993).

3.2.3 Depth

It is recommended that constructed wetlands have a variable depth to promote diversity of habitat and biological and physical treatment processes. Urbonas & Stahre (1993) state that a shaped bottom assists in preventing the development of preferred flow routes within the wetland as sediments accumulate on the bottom with time. This can be achieved by designing a base pattern that provides transverse barriers to the direction of flow between the inlet and outlet.

3.2.4 Groundwater interactions

The impact of the stormwater treatment facilities on groundwater quality and quantity needs to be considered prior to the design stage. Groundwater in Perth is frequently very close to the surface, and a range of pollutants including breakdown products from plastics and other rubbish have been observed in groundwater beneath infiltration structures in Perth. The construction of a wetland or detention basin may unacceptably affect existing natural wetlands surrounding the facility if groundwater interactions occur. Construction costs may be significantly increased if large quantities of fill or clay seals are required to manage groundwater interactions.

Groundwater may act as a source or a sink for nutrients to the stormwater treatment facility. Groundwater contributions may increase the total pollutant load even if the concentrations in the outflow are reduced by dilution. However, groundwater may already have high concentrations of pollutants if it intersects with septic tanks, leachate or nutrient intensive land use. Groundwater contributions to flow and pollutant loads may be significant and lead to operational difficulties and confound performance auditing.

3.2.5 Mosquito considerations

Mosquitos pose a human health risk so it is important that they be managed. Considerations must be made in the design process to reduce the potential for their breeding. Mosquitoes will readily populate standing water sites given appropriate conditions, so potential breeding habitats should be minimised. It may not be possible to completely eliminate them from a wetland, so efforts should aim to reduce mosquito population numbers to acceptable levels for both human comfort/safety and wildlife management purposes. Such measures could involve the following:

- fluctuating water level to disrupt the breeding cycle of mosquito larvae in the reed bed zone

- appropriate plant selection and habitat enhancement to increase the diversity and abundance of mosquito predators
- Provision of sufficient depth
- Prevention of stagnant pools

3.2.6 Soil amendment

The ability of a soil to adsorb phosphorus is indicated by its Phosphorus Retention Index (PRI) (Allen & Jeffrey, 1990). However, this index gives no indication of the remaining phosphorus adsorption capacity which is reduced as phosphorus adsorption sites are exhausted over time. Sands from the coastal plain in Perth have very low PRI values so the phosphorus removal efficiency of stormwater treatment facilities here is expected to be lower than those obtained from sites in the Eastern States and overseas. This is because the major removal pathway of dissolved and very fine forms of phosphorus is via adsorption onto settleable particles and their subsequent sedimentation.

There is potential for increased removal of dissolved phosphorus from stormwater by the use of substances with high PRI values or chemical precipitation. However, the application techniques of amending substances and chemicals requires further research to determine the optimum treatment procedures. The most effective method using amended soil for nutrient removal is to use the amended material as a filtration medium, but this is not always feasible. Agents such as gypsum neutralised bauxite residues, synthetic rutile production (SRP) wastes, crushed limestone or natural clay have potential to amend the nutrient binding capacity of local Perth sands. Investigations using metal salts that contain aluminium or iron, such as alum ($AlSO_4$), have shown that orthophosphate is effectively removed from stormwater by chemical precipitation and flocculation (Hale, 1995; Livingston et al, 1994).

3.2.7 Constructed wetlands vs detention basins

It is not clear whether constructed wetlands are more effective than wet detention basins for nutrient removal. Certainly, wetlands have been extremely effective in removing nutrients from wastewater, but stormwater is much more variable in nature compared to wastewater effluent. Inflow concentrations are much higher in wastewater systems than in stormwater and untreated stormwater has concentrations of phosphates equivalent to those found in effluent from wastewater treatment wetlands (Urbanos & Stahre, 1993).

The removal of suspended solids (SS) may not be accompanied by a proportionate removal of other pollutants. However, as most pollutants tend to have a strong affinity to SS, the removal of SS will also remove many other pollutants from stormwater. This is not the case for some dissolved solids, nitrites and nitrates (NO_x) and soluble phosphorus (SP) (Urbanos & Stahre, 1993).

The high proportion of P in the FRP form (ie < 0.45μm) from some catchments in WA poses special problems locally. The removal of dissolved phosphorus may be increased if aluminium or iron are available and the chemical conditions are conducive for adsorption or precipitation reactions to occur. Detention basins that have a permanent pool appear to provide better removal efficiencies of NO_x and SP than dry detention basins (Urbanos & Stahre, 1993). However, in some circumstances it has been found that phosphorus is removed far more effectively following a wetting and drying cycle.

Table 3.1 presents the pollutant removal efficiencies obtained from published accounts of constructed wetlands and wet detention basins throughout the world.

3.3 Pollutant removal

Wet detention systems, wetlands and artificial systems containing aquatic plants have been used successfully to remove nutrients from water passing through them in many parts of the world (Kadlec & Knight, 1996). Wet detention basins and constructed wetlands can enhance water quality through a number of processes including:

- sediment retention
- flood attenuation thus lower erosion potential
- pollutant removal by complex soil-water-vegetation interactions including adsorption, precipitation, flocculation, coalescence, volatilisations and biological uptakes

The major pathway for removal of pollutants from wet detention basins and constructed wetlands is via sedimentation. Studies by Duncan (1997) found that the effectiveness of stormwater detention ponds are dependant on pollutant behaviour in the pond over time. Consequently, the performance of basins and wetlands will depend greatly on the incoming stormwater characteristics. Pollutants that undergo gravitational settling will be removed more effectively than dissolved fractions. In general, the greater the proportion of settleable material, the greater the removal efficiency. If the majority of the pollutants are in dissolved form, basins and wetlands may not be very effective unless the pollutants become bound to particulate material in the stormwater detention structure. The extent of attraction of pollutants to settleable particulates depends on the chemical characteristics of the substances, surface properties and other water quality parameters including pH and dissolved ions.

Results are varied when it comes to nutrient removal. Urbonas & Stahre (1993) concluded that basins and wetlands are less effective for the removal of nitrogen, and that phosphorus removal varies with design, loading rates, wetland type, climate and site conditions (eg the availability of extractable aluminium in soil). However, other researchers have found that basins and wetlands are effective in nutrient removal, depending on numerous design parameters.

Table 3.1: Percentage Removal of Pollutants from Various BMPs

BMP	Source	SS %	TP %	SP %	TN %	NO3 %	NH4 %	COD %	Zinc %	Lead %	HRT days
Wet Detention Pond	Kulzer, 1989		60								
Extended Detention Dry Ponds	Urbonas & Stahre, 1993	50-70	10-20		10-20				30-60	75-90	40
Wet Detention Pond	*Wotzka & Obert, 1988	91	78		85			90		90	
Wet Detention Pond	*Martin, 1988	66	38	72	18		55		40	39	
Wet Detention Pond	*Horner et al., 1986	75	67					77	38	23	
Wet Detention Pond	* Cullum	64	60	80	15	80					
Wet Detention Pond	*Yousef et al., 1986			90		87	82	96	95		
Wet Detention Pond	*Athanas & Stephenson, 1991	65	39	44	23	55	55				
Wet Detention Pond	*Rushton & Dye, 1990	64	55	65					34		
Wet Detention Pond	*Bartone, 1983	76	54	40			55				
Constructed Wetlands	Schueler, 1992	75	45					15	50	75	
Constructed Wetlands	Strecker, 1992	80.5	58						42	83	
Constructed Wetlands	*Driscoll, 1983	85	3	29		80					
Constructed Wetlands	*Wotska & Oberts, 1988	94	78		83			93		90	
Construted Wetlands	Moustafa et al., 1995		71		26						
Constructed Wetlands	Ding & Wang, 1995	94	55		65	73	59	81			
Constructed Wetlands	Haberl et al., 1995		47		40		30	70			
Constructed Wetlands	Xianfa & Chuncai, 1995	80-94	55-86		30-85						
Constructed Wetlands	Tanner et al., 1995	37 74		48 75		34 71					2 7

* Cited in Evangelisti (1993)

Monitoring of constructed wetlands has shown that in general they have higher Contaminant Removal Efficiency (CRE) than many natural wetlands (Table 3.2). The efficiency of removal is based on factors such as HE, HRT, wetland storage volume, wetland morphology, substrates and vegetation.

There is considerable interest in using wet detention basins and constructed wetlands for the control of pollutants and nutrients in both Australia and overseas. However, the variable levels of contaminants and pulsing nature of stormwater presents unique problems in their design.

The ability of these BMPs to remove nutrients depends on the concentration of nutrients in the inflow, wetland design, wetland storage volume relative to the catchment area, wetland morphology, substrate and vegetation. The optimum CRE of wetlands receiving wastewaters generally occurs at low nutrient concentrations (Mitsch and Gosselink, 1993). Published data suggests that to achieve a 50% CRE of nitrogen, loading should not exceed 25g N/m^2/yr, while for 65% - 90% CRE of phosphorus, the loading rate should be less than 5g P/m^2/yr (Braid and Lavery, 1996).

Statistical analysis of over 50 constructed pollutant removal basins by Duncan (1997) found that the area ratio (basin/total catchment area) was generally the best measure of pollutant removal effectiveness. The analysis also emphasised the need for input concentrations to be reported as they are more closely related to pollutant removal than percentage removals. As recommended by Livingston, (1994) and indicated by relationships derived by Duncan (1997), two smaller basins in series are more effective at removing pollutants than one larger basin with the same total area.

A very long detention time may have limited impact on the colloidal fraction of nutrients, and as with the dissolved fraction, unless adsorption and flocculation processes are significant, only limited removal will be possible. The high level of tannins and organic acids cause a dark colouring of the water. This prevents penetration of sunlight to deeper levels in constructed wetlands and may limit biological uptake of nutrients as the water may be too dark and cold for photosynthesis to occur. Careful planting with cold tolerant emergent macrophytes may help alleviate this problem.

Field evidence from the Perth area suggests that longer hydraulic residence times (HRTs) result in greater pollutant removal of both dissolved and particulate fractions. However, research by Harper et al (1988) suggests that there may be a critical time after which phosphorus removal efficiencies decrease due to redox changes in the stormwater. Systems that enhance sediment/water interactions and optimise emergent plant growth and nutrient uptake by plants and sediments are more likely to have greater pollutant removals but they still require sufficient HRT.

It has been suggested that constructed wetlands in Perth may be less efficient at removing pollutants from stormwater because of high gilvin concentrations. Figure 3.1 shows the locations of natural wetlands in Perth, and typical gilvin concentrations. Coloured wetlands have lower primary productivity in the water column than those with clear water (Wrigley et al 1989, Chambers et al 1993). Constructed wetlands with high gilvin concentrations may have lower nutrient removal rates than constructed wetlands with clear water in similar locations.

Runoff from impervious surfaces is generally far less coloured than groundwaters on the Swan Coastal Plain. Figure 3.1 shows that even some natural wetlands have very low levels of gilvin. Careful design of outlet structures for constructed wetlands may minimise the input of coloured groundwaters to constructed wetlands.

Table 3.2 Sediment and Phosphorus Retention in Wetlands (Braid & Lavery, 1996).

	Sediments		**Phosphorus**	
Wetland Type	**Loading Kg/m²/yr**	**Retention %**	**Loading g/m²/yr**	**Retention %**
Natural Wetlands	150	3	8 - 80.2	4.5 -10
Restored and Created Wetlands Non Point Source Control	3-21	88 - 98	0.4 - 3.6	63 -98
Waste Water:				
Surface flow	1. - 5.	61 -98	4.7 -56	46 -80
Subsurface flow	15 - 59	49 - 89	131 - 631	8 - 89

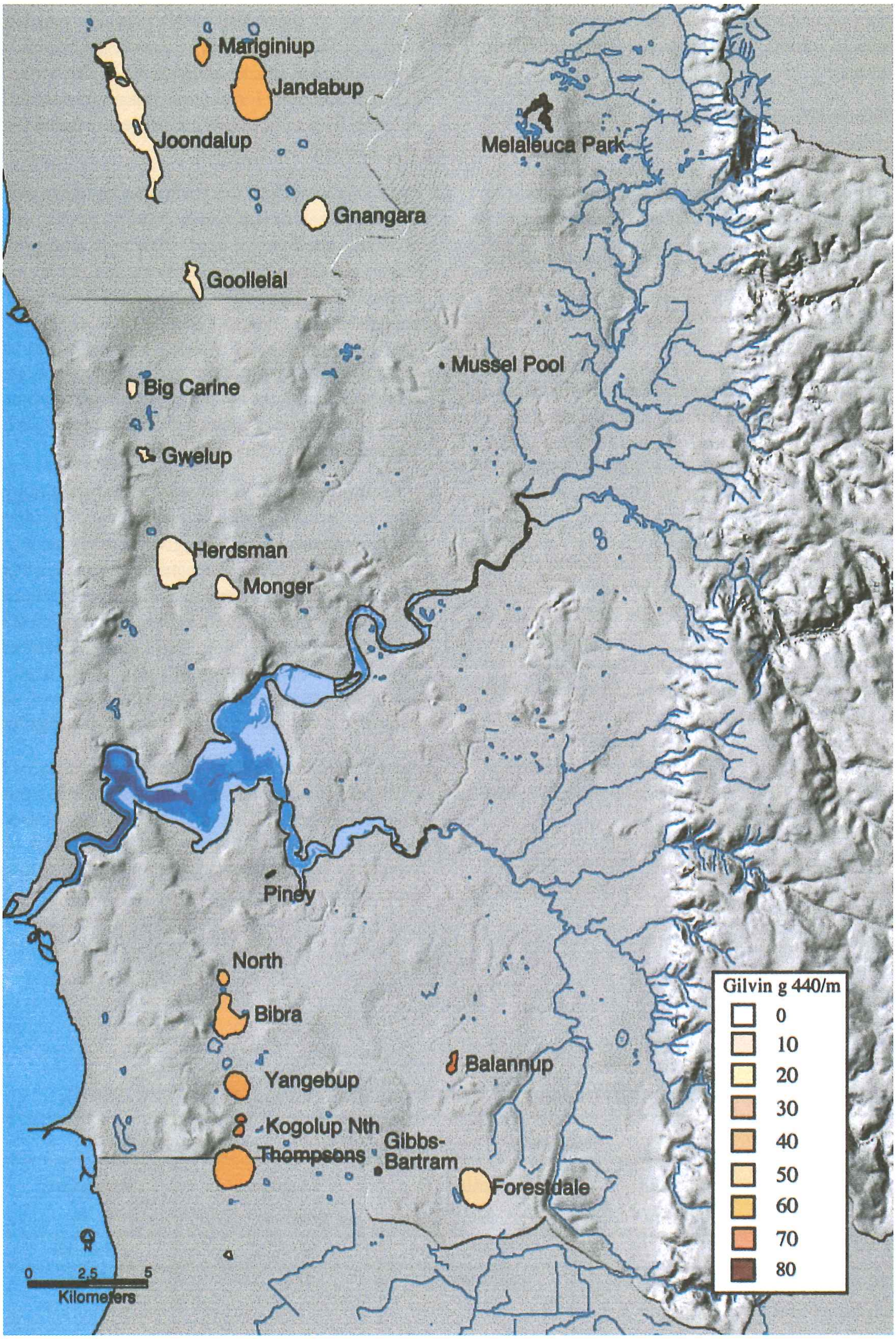

Figure 3.1: Gilvin Concentration in Natural Wetlands in Perth.

4. Effectiveness of existing constructed and natural wetlands and wet detention basins in pollutant removal

4.1 Bartram Rd

4.1.1 Background

Located in Jandakot, 40km south of Perth, the Bartram Road Buffer Lakes were developed to reduce the impact of the South Jandakot urban development on the Beelier wetlands. Just over forty percent of the 10.5 km^2 catchment has been zoned urban. The lake system is a modified natural wetland which has five cells whose functions range from sedimentation, pollutant entrapment and transformation, to storage for flow attenuation (Braid & Lavery, 1996). This constructed wetland system was the most complex in design in Western Australia with an estimated residence time of six days.

The primary nutrient removable objective of the Bartram Rd Buffer Lakes was to reduce phosphorus concentrations by 30%. The report by the Technical Review Committee for the Jandakot Drainage Management Scheme suggested that there was no significant difference between inflow and outflow concentrations at Bartram Rd. However, this report did not provide information on the statistical power of the monitoring programme, hence it was difficult to make a definitive conclusion on the effectiveness of the constructed wetlands for pollutant removal.

4.1.2 Monitoring

Monitoring data recorded in 1994 and 1995 at Bartram Rd show large variations in CRE. Analysis by Fuller and Dean (1995) for 1994 showed large variations in CRE, with seasonal CRE in the range of -4.79% for filterable reactive phosphorus to 43% for nitrite and nitrate. The periods of maximum and minimum CRE corresponded to the maximum and minimum flows respectively (Braid & Lavery, 1996).

While a net retention of all other measured contaminants was observed investigations in 1995 indicated that the system was not performing well with regard to phosphorus during the study period (Braid & Lavery, 1996). It was suggested the phosphorus removal objective may be achievable with design modifications.

4.1.3 Design critique

A number of problems were associated with the lining of the Bartram Rd ponds with bauxite residue. Soil amendment may be less effective for removing nutrients from stormwater unless used as a filtration medium. Braid & Lavery (1996) found that the bauxite residue amended substrates in cells 1, 2 and 3 were unevenly mixed. Also, the easy resuspension of red mud with light rains was noted by the amount of red mud washed into the basins by relatively minor embankment run-off. This dispersive effect of rainwater on the red mud is consistent with the physio-chemical properties of clays (Jeffrey, 1996).

Vegetation translocating was caused by removing a strip which created a channel for water to flow through, effectively short-circuiting cell 4 (Braid & Lavery, 1996). Rhodamine dye studies identified dead zones and channelling of water within individual cells. It was estimated that the hydraulic residence time was 6 days, a factor of four less than the theoretical time. It is possible that this was connected to the short-circuiting that resulted from channel flow.

Much of the phosphorus in Perth stormwater is present in dissolved form or as fine colloids that are less than 45μm (Douglas, 1993). This high ratio of very fine or dissolved phosphorus generally does not settle out with longer residence times unless it becomes adsorbed onto settleable particulate material or is precipitated out of solution. Together with poor outflow mechanics, this was likely to be one of the main reasons that phosphorus levels were not effectively reduced in the Bartram Road Buffer Lakes. However, it was difficult to determine the effectiveness of the system because of the lack of statistical power of the monitoring programme.

The high level of organic acids (humic and fulvic acids) in stormwater at this site resulted in a highly coloured solution. This colouring (gilvin) reduces the penetration of sunlight and consequently inhibits photosynthesis, which may have resulted in even lower nutrient removal performances.

Braid & Lavery (1996) report that no evaluation of the groundwater contribution to the constructed wetlands was made. It was also suggested that there were indications that groundwater contributions could have significantly reduced the treatment storage capacity, and thus the Hydraulic Residence Time (HRT). The HRT is expected to be further reduced as expanding urbanisation increases runoff volumes (Braid & Lavery, 1996). It should be noted, however, that the primary treatment objective for this system was the treatment of surface water, not groundwater.

In addition to this, Braid & Lavery (1996) determined that a surface area of 5.5 - 6 ha was required for more desirable loading rates to the constructed wetland. The surface area that existed was only 3.2 ha, almost half of that recommended.

In summary, an adequate judgement of the CRE of the Bartram Rd Buffer Lakes was not possible because of monitoring inadequacies, yet short circuiting and an insufficient HRT appear to be limiting the system's efficiency.

4.2 Hird Rd

4.2.1 Background

The Hird Road Buffer Lakes are located in the Jandakot district, approximately 40km south of Perth and 3km north of the Bartram Road wetland system. They consist of a detention basin connected to a degraded natural wetland. The system treats stormwater from a recent urban housing development.

4.2.2 Monitoring

Very limited monitoring data was available for the evaluation of the Hird Road system. Evaluation of results of rigorous monitoring programmes can be complicated by the seasonal fluctuations of CRE, this variability is largely dependant on the buffering capacity of assimilation processes within the wetland. The lack of baseline data for the Hird Road wetland has made definitive statements regarding the effectiveness of the system for nutrient removal even more difficult.

It has been suggested that the wetland acted as a source of all nutrients tested during the 1995 study period (Braid & Lavery 1996). It was also claimed that the CRE was negative to the extreme for total phosphorus, FRP and total Kjeldahl nitrogen. However, a more extensive monitoring programme is required in order to have the statistical power to make valid statements about the long term performance of the stormwater treatment facility.

The values obtained by Braid & Lavery (1996) were reflected by the imbalance in favour of discharge volumes. Flow data for Hird Road indicated that two-thirds of the water budget was from groundwater contributions. Water quality monitoring in 1994 also indicated that the wetland was a source of nutrients, rather than a sink.

4.3 Russell St

4.3.1 Background

The Russell Street basin is located in the suburb of Morley, approximately 10km northeast of Perth central. It is essentially a single cell, square wet detention basin with minor planting and bathometric alterations. The Russell Street Wetland was not intended as a pollutant control feature alone, but was also designed for its amenity value and for wetland re-creation. There was also a need to provide larger peak storage at this site, and this lead to the retention of the outlet invert level, since enlarging the compensating basin was not possible. The outlet invert level is about 500mm below the AAMGL and this in turn flows much more groundwater containing more nutrients into the basin. In addition, and more importantly, raising of the outlet invert level is not possible unless flooding is allowed to occur in the catchment.

One of the target objectives for pollutant removal was to reduce phosphorus by 50% and to achieve a seven day HRT. Despite this objective, the multiple design purpose of the system means that it should not be viewed as a working example of a wet detention basin, but rather may be used as an example to highlight the shortcomings of the system for nutrient removal.

4.3.2 Monitoring

To date, there have been no comprehensive performance evaluations published for the Russell Street wet detention basin. Results of the Braid and Lavery (1996) study for the sampling period 28 - 31 August 1995, showed that the CRE was negative for all analyses except for Filterable Reactive Phosphorus (FRP) and lead. The concentration and loading of FRP and lead was very low for the period and the residence time for stormwater in the basin was also significantly less than the design objective.

Rhodamine dye studies carried out by Braid & Lavery (1996) determined that the HRT was significantly less than the design objective. Short circuiting was observed to occur as the island was flooded during periods of moderate or high flow. The surface area of the basin was only 1% of the catchment area, much less than that recommended.

In summary, it was concluded that the Russell Street basin was under-designed to achieve consistent nutrient removal in any form (Braid & Lavery, 1996). Once again a lack of monitoring data confounded an appropriate evaluation, but the system was considered to be immature with insufficient HRT, and short circuiting.

4.4 Ellenbrook

4.4.1 Background

Woodlake Village Lake was the first of the wet detention basins to be constructed at Ellenbrook. The detention time in the lake was in the order of several days and the performance objective was to remove 15% of particulate phosphorus.

4.4.2 Monitoring

Jim Davies & Associates (1996) undertook water quality sampling of inflow and outflow from Woodlake Village Lake in June, August and September 1996 to provide baseline data for monitoring in future years. During a storm event in September the particulate phosphorus load was 0.020kg while that for the outflow was 0.023kg. The higher outflow load was thought to be associated with inflow of particulate phosphorus due to previous rainfall. However, the lack of statistical power of the monitoring programme meant that the difference observed may not have been significant.

The effectiveness of the detention basin at removing nutrients and its performance relative to the criteria specified in the Drainage and Nutrient Management Plan for the area could not be determined as there was insufficient data (Jim Davies & Associates, 1996). A more intensive monitoring programme is required so that the effects from previous inflows to the lake can be accounted for and to ensure that the inflow and outflow are both monitored for the same event. It would also enable the relationships between pollutant input and output concentrations to be determined and allow an accurate view of possible seasonal variability. A good monitoring programme is required to have the statistical power to make valid statements about the long term performance of the stormwater treatment facility (Gilbert, 1987).

One of the contingency plans in the Drainage and Nutrient Management Plan for the future wet detention basin was to amend the substrate. It should be noted that this is not expected to increase the effectiveness of phosphorus removal unless the basin will be used as an infiltration retention system.

4.5 The Spectacles

4.5.1 Background

The Spectacles are a natural, semipermanent wetland system located within the East Beeliar Chain of Wetlands approximately 8km east of Kwinana Beach. They represent approximately 10% of the catchment area and is located near the top of the catchment. Importantly, the wetland has a long HRT which is likely to be weeks rather than days as there is no defined channel through the wetland, is well vegetated with both fringing vegetation and closed Melaleuca woodland and is a very mature system. The wetland receives effluent from agricultural and residential land uses to the north.

4.5.2 Monitoring

Chambers & Hale (in press) have been studying the efficiency of the Spectacles wetlands at removing nutrients, focusing in particular on the removal of nitrogen and phosphorus. The wetland was very effective at removing both of these nutrients (Table 4.1).

While high concentrations of nutrients entered the Spectacles, there was a low rate of flow within the wetland. This, together with the large area relative to the catchment and fringing vegetation was likely to account for its high nutrient removal efficiency.

4.6 Constructed and natural wetlands in the Peel Harvey estuary

Investigations into three natural wetlands in the Harvey Estuary Catchment, Western Australia (Chambers et al., 1993), showed a positive correlation between the amount of fringing vegetation removed and the phosphorus concentrations in the water. This trend may have been a result of nutrient uptake by fringing vegetation or a reflection of the amounts of fertilisers applied to surrounding areas. Phosphorus was, on mass, highest in the surface sediments in undisturbed systems. This may have been low molecular weight, stable 'native' organic compounds with high phosphorus content that was very tightly bound and not available (Allen, 1986). Disturbed wetlands have more carbon, silt and organic matter with less total but more available phosphorus.

The use of vegetation to intercept runoff entering agricultural drains was discussed by Chambers et al. (1993). It was suggested that phosphorus reduction would be achieved in all but high flow rates. It was also noted that the wetland plants would play a significant role in reducing flow rates. Small experimental systems by Chambers et al. (1993) that used wetlands plants and substrate showed significant phosphorus removal from inflowing water, with the degree of removal dependent on concentration of phosphorus and flow rates.

The use of artificial wetlands at the outlet of swamps and major drains was also discussed by Chambers et al. (1993).

Table 4.1: Nutrient Removal by the Spectacles Wetlands

	Total Phosphorus	Phosphate	Total Nitrogen	Ammonium N	Nitrate N
1994					
Inflow	599	422	5,818	245	3,031
Outflow (kg)	210	53	1,710	27	210
% Removal	**65**	**87**	**70**	**89**	**93**
1995					
Inflow (kg)	615	286	3,962	164	2,173
Outflow (kg)	84	31	1,412	16	18
% Removal	**86**	**89**	**64**	**91**	**99**

(Chambers & Hale, in press)

The major problem raised is that in a Mediterranean climate, large volumes of water flow from the catchment in a short time during heavy winter rains. Therefore, to achieve desirable retention times, constructed wetlands would require a very large area. However, experimental evidence is showed that in moderate flow rates (4000 m^3d^1) a significant phosphorus reduction may have been achieved.

4.7 Summary

All three of the constructed wetlands studied by Braid and Lavery (1996) were observed to be poor at removing nutrients entering the wetland, phosphorus removal in particular was low. The Bartram Road System was effective in nitrogen removal (30%) but yielded a net export of total phosphorus. Insufficient data were available to determine the effectiveness of the Woodlake Village Lake. Constructed wetlands in the Peel - Harvey catchment were able to remove significant amounts of phosphorus (71%) at moderate to high flow rates (Chambers et al., 1993).

The poor performance of the constructed wetlands in urban catchments was attributed to non compliance with design specifications (Table 4.2). Residence times were lower than designed for all three wetlands, notably by a factor of four for the Bartram Road and Hird Road wetlands, with channelling of flow one of several flaws in the design of each of the constructed wetlands and basins. In addition, the contribution of groundwater to each of the wetland sites was not acknowledged or quantified in the design. It was therefore not possible to determine whether the groundwater diluted or concentrated surface flows, which in turn made accurate performance evaluation difficult (Braid and Lavery, 1996).

In contrast, the Spectacles, a natural wetland, was highly efficient at removing both nitrogen and phosphorus. This efficiency was attributed to the wetlands low rate of flow, large area relative to its catchment and dense fringing vegetation. Natural wetlands in the Peel-Harvey Estuary act as collection sites for phosphorus from surrounding farmlands (Chambers et al., 1993).

Vegetation assemblages were recognised as a nutrient sink in both natural and constructed wetlands (Chambers & Hale, in press; Braid & Lavery, 1996). Braid and Lavery (1996) concluded that in addition to their potentially substantial contributions to the total nutrient store, wetland vegetation contributes to controlling flow patterns, which may have increased the potential for nutrient uptake and transformation, and increased soil-water-plant interactions, especially in low flow conditions.

Inflows and outflows used to determine the performance of wetlands and basins need to be carefully correlated (Kadlec & Knight, 1996). The overall performance evaluation of these BMPs needs to be determined on the smallest feasible time scale if a realistic estimate of CRE is to be gained. Long term, average estimates may well disguise periods of exceptional inefficiency or efficiency. The seasonal variability needs to be defined in mature systems to asses long term performance and stochastic patterns of variation. Monitoring programmes need to take account of seasonal variability in the discharge/ concentration relationship.

In conclusion, to be effective at nutrient removal, constructed wetlands and wet detention basins should:

- Meet design specifications for area, hydraulic retention time, flow patterns and hydraulic outflow control as detailed in the Stormwater Quality Management Manual.
- Utilise vegetation for controlling flow, reducing short circuiting and aiding in nutrient uptake and transformation.
- Consider potential groundwater interactions.
- Ensure careful analysis and correlation between inflow and outflow monitoring data

Performance auditing of constructed wetlands and wet detention basins should take these requirements into account.

Table 4.2: Comparison of Constructed Wetlands With Design Criteria

Design Parameter	**Russel St**	**Hird Road**	**Bartram Road**
Surface Area ratio between 3-5% of catchment area	No	No	No
Minimum aspect 2:1	Yes (unless island inundated)	Yes	Yes
Vegetation to open water ratio	low	low	moderate
Gentle batters (>1:6)	No	No (constructed cell) in limited areas	No
Basin design to avoid channels	Yes	No	No
Substrate Amelioration	No	No	Yes (red mud & natural peat areas)
System complexity	Simple	Moderate (2 cells)	Complex (5 cells)
Preproject assessment	No	No	Partial
Compliance Audit	No	No	No

(Braid & Lavery, 1996)

5. Monitoring

5.1 General

Monitoring of water discharged from stormwater treatment facilities is required in order to effectively evaluate the pollutant removal efficiency of the system. The impact on the receiving environment to which the water is discharged needs to be considered, as well as potential health risks for humans which may arise from their use of the area for recreation or other purposes.

5.2 Criteria

Monitoring programmes need to take account of variability in each pollutant of concern. In the absence of any clear criteria for nutrient levels in stormwater runoff, a number of factors must be considered when developing a monitoring programme. These include:

- Observed or predicted hydraulic loads and pollutant concentrations
- Likely impact of seasons on loads and concentrations
- Flow/discharge relationships

Criteria for pollutant removal may be set using various methods, depending on the above factors. Percentage removal, maximum permissible loads or maximum concentrations can be used and further restrictions provided under specific conditions. For example, a particular pollutant may not exceed a specified concentration for certain amount of time. Alternatively, a combination of maximum concentrations and maximum permissible loads could be applied.

The lower a pollutant concentration, the more difficult it becomes to remove a set percentage of it. This is because the pollutant concentrations generally approach a minimum limit rather than be totally removed. For example, it would be easier for a catchment with very high pollutant concentrations to remove 50% of pollutants than one that is close to natural conditions. This would discourage the use of source control of pollutants as the end of line stormwater treatment facilities would appear more effective. For this reason, a blanket percentage reduction of pollutants should not be used.

If criteria set only limiting concentrations, this may lead to the use of groundwater for dilution purposes to achieve the desired concentrations. This may actually lead to an increase in pollutant loads even if lower effluent concentrations are achieved, especially if the groundwater already has a significant amount of pollutants. If only total load limits are set, there is no control of pollutant concentrations, which may adversely impact on the receiving environment.

5.3 Physiochemical monitoring

5.3.1 General

Physiochemical monitoring of a water body involves the measurement of physical properties such as temperature and pH, together with the analysis of the chemical constituents of the water. The following parameters may need to be monitored in both the inflow and outflow of the stormwater treatment facility:

- Flow
- Rainfall
- Conductivity
- Temperature,
- Dissolved Oxygen
- pH
- Suspended Solids
- BOD_5
- Nitrite, Nitrate, Total Kjeldahl Nitrogen, Ammonium, Total Nitrogen
- Filterable Reactive Phosphorus, Total Phosphorus

5.3.2 Monitoring programmes

The most common sampling procedure for nutrients involves the collection of surface grab samples. Weaver (1993) points out that sediment concentrations and associated constituents (eg total phosphorus) are often underestimated by this method, especially where there has been limited mixing. Larger, heavier particles are settled more quickly than fines and hence are concentrated in the deeper sections so they may be missed when grab sampling from the surface.

Monitoring programmes widely used in Australia have been based on fixed frequency sampling where samples are taken at predefined time intervals (eg weekly or monthly). The main problem with this form of sampling is that important events and concentration changes may be missed if they are not sampled. Weaver (1993) emphasises the importance of having a sampling frequency that varies with discharge as the concentration of solutes and particulates varies with discharge. Opportunistic sampling is another form of sampling that takes into account river flow or runoff events. Regular sampling intervals have been successfully used during low flow conditions but high flow events need to be accompanied by more intense sampling that takes account of flow rate but is not necessarily done at regular intervals. Flow proportional sampling utilises a fixed frequency sampling strategy but sub samples are mixed according to recorded flow data to give flow weighted concentrations.

When calculating loads, the interval (cell width) between sampling and the interpolated concentration values used for each cell has a significant effect on the calculated load. The accuracy of sampling data deteriorates rapidly as cell width increases, especially over 1 day, and varies depending on whether the mean, maximum, minimum or initial concentration is used (Weaver, 1993).

The Water and Rivers Commission (WRC) are in the early stages of a three year project that is field testing an automatic discrete sampling programme which enables the contaminant flux patterns to be determined. Prior to sampling, analysis of the flow characteristics must be undertaken using existing hydrographs. The automatic sampler can then be programmed to recognise whether a storm event has occurred by changes in flow/stage levels. Samples are collected individually as programmed into the machine and may be taken from the rising, peak and falling limbs of storm events. Samples are also taken on a fixed time interval between storm events.

The national riparian programme currently being undertaken by CSIRO uses auto samplers that are both fixed frequency and stage triggered. Samples are composited flow proportionately to reduce analytical costs. This method is a reasonable compromise between cost and accuracy. Low cost monitoring programmes have used flow proportional compositing of stage height samples and fixed frequency grab samples. Estimation in these types of low cost systems could be improved by defining the discharge/concentration relationship for early and later hydrographs.

After initial investigations, the monitoring programme can be designed for a predefined level of bias/precision or cost. After 18 months of sampling, the data obtained can be used to determine a more accurate sampling strategy, costs and bias/precision errors in the data. Statistics are used to determine uncertainties and trends in the data.

As part of performance monitoring the HRTs should be assessed as they will vary depending on hydraulic conditions and must be considered when comparing results. It should be noted that all monitoring programmes will be limited by seasonal variability, whether using a discrete or composite sampling system.

Two main problems associated with water quality sampling need to be given particluar attention: the ability to collect representative samples in terms of sampling locations and timing; and sources of error. Biased sampling can occur with both depth and position, temporal water quality variation also occurs from the effects of human activities and natural factors such as weather conditions (George et al, 1996). Sources or error include the contamination of the water sample at collection, and the modification during transport and storage.

Walker & Rueter (1996) provide the following general advice for water quality sampling:

- Water quality and flow conditions vary considerably both spatially and temporally. Although contaminant concentration is frequently used for assessing water quality, concentration is dependant on the flow conditions. Flow weighted comparisons should be compared when detecting trends to remove the influence of streamflows.
- Water samples should be taken so that they are representative of the water body. Stream samples should be taken close to the centre (horizontal and vertical) to avoid surface, bottom or edge layers.
- Water temperature should be recorded with all measurements as it may affect many physical and chemical parameters.
- In general, tests should be performed upstream and downstream of trouble spots, and where there are major differences in stretches of the stream.
- Tests should be performed every 3 weeks to establish seasonal trends, after which the suggested frequency is:
    - before and after storm events and,
    - before and after terrestrial or upstream practices that may affect water quality such as sewage works or clearing,
    - or at least 4 times a year.

5.4 Biological monitoring

5.4.1 General

Biological communities which are exposed to pollutants frequently act as integrators of environmental impacts. Physical and chemical characteristics of water bodies affect the abundance, species composition, stability, productivity, and physiological condition of aquatic organism populations. This attribute makes them useful as indicators for water quality change. Stressed aquatic systems often show a reduction in species richness, with the disappearance of sensitive or rare species, a predominance of pollution tolerant species, and a change in the number of individuals within a taxon, with a tendency towards becoming monospecific (Rapport 1991, cited in Walker & Rueter, 1996). Reliable indicators include species with narrow and specific tolerances to pollution, and they should ideally provide an indication or early warning of change, either at the ecosystem, population, or generic level (Walker & Rueter, 1996).

Biomonitoring of communities is considered by many to be the most sensitive means of detecting alterations in aquatic ecosystems. Caution should, however, be used to ensure that biological indicators are not be applied to geographical locations for which they were not designed (Walker & Rueter, 1996)

Eaton, Clesceri & Greenburg (1995) list a range of applications that biological monitoring may be used for:

- To explain the cause of colour, turbidity, odour, taste or visible particulates in the water.
- To aid in the interpretation of chemical analyses, for example, in relating the presence or absence of

certain biological forms to oxygen deficiency or supersaturation in natural waters.
- To identify the source of a water that is mixing with another water.
- To explain the clogging of pipes, screens, or filters, and to aid in the design and operation of water and wastewater treatment plants
- To determine optimum times for treatment of surface water with algicides and to monitor treatment effectiveness.
- To identify the nature, extent, and biological effects of pollution.
- To indicate the progress of self purification in bodies of water.
- To aid in determining the condition and effectiveness of unit processes and biological wastewater treatment methods in a wastewater treatment plant.
- To document the short and long term variability in water quality caused by natural phenomena and/or human activities.
- To provide data on the status of an aquatic system on a regular basis.
- To correlate the biological mass or components with water chemistry or conditions.

5.4.2 Indicator groups

Plankton

Plankton includes microscopic aquatic life forms which have little or no resistance to currents and live free floating and suspended in natural waters. This group includes phytoplankton (planktonic plants) and zooplankton (planktonic animals)

Phytoplanton in particular have long been used as an indicator of water quality. Because their life cycle is so short, they respond quickly to environmental changes. Some species flourish in highly eutrophic waters while others are very sensitive to organic and/or chemical wastes (Eaton, Clesceri & Greenburg, 1995).

Biological monitoring of plankton should be interpreted in conjunction with physiochemical and other data because of their transient nature, and often patchy distribution.

Periphyton

Periphyton are microorganisms which grow on stones, sticks, aquatic macrophytes and other submerged surfaces. This group includes zoological and filamentous bacteria, attached protozoa, rotifers, and algae, and the free-living microorganisms that swim, creep, or lodge among the attached forms (Eaton, Clesceri & Greenburg, 1995). These species are considered to be very useful in assessing the effects of pollutants on streams, lakes and estuaries.

Unlike the plankton which often do not respond fully to pollution in rivers for a considerable distance downstream, periphyton show an immediate response directly below pollution sources. Examples are beds of *Sphaerotilus* and other 'slime organisms' commonly observed in streams below discharge of organic wastes (Eaton, Clesceri & Greenburg, 1995).

The use of periphyton in assessing water quality is often hindered by the lack of suitable substrates at the desired sampling location. Furthermore, it is often difficult to collect quantitative samples from these surfaces. To circumvent these problems artificial substrates are usually used to provide a uniform surface type, area, and orientation.

Macroinvertebrates

Macroinvertebrates are defined as those invertebrates that are retained by a 500 μm mesh sieve. Macroinvertebrates which are used in monitoring activities generally comprise the immature stages of insects such as dragon and damsel flies, stoneflies, bugs, beetle and true flies.

The assessment of benthic macroinvertibrates forms the principal method of aquatic biological monitoring in Australia and overseas. The reasons for this are:

- The ability to select amongst the many invertebrate taxa in any aquatic system, according to the resolution required.
- The availability of many ubiquitous or widely distributed taxa, allowing elimination of non-ecological reasons why a taxon might be missing from an area.
- The functional importance of macroinvertebrates in aquatic ecosystems, ranging from secondary producers to top predators.
- The ease and lack of ethical constraints in sampling aquatic macroinvertebrates, giving numbers of individuals and taxa that can be handled.
- the ability to identify most aquatic macroinvertebrates to a meaningful level.
- The predictable and easily detectable responses of many aquatic macroinvertebrates to disturbances such as particular types of pollution.

Amphibians

Frogs and toads are good indicators of aquatic habitat quality and are easy to monitor in a non intrusive manner using their distinctive calls. Amphibians generally are particularly sensitive to pollution, partly because of breathing through their skin.

5.5 Suggested sampling sites

5.5.1 General

All of the suggested sampling sites below should have a monitoring programme that takes account of the seasonal variability and defines flow/concentration relationships for several hydrographs.

5.5.2 Bartram Rd

The Bartram Road Buffer Lakes should continue to be monitored intensively. The existing monitoring program should utilise the combined fixed frequency and stage triggered sampling procedure. Also, groundwater inputs and effects should be determined and design changes recommended by Braid & Lavery (1996) considered.

5.5.3 Ellenbrook

Woodlake Village Lake is the first of the detention basins to be constructed at Ellenbrook. This facility should be monitored intensively to determine its effectiveness at removing stormwater pollutants and to gather other valuable information from this new development. A detailed monitoring programme should be prepared to ensure consideration of all appropriate factors.

5.5.4 Welshpool Rd/Roe Hwy and other sites

The Main Roads Department is currently funding a research project with Murdoch University that has undertaken 1 year of basic monitoring of 6 sites including detention basins and constructed wetlands. The 6 sites monitored were the Roe Hwy /Welshpool Rd constructed wetlands (2 basins); Hamilton Interchange Basins; Erindale Rd/Kwinana Fwy Basin; Vincent St/Mitchell Fwy Basin. At this stage, only grab samples have been taken once a month to gain some insight into the range of pollutants at the sites and to collect some baseline data on them. As a clearer picture of the problems associated with the monitored sites is formed, the monitoring programme and resources will be reviewed and allocated accordingly.

It is recommended that the basins at the Welshpool Rd/ Roe Hwy constructed wetland should be monitored more thoroughly as it is the best example of constructed wetlands that the MRD have built.

New residential developments in Canning Vale that have included constructed wetlands and wet detention basins also provide a good opportunity for monitoring the impact of urban development on hydrology, pollutant concentrations and loads and the effectiveness of the constructed wetlands or wet detention basins for stormwater quality management. These developments include Livingston Estate, Ranford, Brooklands Green and The Avenues.

Other sites that may provide valuable information on the effectiveness of constructed wetlands and wet detention basins in Perth are presented in Table 5.1 below:

Table 5.1 Possible Monitoring Sites

Possible Monitoring Site	Suburb	Local Authority
Jackadder Lake	Woodlands	City of Stirling
Emu Swamp	Ballajura	Shire of Swan
Altone Park Lake	Beechboro	Shire of Swan
Fred Baldwin Lake	Kardinya	City of Melville
Shenton Park Lake	Shenton Park	City of Subiaco
Ron Stone Lake	Menora	City of Stirling
Dog Swamp	Yokine	City of Stirling
Lake Gwelup	Gwelup	City of Stirling
Shearwater Dr Lakes	Stirling	City of Stirling
Forrest Lakes	Thornlie	City of Gosnells
Tomato Lake	Kewdale	City of Belmont
Ascot Racecourse Lakes	Ascot	City of Belmont
Hyde Park	Perth	Town of Vincent

Further research

6.1 General

Investigations need to be made to determine which sediment/water quality parameters influence pollutant removal, especially FRP. This may be undertaken using stormwater and sediment collected at existing stormwater treatment facilities to determine the potential for nutrient reduction. If studies prove that the dissolved fraction of P is not reduced, then chemical flocculation and precipitation (of phosphorus) may be required.

It would also be useful to investigate the pollutant removal capacity, especially FRP, associated with suspended sediment that is transported by the first flush. This would allow a more accurate determination of the pollutant removal achieved as well as the extent of adsorption processes that may contribute to pollutant removal. If adsorption and subsequent settling of pollutants is found to be significant, the potential for desorption should also be investigated.

Studies similar to those completed by Grizzard et al. (1986) where laboratory settling results were compared with pollutant removal rates should also be undertaken. The settling column procedures used in such studies provide important information about stormwater characteristics that may be used for the evaluation of BMPs whose principle pollutant removal mechanism is sedimentation. Observations of pollutant removal by Grizzard et al (1986) and Randal et al. (1982), indicate that the pollutant removal process of sedimentation consisted of discrete and flocculent settling. They found that adsorption and flocculation processes increased the removal of pollutants over time.

Worthwhile investigation may include the potential for pollutant removal, especially FRP, from Perth stormwater samples when sediment from constructed wetlands/ detention basins is resuspended. If a riser system is used at the stormwater treatment facility, the resuspension effects may influence the removal of dissolved pollutants, especially during the first flush. However, this needs to be thoroughly investigated both in the laboratory and in the field. Also, the risk of releasing effluent with greater concentrations or loads than the influent should be investigated.

Additional field studies are required on how wetlands respond to stormwater input over time. This research is needed to develop reliable design techniques and for models to be developed that predict how various wetland designs will remove pollutants from stormwater, especially nutrients, under different climatic/hydraulic conditions. Relationships need to be determined between CRE and HRT and the seasonal variability defined.

Research should also be carried out on existing retention/ detention basins in Perth so that their pollutant removal performances may be compared to those from wet detention basins and constructed wetlands. These studies should be carried out in parallel with those on constructed wetlands. Urbonas and Stahre (1993) recommend that data on water quality, sediment accumulation, maintenance costs and other pertinent information be collected for a minimum of 5 years.

6.2 Stormwater research network

It is recommended that an informal Stormwater Research Network be established. This would be a coordinating body whose role would be to provide a forum for groups undertaking research and monitoring of stormwater runoff quality. The main aim of the group would be to increase awareness of research activities and other work being undertaken in the field of stormwater quality management by providing networking opportunities and increasing communication. This should lead to an exchange of information, resulting in uniform management standards, known levels of bias and precision, then more efficient research, identification of areas that require further investigation and improving the cost effectiveness of monitoring programmes.

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