Integrated Catchment Management Plan: Lake Richmond, Rockingham

City of Rockingham

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Rev No.	Author	Approved for Issue	Date
0	Ecoscape/Hyd2o	NR	Dec 2011
1	Ecoscape/Hyd2o	NR	March 2012

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Summary

Lake Richmond Reserve is approximately 77 hectares and is one of the largest freshwater lakes occurring in close proximity to the ocean. The surrounding land use is primarily urban development but also includes parks and reserves as well as some light industrial areas; therefore the reserve requires an integrated approach to its management and monitoring to ensure the values of the reserve are maintained.

Lake Richmond is a highly valuable conservation asset within the City of Rockingham that supports many biological and social values. The water quality of the Lake is an important factor to the survival of the two Threatened Ecological Communities that surround the lake (CALM 2000). Both of these TECs are nationally listed as endangered, meaning that they are at a very high risk of extinction in the near future. These TECs are the Thrombolite (microbial) community of the coastal freshwater lakes of the Swan Coastal Plain (Richmond-microbial) and the Sedgelands in Holocene dune swales of the southern Swan Coastal Plain (SCP 19). The water quality is also an important consideration to the variety of fauna that use the reserve for drought refuge, foraging and breeding habitat, such as waterbirds.

Environmental priority catchments were determined on the basis of existing and historical land use impacts, and the environmental and social values of the receiving environment. With developments in urban stormwater quality management having a shift of emphasis from attempts to trap pollutants, to a more fundamental philosophy of prevention is better than cure, there is greater emphasis on the use of non-structural controls and catchment management measures to reduce pollutant input, while still incorporating previously accepted water sensitive urban design (WSUD) measures and best management practices.

This Integrated Catchment Management Plan has identified environmental priority catchments and it is recommended that these be used as a basis for targeting areas for improvement works.

1.0 Introduction

1.1 Background

Lake Richmond is an urban wetland located in the suburb of Rockingham and is one of the largest freshwater lakes occurring in close proximity to the ocean. Lake Richmond and its associated reserve support many biological values including two nationally listed TECs, a vegetation community known as *Sedgelands in Holocene Dune Swales* and a Thrombolite community known as the *Richmond Microbial Community*.

Lake Richmond was also one of the wetlands chosen within the State of Environment Report for City of Rockingham (2005) as an environmental indicator for water quality with levels being required to be within Australia New Zealand Environment Conservation Council water quality guidelines (ANZECC 2000).

Historic water quality monitoring results indicate that the water quality of Lake Richmond may be in decline. In 2009, Ecoscape prepared the Lake Richmond Environmental Management Plan which contained an Action Plan that identified water quality monitoring as a high priority within Lake Richmond (Ecoscape 2009).

1.2 Objective

The objective of the Integrated Catchment Management Plan (ICMP) is to ensure that the conservation values of Lake Richmond are maintained or improved. This document will discuss ways in which water quality can be managed utilising best management practices and includes a range of recommendations to respond to the water quality issues that face Lake Richmond.

Specific objectives addressed within the ICMP are:

- Catchment Mapping
  - To identify surface water and groundwater boundaries
  - To identify current extent of stormwater drainage system and associated infrastructure
  - To identify historical and current land uses
- Water Quality
  - To identify possible causes and sources of pollutants
  - To provide recommendations for the management of water quality issues identified in the water Quality Study existing and potential pollutants
- Environment
  - To identify strategies and opportunities for enhancing and protecting environmental values

    - To provide recommendations for managing the Thrombolite community and riparian vegetation
- Social
    - To provide recommendations towards a community awareness programme
    - To provide a set of operational guidelines for fertiliser application within the catchment

1.3 About This Report

This study has been undertaken jointly by a team comprising of Hyd$_2$o (Hydrologists) and Ecoscape (Australia) Pty Ltd. Hyd$_2$o undertook the desktop review, catchment boundary and land use mapping for the ICMP, while Ecoscape culminated the ICMP report and provided the management recommendations within this report for the City of Rockingham.

As part of the process of undertaking the ICMP, a water quality monitoring program for 2011 was also undertaken by Ecoscape, which included the collation and review of all available historical water quality data for the lake. The outcomes of this water quality monitoring program and review are including in this report and are used to guide the management recommendations for water quality in this ICMP report.

2.0 Existing Environment

2.1 Location

Lake Richmond is an urban wetland located in the suburb of Rockingham, approximately 40 kilometres south of Perth, Western Australia (**Figure 1**). The reserve is approximately 77 hectares in area and is one of the largest freshwater lakes occurring in close proximity to the ocean.

The reserve forms part of the larger Rockingham Lakes Regional Park (CALM, 2003) and is part of the Perth Metropolitan Regional Linkages. The reserve is declared a Bush Forever site by the Western Australian Government (WAPC, 2000) and is linked to four other Bush Forever sites. Lake Richmond is protected under the *Environmental Protection (Swan Coastal Plain Lakes) Policy 1992* and is also recognised as a Conservation Category Wetland by the Department of Environment and Conservation (DEC, 2008). The reserve is on the City of Rockingham Municipal Heritage Inventory, is listed on the Register of Aboriginal sites by the Department of Indigenous Affairs (DIA) and is on the State Register of Heritage Places.

Figure 1: Location of Lake Richmond

2.2 Climate

The Perth metropolitan area is characterised by a mild Mediterranean type climate with hot dry summers and mild wet winters. The climate varies seasonally, with rainfall, temperature and winds following a well-defined annual cycle. The majority of the rainfall occurs in the winter months with most falling between May and August (BOM, 2011).

Historic temperature records from the Kwinana BP Refinery weather station located approximately 8km north of the study area; indicate that lowest temperatures are in July with an average daily minimum and maximum temperature of approximately 10.6°C and 17.7°C, respectively. Historic records indicate that highest temperatures occur in February with an average daily maximum of 29.3°C and average minimum of 19.1°C (BOM, 2011)

2.3 Landform

Lake Richmond reserve is gently undulating reaching an elevation of about 5 metres above sea level. The lake is a marine relic which was once part of the Cockburn Sound, but was separated from the ocean about 4000 years ago by the seaward advancement of the coastline.

Lake Richmond is located on the Quindalup Dune system, the youngest and most westerly soil system often referred to as the Safety Bay Sands. It overlies the Spearwood dune system which was formed over the last 10,000 years when the sea level began to rise (CoR, 2005).

2.4 Acid Sulfate Soils

The lowest portions of Lake Richmond Reserve are identified as having a high risk of actual acid sulfate soils (AASS) and potential acid sulfate soils (PASS) at less than 3m from the surface (WAPC, 2003).

AASS are generally naturally occurring soils containing sulfides that have reacted with oxygen to produce acids. PASS contain sulfides that have not reacted with oxygen, usually due to being permanently waterlogged. They produce acids when exposed to air by excavation, filling, creation of artificial water courses, or groundwater abstraction/dewatering.

If the groundwater level falls as a result of groundwater abstraction in the Warnbro Groundwater Area, there is the potential for sulfides to be released when layers of the soil that exist below the historic permanent water table are exposed to air (Strategen 2006).

2.5 Hydrology

Lake Richmond is a perennial freshwater lake that is fed by stormwater and groundwater and has become progressively fresher since 1970s (Naragebup, 2004). The lake is 1000m by 600m and up to 15 metres deep, but much shallower near the edges. Lake Richmond is located within the Warnbro groundwater subarea. The Superficial aquifer is unconfined and up to 30 metres deep, with recharge through infiltration and rainfall. It discharges into Lake Richmond as well as the ocean and into the Rockingham Sand aquifer through downward leakage (DOW, 2007).

Lakes Richmond, Cooloongup and Walyungup are the only wetlands in the Rockingham Groundwater Area that have been monitored by the Department of Water prior to the 1970s. Monitoring data indicates that lake levels have declined about two metres since monitoring began in the 1920s (DOW, 2007). For the period of 1945-1975 Lake Richmond declined up to 0.5 metres but has been stable from 1975 to 2005, which is probably due to the construction of an outlet drain in 1968 by the Water Corporation.

Occasionally since the late 1980s water levels have been below the staff gauges in all wetlands, which makes it difficult to determine trends. Subsequently the DOW (2007) has recommended monitoring points to be moved to enable measurement of low water levels.

The extent of the surface water catchment contributing flow to the lake is discussed in **Section 6.4**.

2.6 Vegetation

Heddle et al (1980) mapped broad vegetation boundaries of the Swan Coastal Plain which are based on geomorphological units. The vegetation of the Lake Richmond area has been mapped as the Quindalup Complex which is described as coastal dune vegetation consisting of the foredune species and stable dune species with local variations such as Melaleuca lanceolata and Callitris preissii low closed forest and Acacia rostellifera closed scrub. A vegetation survey undertaken by Ecoscape (2008) identified seven vegetation types within the reserve which consist of coastal species. The vegetation varied from sedgelands surrounding the lake, shrublands and woodlands. The sedgeland occurring at the reserve is identified as the Threatened Ecological Community SCP19.

2.6.1 THREATENED ECOLOGICAL COMMUNITIES

There are two Threatened Ecological Communities (TECs) occurring at Lake Richmond Reserve (English & Blyth 1997):

1. Richmond- microbial: Thrombolite (microbial) community of the coastal freshwater lakes of the Swan Coastal Plain
2. SCP19: Sedgelands in Holocene dune swales of the southern Swan Coastal Plain.

Thrombolites are ‘microbialites’, which are organosedimentary structures formed by the growth and metabolic by-products of benthic communities. Lake Richmond is one of the few places in the world where ‘living rocks’ grow and are a modern example of structures that dominated the world’s oceans 600 million years ago (DEWHA 2007; Rockingham Regional Environment Centre 1998). The growth of the thrombolite community is dependent upon light and the continuing supply of fresh water rich in calcium, bicarbonate and carbonate (CALM, 2000; DEWHA 2007).

Surrounding the Thrombolites is the 'critically endangered' Sedgelands in Holocence dune swales vegetation community which acts as a buffer to the thrombolites. Only about 20 percent of the original extent of the sedgeland community remains in the Rockingham area. The health of the sedgeland community is also important to maintain the health of the thrombolites. Some of the threatening processes to the survival of the sedgelands include clearing, hydrological changes and changes to groundwater quality. The survival of the sedgeland community is dependent on an increase in the area of the community, maintenance in species composition and diversity and maintenance of water quality and water levels.

2.7 Fauna

Lake Richmond provides important habitat for a variety of bird species. It is a perennially fresh lake which provides drought refuge for birds in the summer and the shallow edges are a feeding ground for waders. 109 bird species have been recorded at Lake Richmond (Naragebup NRM Office 2004). There are also 12 bird species that have been recorded at Lake Richmond that are recognised under the Japan Australia Migratory Bird Agreement (JAMBA) and China Australia Migratory Bird Agreement (CAMBA) (Ecoscape 2008).

Surveys for fish have been conducted in 1998 and 2004 (Rose, Morgan & Gill 2004). These surveys found two native and two introduced fish species and an introduced crayfish, the yabbie.

A survey for benthic macroinvertebrates by David Cale in 1998 (Rockingham Regional Environment Centre 1998) found 20 taxa which were typical species of the Swan Coastal Plain wetlands. The macroinvertebrates were found in the shallow edges of the lake and none in the deeper parts which was possibly due to the anaerobic sediment conditions.

Other species that have been sited at the reserve include (Naragebup NRM Office 1998):

- The Long Necked turtle (*Chelodina oblonga*)
- Five species of frog:
    - i) Motorbike frog (*Litoria moorei*)
    - ii) Banjo frog (*Limnodynastes dorsalis*)
    - iii) Moaning frog (*Heleioporus eyrie*)
    - iv) Marbled Burrowing frog (*Heleioporus psammopjilus*)
    - v) Glauert's Froglet (*Crinia glauerti*)
- Two Species of snake:
    - i) Tiger snake (*Notechis scutatus*)
    - ii) Dugite (*Pseudonaja affinis*)
- Bobtail (*Tiliqua rugosa rugosa*)
- Gould's Monitor (*Varanus gouldii*)
- Racehorse Monitor (*Varanus tristus*)

- Fence Skink (*Pogona Minor*)
- Burton's Legless Lizard (*Lialis burtonis*)

The water quality at Lake Richmond would be an important factor in maintaining the fauna habitat for the species that use the lake.

2.8 Land Use

2.8.1 HISTORICAL LAND USE

Lake Richmond is a site of historic and current social and cultural significance. In 1992 the Australian Heritage Commission listed Lake Richmond on the register of National Estate. It is also listed as an Aboriginal site for ceremonial and artefact significance. The lake was once an important source of food, water and shelter for traditional Aboriginal groups. Since European settlement the site was used for grazing by pioneer farmers till about the 1920s (Naragebup NRM, 1998). Around the 1960s it became a site for recreation and in 1977 the first biological survey was conducted by the Western Australian Naturalists Group (Naragebup NRM, 1998). Today the reserve continues to be a site of social significance providing the community an area for recreation, education and conservation opportunities.

2.8.2 DEVELOPMENT

Residential urban development surrounds the reserve with Anchorage Estate being the most recent residential development in the vicinity of the reserve.

The Cape Peron Marina (Mangles Bay Marina) is a new development proposal which is proposed to cater for increased boating pressure within the City of Rockingham, and is approximately 200 metres from Lake Richmond (Worley Parsons 2005). Worley Parsons has undertaken a groundwater impact assessment to identify the potential hydrological impacts the development could have on Lake Richmond and groundwater bores in the area. The proposed development is located on the Safety Bay groundwater mound which is an important recharge site for coastal groundwater regimes including Lake Richmond. The main areas addressed were impacts on water quality, particularly increased salinity and water levels of the lake and groundwater. Changes to these hydrological parameters may adversely impact the freshwater ecology of the lake. These impacts may result from; dewatering during the construction phase of the development and the inland movement of the saltwater-groundwater interface after development.

Advice from the Water Corporation indicates the majority of the urban area in the vicinity of the Lake to be connected to deep sewerage.

3.0 Review of Historical Water Quality Data

Lake Richmond Reserve was included as part of the areas urban drainage scheme in the 1960's and subsequently the former Water Board constructed three inlet drains and one outlet drain in 1968 (Naragebup NRM Office 1998). The inlet drains are on the north east and south east areas of the reserve and the outlet drain is in the north-west area. These drains collect runoff from the surrounding urban area and there are reflux gates on the outlet drain to prevent seawater entering the lake.

Prior to the 1960s the lake was saline with salinity ranging from 2000 to 3500 mg/L total dissolved salts (TDS). After installation of the drains, salinity reduced to 300 – 400 mg/L TDS (Strategen 2006).

Water quality was considered to have deteriorated between 1998-2004 based on an increase in phytoplankton scums and epiphytic growth on the thrombolites. This is likely to affect the condition of the thrombolites due to smothering and therefore blocking light and changed water chemistry (Rose, Morgan & Gill 2004).

To date a number of water quality programs have been undertaken at Lake Richmond but a consistent and coordinated seasonal monitoring program has yet to be implemented. At present both the Department of Water (DoW) and the Water Corporation (WC) do not conduct water quality monitoring for Lake Richmond.

The following is a summary of the monitoring programs that have been undertaken to date:

- DoW – twice yearly monitoring from 1970 to 1986, then once in 1995 (DoW 1995)
- Naragebup NRM office – three month monitoring period in the winter months in 2002 (Naragebup NRM Office 2003)
- MWH – conducted monthly monitoring from January 2010 to March 2011 (MWH 2010)
- RPS – conducted quality monitoring from 2001-2008 at various sites including the drains at Lake Richmond as part of the Anchorage Estate groundwater and surface water monitoring program (RPS 2008).

With respect to groundwater, there is limited data in the areas with the nearest DoW bore being located approximately 3km east of Lake Richmond. This DoW bore has recorded water level data since the mid 1970's, and no significant water quality data.

Table 1 summarises the previous water monitoring that has been undertaken at Lake Richmond Reserve (adapted from MWH, 2010). Locations of these monitoring sites are shown on **Map 1.**

Table 1: Surface water monitoring at Lake Richmond Reserve

Site ID	Site Name	Type of Monitoring	Date	Number of Readings	Agency/Ref
13662	Lake Richmond	Water level	1945 – current[1]	330	Department of Water
13662	Lake Richmond	Water quality	1970 – 1986	35	Department of Water
23002414	Lake Richmond outlet drain	Water level	2002 – 2003	10	Department of Water
23002414	Lake Richmond outlet drain	Water quality	2003	10	Department of Water
23015714	Mangles Bay drain	Water quality	2003[2]	20	Cockburn Sound Management Council
23015717	Rockingham North drain	Water quality	2003	2	Cockburn Sound Management Council
23015718	Rockingham Central drain	Water quality	2003	5	Cockburn Sound Management Council
23015720	Lake Richmond	Water quality	2003	1	Cockburn Sound Management Council
23015721	Lake Richmond	Water quality	2003	1	Cockburn Sound Management Council
23018873	Safety Bay SW drain	Water quality	2003	9	Department of Water
DO (formerly D1)	Water Corp Drain	Water quality	1999-2007[2]	47	RPS (2008)
D2	Water Corp Drain	Water quality	1999-2003[2]	26	RPS (2008)
D3	Water Corp Drain	Water quality	1999-2000[2]	12	RPS (2008)
D4	Water Corp Drain	Water quality	1999-2000[2]	11	RPS (2008)
D5	Water Corp Drain	Water quality	1999-2004[2]	38	RPS (2008)
D6	Water Corp Drain	Water quality	2001-2003[2]	11	RPS (2008)
LI	Lake Richmond in flow drain	Water quality	2001-2008[2]	39	RPS (2008)
LO	Lake Richmond out flow drain	Water quality	2001-2008[2]	30	RPS (2008)
MP	Water Corp Drain	Water quality	2001-2008[2]	34	RPS (2008)
MPW	Water Corp Drain	Water quality	2003-2008[2]	26	RPS (2008)
LR1	Lake Richmond	Water quality	2010[3]	8	MWH (2010)
LR2	Lake Richmond	Water quality	2010[3]	8	MWH (2010)

[1] Water levels have been recorded consistently since 1978

[2] Monitoring conducted on a quarterly basis for multiple water quality parameters, occasionally samples were not taken when surface drains were dry. Number of readings refer to number of days sampled

[3] Monthly sampling undertaken from Jan-Aug 2010 for multiple water quality parameters. Number of reading refer to number of days sampled.

3.1 Naragebup Lake Richmond Drain Outlet Water Quality Study (2003)

The Naragebup NRM office (2003) conducted a study of the water quality of the outlet drain at Lake Richmond to determine the level of nutrients entering into Mangles Bay and Cockburn Sound.

Monitoring was conducted over a three month period after the winter months in 2002. Results indicated that:

- pH was between 8.26-8.79 which is alkaline but expected due to the limestone geology of the catchment
- dissolved oxygen was above recommended levels for lowland rivers
- all nitrogen samples were above recommended levels for freshwater lakes
- total phosphorus was above recommended levels for freshwater lakes and lowland rivers
- toxicants such as heavy metals, oils and pesticides were below recommended levels for freshwater ecosystems except for zinc
- algal blooms were obvious during the survey in September, with high levels of toxic blue-green algae (*Microcystis cyanobacteria*). Scum was also observed around the shallow lake edges, particularly in reed beds in the north-west area of the lake. There was no evidence of the algal bloom during a follow up survey about a month later in October 2002.

It was surmised that total nitrogen and phosphorus level would make a significant contribution to existing levels if they entered into Mangles Bay, as the levels were above recommended guidelines for freshwater ecosystems (Naragebup NRM Office 2003). These levels were noted to be higher than those collected from the previous year by the WC. Water quality samples did not indicate a significant contribution of herbicides and pesticides although a few samples with high levels of phosphorus could be attributed to lawn fertilisers entering into the drains via stormwater runoff.

Table 2 is a summary of water quality results at Lake Richmond from the 2003 survey as presented in the State of the Environment report (City of Rockingham 2005). The water quality at Lake Richmond is used as one of the environmental indicators of the health of inland waters within the City of Rockingham.

Table 2: Lake Richmond Water Quality Results 2003

Nutrients	Lake Richmond indicators of water quality tested in 2003 ($\mu g\ L^{-1}$)	ANZECC Guidelines ($\mu g\ L^{-1}$)		Results
		F/water lake	Wetlands	
Nitrogen	650 to 840	350	1500	Exceeds guidelines for freshwater lakes but not for wetlands
Reactive Nitrogen (Nox)	12 to 25	10	100	Exceeds guidelines for freshwater lakes but not for wetlands
Total Phosphorous	12 to 30	10	60	Exceeds guidelines for freshwater lakes but not for wetlands
Filterable reactive phosphorous (FRP)	7 to 12	5	30	Exceeds guidelines for freshwater lakes but not for wetlands

3.2 MWH Cape Peron Water Quality Study (2010)

MWH (2010) conducted a monthly monitoring program from January 2010 to March 2011, with an interim report released in September 2010. Monitoring was conducted at two sites within Lake

Richmond as part of the approvals process for the Mangles Bay Marina. The monitoring program consisted of:

- water level monitoring
- water sampling
- stratification monitoring
- depth transects.

Results of the monitoring program undertaken by MWH indicate that (Strategen 2011):

- the maximum depth of the lake is 14.4m
- water quality is fresh to slightly brackish at the surface with an increase in salinity and a drop in pH below 8 metres in depth
- nutrient levels are slightly above ANZECC guidelines
- water levels varied from 0.1m AHD in January 2010 to 0.8m in August 2010.

3.3 RPS Anchorage Estate Water Quality Monitoring (2008)

The Anchorage Estate groundwater and surface water monitoring program was also undertaken from 1999-2008 during the development of the estate by the Australand Property Group. The main focus of the program was to protect the water quality and subsequently the survival of the thrombolites surrounding the lake. Surface water monitoring was undertaken on a quarterly basis from sites located along Water Corporation drainage lines (RPS 2008).

Results indicate that groundwater levels fluctuated seasonally and did not show any irregular trends which suggests that the development associated with Anchorage Estate has had minimal impact on groundwater levels.

Surface water results indicated that Total Nitrogen (TN) and Total Phosphorus (TP) exceeded ANZECC criteria at some monitoring locations. Contributing factors are likely to be attributed to the following:

- construction activities associated with the Anchorage Estate
- seasonal fluctuation associated with warmer temperatures which are favourable to nitrogen production
- lawn fertiliser from surrounding gardens and Public Open Space (POS).

The surface water drains entering Lake Richmond extend beyond the Anchorage Estate area and therefore nutrient input is likely to be from a wide range of sources.

4.0 Water Quality Monitoring Program 2011

The management plan for the reserve prepared by Ecoscape (2009) for the CoR identified water quality monitoring as a high priority action. While monitoring of the lake had occurred sporadically over the years as discussed in Section 3, no consistent program had previously been implemented. Ecoscape (2009) identified a seasonal monitoring program as being beneficial for the reserve, particularly with increased urban development pressures such as the Mangles Bay Marina proposal.

As part of commencing a continuing, more coordinated monitoring program for the lake, monitoring from four locations within the Lake was undertaken as part of the ICMP.

Surface water monitoring for 2011 was undertaken by Ecoscape on two occasions, once during summer on February 28 2011, and once during winter on August 10, 2011.

Monitoring was conducted at four locations, shown in **Table 3** and **Map 1**. The locations monitored for water quality by MWH from January – March 2011 are also shown in **Table 3** and **Map 1**.

Table 3: Coordinates of water quality sampling locations (MGA50)

Location	Easting (X)	Northing (Y)	Consultant
EcoLR1	379234	6426700	Ecoscape
EcoLR2	379055	6427391	Ecoscape
EcoLR3	378703	6427545	Ecoscape
EcoLR4	378806	6426899	Ecoscape
LR1	378787	6427116	MWH
LR2	379059	6427057	MWH

The eastern and southern sides of Lake Richmond collect surface water and groundwater via the WC main drainage system which comprises of a network of open drainage channels and an outlet drain on the northern side to Mangles Bay (RPS 2008). The locations of the four monitoring sites were provided by the City of Rockingham and were positioned on the edges of all sides of the Lake. One was located at the end of the stormwater inlet on the southern edge, one was close to the stormwater outlet drain on the northern edge, and one was in front of the boardwalk on the eastern edge and one on the western edge north of another identified drain point. The two MWH monitoring sites were located to the centre of the Lake.

4.1 Monitoring Parameters

Water quality parameters selected for monitoring include those that are believed to be important for thrombolite function as well as indicators of potential for groundwater and surface water contaminants. These parameters are listed in **Table 4**.

Table 4: Parameters tested at Lake Richmond 2010-2011

Water Quality Parameters	
pH	conductivity
colour	salinity
chlorophyll a (Chlα)	dissolved oxygen (DO)
turbidity (NTU)	total nitrogen (TN)
oxides of nitrogen (NOx)	ammonium (NHx)
total phosphorus (TP)	filterable reactive phosphate (FRP)
total dissolve solids (TDS)	total recoverable hydrocarbons (TRH)
Sulphate	Sodium
Potassium	Calcium
Magnesium	Chloride
Carbonate	Bicarbonate
soluble Iron (Fe)	Nitrate
Fluoride (F)	soluble Manganese (Mg)
soluble Silica (Si)	cation/anion balance
soluble Arsenic (As)	soluble Cadmium (Cd)
soluble Chromium (Cr)	soluble Copper (Cu)
soluble Lead (Pb)	soluble Mercury (Hg)
soluble Nickel (Ni)	soluble Zinc (Zn(

4.1.1 PHYSICAL AND CHEMICAL STRESSORS

A number of naturally-occurring physical and chemical stressors can cause serious degradation of aquatic ecosystems when ambient values are too high and/or too low. The following physical and chemical stressors are typically considered during water quality assessments and were part of the water quality analysis for Lake Richmond; nutrients, , dissolved oxygen, turbidity, colour, total dissolved solids (TDS), temperature, salinity, conductivity, pH and chlorophyll a (ANZECC 2000).

An excess of nutrients within a waterbody can stimulate nuisance growths of aquatic plants and measuring this can indicate how eutrophied (nutrient polluted) a waterbody is and how susceptible it will be to nuisance plant growths occurring (ANZECC 2000)..

The dissolved oxygen (DO) concentration measured in a waterbody reflects the equilibrium between oxygen-consuming processes (e.g. respiration) and oxygen-releasing processes (e.g. photosynthesis and the physical transfer of oxygen from the atmosphere to the waterbody). Measures of DO indicate whether there is a disturbance to these competing processes and defines the living conditions for aerobic (oxygen requiring) organisms (ANZECC 2000)..

The turbidity or 'muddiness' of water is caused by the presence of suspended particulate and colloidal matter consisting of suspended clay, silt, phytoplankton and detritus. Increased turbidity can reduce the light climate and change an ecosystem significantly. Measures of turbidity indicate the extent of catchment and riverbank erosion, and how much the light regime is being affected. Some suspended particulate matter arises from point sources such as sewage outfalls, industrial wastes (e.g. from pottery and brick making plants) and stormwater drains, but most arises from diffuse land runoff due to soil erosion. Turbidity is highly dependent upon flow, with very large increases noted during flood events (ANZECC 2000)..

Salinity or electrical conductivity (EC) are measures of the total concentration of inorganic ions (salts) in the water. EC is used to measure the total ion concentration in fresh and brackish waters. Freshwaters are generally considered to have an EC of less than 1000 µS/cm. Measures of salinity and EC indicate whether the chemical nature of aquatic ecosystems is being altered and provides a warning of the potential loss of native biota. Salinity and electrical conductivity are relatively simple methods that can provide a broad characterisation of the amount of dissolved inorganic material in a particular waterbody.

Aquatic ecosystem functioning is very closely regulated by temperature. Biota, and physical and chemical processes like oxygen solubility and hydrophobic interactions are sensitive to temperature changes. Temperature changes can occur naturally as part of normal diurnal (daily) and seasonal cycles, or as a consequence of human activities. Measures of water temperature indicate how much an ecosystem's normal temperature regime is being disturbed by human activities (ANZECC 2000)..

pH is a measure of the acidity or alkalinity of water and has a scale from 0 (extremely acidic) to 7 (neutral), through to 14 (extremely alkaline). Low pH can cause direct adverse effects on fish and aquatic insects, while pH changes (particularly reduced pH) can result in the toxicity of several pollutants (e.g. ammonia, cyanide, aluminium) to significantly increase (ANZECC 2000).

4.1.2 TOXICANTS

Toxicants is a term used for chemical contaminants that have the potential to exert toxic effects at concentrations that might be encountered in the environment. These can include Metals and Metalloids (As, Cd, Cr, Cu, Fe, Hg, Pb, Mg, Ni, Si, Zn), Non Metallic Inorganics (Ammonia, Chloride, Nitrate), and Hydrocarbons (Total Recoverable Hydrocarbons (TRH) C6-C9) (ANZECC 2000).

Other measurements included the cation/anion balance which measure; cations (such as calcium, magnesium, sodium and potassium) and anions (such as chloride, bicarbonate, sulfate and bromide). These can be used as tracers to determine groundwater input to a stream during high flow and low flow periods (Australian Government 2006).

4.2 Sampling Method and Analysis

Water samples were collected from approximately 0.2m below the water surface before being stored in an esky for transport to SGS Australia Pty Ltd for analysis as soon as possible after sampling.

SGS Australia Pty Ltd provided the bottles and preservatives to store the samples and also conducted the laboratory analysis.

4.3 Results

4.3.1 PHYSICAL AND CHEMICAL STRESSORS

Across all sample locations and sample dates, total nitrogen (TN) and total phosphorus (TP) were below the ANZECC guidelines for wetlands in Western Australia. However, all sites exceeded the TN trigger value associated with Freshwater Lakes in Western Australia and some sites (ECOLR01 and ECOLR04) exceeded the TP values associated with Freshwater Lakes in Western Australia (**Table 5 and 6**). The following parameters were also recorded as being lower than the ANZECC guidelines during both sampling periods; Conductivity, chlorophyll a, TSS and Turbidity, while pH levels were higher than the recommended range (**Table 5 and 6**).

Table 5: Lake Richmond Water Quality Results for Physical and Chemical Stressors (28 Feb 2011)

Nutrients	Lake Richmond indicators of water quality tested in 2011 ($\mu g\ L^{-1}$)				ANZECC Guidelines ($\mu g\ L^{-1}$)	
	ECOLR01	ECOLR02	ECOLR03	ECOLR04	F/water lake	Wetlands
Chl a	9.4	3.7	14	2.2	3 to 5	30
Total Phosphorus	<10	<10	30	<10	10	60
FRP	<2	<2	<2	<2	5	30
Total Nitrogen	840	820	940	830	350	1500
Reactive Nitrogen (Nox)	11	<5	<5	<5	10	100
NH_4^+	53	12	22	18	10	40
pH	9.0	9.0	9.1	9.1	6.5 to 8.0	7.0 to 8.5
Electrical Conductivity (µg/cm)	1100	1000	1000	1000	n/a	300 to 1500
TSS (mg/L^{-1})	<5	<5	<5	12	n/a	80
Turbidity (NTU)	1.3	0.9	1.3	1.4	n/a	10 to 100

Table 6: Lake Richmond Water Quality Results for Physical and Chemical Stressors (10 Aug 2011)

Nutrients	Lake Richmond indicators of water quality tested in 2011 ($\mu g\ L^{-1}$)				ANZECC Guidelines ($\mu g\ L^{-1}$)	
	ECOLR01	ECOLR02	ECOLR03	ECOLR04	F/water lake	Wetlands
Chl a	<5	<0.5	2	3.4	3 to 5	30
Total Phosphorus	40	10	10	20	10	60
FRP	8	<2	<2	<2	5	30
Total Nitrogen	730	550	850	790	350	1500
Reactive Nitrogen (Nox)	230	51	48	38	10	100
NH_4^+	46	34	35	27	10	40
pH	7.9	8.7	8.7	8.6	6.5 to 8.0	7.0 to 8.5
Electrical Conductivity (µg/cm)	650	980	990	1000	n/a	300 to 1500
TSS (mg/L^{-1})	<5	<5	<5	<5	n/a	80
Turbidity (NTU)	0.9	2.8	1.1	0.9	n/a	10 to 100

4.3.2 TOXICANTS

Within the ANZECC guidelines the trigger values for toxicants is derived using the statistical distribution method and calculated at four different protection levels, 99%, 95%, 90% and 80%. The protection level signifies the percentage of species that is expected to be protected. The highest level of protection (99%) has been chosen as the default value for Lake Richmond as it is of high conservation value (ANZECC 2000).

4.3.2.1 Metals and metalloids

The following metals recorded readings above the ANZECC guidelines for those that had trigger values: Arsenic, Cadmium, Chromium, Copper, Lead and Zinc. However, it was also noticed that iron levels were very higher at ECOLR01 during the August sampling and nickel levels were high at ECOLR03 during the February sampling (**Tables 7 and 8**).

Table 7: Lake Richmond Water Quality Results for Metals and Metalloids (28 Feb 2011)

Metals and Metalloids	Lake Richmond indicators of toxicants tested in 2011 ($\mu g\ L^{-1}$)				ANZECC Guidelines Trigger Values for freshwater ($\mu g\ L^{-1}$)
	ECOLR01	ECOLR02	ECOLR03	ECOLR04	(Level of Protection 99%)
Arsenic	<20	<20	<20	<20	1.0
Cadmium	<1	<1	<1	<1	0.06
Chromium	<5	<5	<5	<5	0.01
Copper	<5	<5	<5	<5	1.0
Iron	<20	30	<20	<20	ID
Lead	<5	<5	<5	<5	1.0
Manganese	<5	<5	<5	<5	1200
Mercury	<0.05	<0.05	<0.05	<0.05	0.06
Nickel	<5	16	<5	<5	8
Zinc	40	70	100	240	2.4

ID=Insufficient data to derive a reliable trigger value

Table 8: Lake Richmond Water Quality Results for Metals and Metalloids (10 Aug 2011)

Metals and Metalloids	Lake Richmond indicators of toxicants tested in 2011 ($\mu g\ L^{-1}$)				ANZECC Guidelines Trigger Values for freshwater ($\mu g\ L^{-1}$)
	ECOLR01	ECOLR02	ECOLR03	ECOLR04	(Level of Protection 99%)
Arsenic	<20	<20	<20	<20	1.0
Cadmium	<1	<1	<1	<1	0.06
Chromium	<5	<5	<5	<5	0.01
Copper	<5	<5	<5	<5	1.0
Iron	120	<20	<20	<20	ID
Lead	<5	<5	<5	<5	1.0
Manganese	8	<5	<5	<5	1200
Mercury	<0.05	<0.05	<0.05	<0.05	0.06
Nickel	<5	<5	<5	<5	8
Zinc	<10	<10	<10	20	2.4

ID=Insufficient data to derive a reliable trigger value

4.3.2.2 Non Metallic Inorganics

Both Ammonia and Nitrate levels were below the ANZECC guidelines when recorded during the February sampling (**Table 9**). However, Nitrate readings from the August sampling period showed a large increase in amount and levels that were above the ANZECC guidelines (**Table 10**).

Table 9: Lake Richmond Water Quality Results for Non Metallic Inorganics (28 Feb 2011)

Non Metallic Inorganics	Lake Richmond indicators of toxicants tested in 2011 ($\mu g\ L^{-1}$)				ANZECC Guidelines Trigger Values for freshwater ($\mu g\ L^{-1}$)
	ECOLR01	ECOLR02	ECOLR03	ECOLR04	(Level of Protection 99%)
Ammonia	53	12	22	18	320
Nitrate	<5	<5	<5	<5	17

Table 10: Lake Richmond Water Quality Results for Non Metallic Inorganics (10 Aug 2011)

Non Metallic Inorganics	Lake Richmond indicators of toxicants tested in 2011 ($\mu g\ L^{-1}$)				ANZECC Guidelines Trigger Values for freshwater ($\mu g\ L^{-1}$)
	ECOLR01	ECOLR02	ECOLR03	ECOLR04	(Level of Protection 99%)
Ammonia	46	34	35	27	320
Nitrate	970	230	210	170	17

4.3.3 ANION-CATION BALANCE

The anion-cation balance is based on a percentage difference between the total positive charge and total negative charges based on the ions Na+, K+, Ca2+, Mg2+, SO42-, Cl-, HCO3- and CO32. A negative number means there is an excess of anions or a lack of cations while a positive number means an excess of cations or a lack of anions. Lake Richmond is predominantly showing a negative number which can be attributed to the higher combined amounts of the anions (Sulfate, Chloride, Carbonate and Bicarbonate), compared to cations (Calcium, Magnesium, Potassium and Sodium).

A reasonable balance for routine water quality analysis is generally considered to be less than 5% difference. If there is a higher number, further analysis is recommended. The anion-cation balances for Lake Richmond are shown in **Table 11**. The breakdown of the ions contributing to the calculation of these results is shown in **Table 12 and 13**.

Table 11: Lake Richmond Anion-Cation Balance

Sampling Data	Anion-Cation Balance 2011 (%)			
	ECOLR01	ECOLR02	ECOLR03	ECOLR04
28 February 2011	1	1	-1	0
10 August 2011	-1	-3	-3	-2

Table 12: Lake Richmond Ions contributing to Anion-Cation Balance (28 Feb 2011)

Anion-Cation Ions	Lake Richmond indicators of toxicants tested in 2011 (mg/L)			
	ECOLR01	ECOLR02	ECOLR03	ECOLR04
Sodium	120	120	120	120
Potassium	6.4	6.9	6.8	6.9
Calcium	28	24	23	24
Magnesium	58	59	58	58
Sulfate	71	71	71	71
Chloride	190	190	190	190
Carbonate	27	26	30	28
Bicarbonate	210	210	210	200

Table 13: Lake Richmond Ions contributing to Anion-Cation Balance (10 Aug 2011)

Anion-Cation Ions	Lake Richmond indicators of toxicants tested in 2011 (mg/L)			
	ECOLR01	ECOLR02	ECOLR03	ECOLR04
Sodium	52	100	100	100
Potassium	3.8	5.9	5.9	6.0
Calcium	53	28	28	28
Magnesium	25	52	53	53
Sulfate	41	72	75	67
Chloride	86	180	180	780
Carbonate	<1	13	14	13
Bicarbonate	230	250	240	240

4.3.4 AROMATIC HYDROCARBONS

Benzene, toluene, ethylbenzene and xylenes are the simplest C6−C9 aromatic hydrocarbons. They are important and common aromatic solvents used for adhesives, resins, fibres, pesticides and ink, and in the rubber industry, as industrial cleaners and degreasers and as thinners for paints and lacquers (ANZECC 2000).

The high volatility and relatively low water solubility of these chemicals indicates that they would be rapidly lost to atmosphere from a water body, with none of these compounds expected to bioaccumulate. Most of the sites recorded less than 40 µg L^{-1} with site EcoLR01 recording a slightly higher reading of 56 µg L^{-1}, these results are within the trigger values stated in the ANZECC guidelines (2000).

4.4 Comparison to Previous Water Quality Data

Table 14 provides a consolidated summary and comparison for a range of water quality parameters for different monitoring periods via the various monitoring programs.

The summary table highlights the difficulty in providing any conclusive finding in terms of any continuing long term water quality trend on the basis of existing monitoring data. With respect of nutrient for example, the table indicates TP and TN water quality data as having a similar range of values in the 2011 program as recorded in early programs.

This represents a key finding of the 2011 monitoring program, and highlights the need for additional seasonal monitoring as an ongoing program for at least three years to provide the necessary information to inform the assessment of water quality trends, and identify pollutant sources toward improving water quality outcomes for the lake.

This finding is reflected in the approach contained in the ICMP strategy together with identifying likely priority areas for future works based on existing land use.

Table 14: Comparison of 2003 and 2011 Lake Richmond Water Quality Results

Nutrients	Lake Richmond indicators of water quality tested in 2003 ($\mu g\ L^{-1}$)	Lake Richmond indicators of water quality tested in 2011 ($\mu g\ L^{-1}$)
Nitrogen	650 to 840	350-940
Reactive Nitrogen (Nox)	12 to 25	<5 to 230
Total Phosphorous	12 to 30	<10 to 40
Filterable reactive phosphorous (FRP)	7 to 12	<2 to 8

5.0 Surface Water Catchments

5.1 Determining Catchment Boundaries

The existing surface water catchment of Lake Richmond comprises of a network of piped and open drainage and associated infiltration and compensating storages managed by the City of Rockingham and/or Water Corporation.

Catchment and sub catchment boundaries for Lake Richmond were determined based on the following available data:

- Existing local authority drainage network details provided by the City of Rockingham
- Water Corporation Main Drainage details
- Topographic data (1m contours) via the Department of Water's Perth Groundwater Atlas
- Aerial photography via the City of Rockingham
- Field verification of sub-catchments by Hyd2o

In some areas the City of Rockingham existing drainage network data was incomplete. To this extent catchment boundaries presented in this report should be considered indicative only for the purposes of this study and subject to further refinement if required and as more detailed survey and as-constructed information becomes available.

Sub catchment areas and key drainage features including storages and main drainage pathways are shown in **Map 1**.

The total catchment area of Lake Richmond is estimated as 1329 ha. This area is marginally less than that previously estimated by the Water Corporation as a number of sub catchments along the eastern edge of the mapped catchment boundary were previously included as part of the catchment by Water Corporation. As these sub catchments have been developed as infiltration areas, and do not effectively contribute any flow to the lake, these have not been included in this study.

A total of 79 sub catchments were identified, each with an assigned unique identifier for reference purposes. Individual catchment areas are tabulated in **Appendix 1**.

5.2 Classifying Sub catchments by Stormwater Disposal

For assessment purposes, surface water sub catchments were classified into four types, with each catchment assigned a classification based on how stormwater from the catchment is disposed of, effectively representing the potential for treatment of stormwater.

Sub catchments were classified as follows :

- **Compensated –** where the catchment flows to a compensating storage prior to discharge to drains conveying water to Lake Richmond
- **Uncompensated –** where the catchment flows to directly to a drain conveying water to Lake Richmond
- **Infiltrated – where the c**atchment drains to an infiltration basin or swale without any outlet.
- **No Formal Drainage –** when a catchment has no formal drainage and is infiltrated diffusely (eg foreshore and conservation reserves, areas without any piped drainage or formal drainage area)

Subcatchment classifications are shown in **Map 2**, with a catchment overview summary presented in **Table 15**. Note that catchments classified with the above drainage receiving environments may also contain soakwells to infiltrate stormwater at a lot scale or within some road reserves. The above classifications relate to the predominant receiving environment of the local authority and Water Corporation drainage network systems.

Based on the mapping, approximately only 9% of the area was estimated to be infiltrated or with no formal drainage system with the remainder of the catchment (91%) discharging to Lake Richmond. Conveyance of stormwater to Lake Richmond is therefore the most prominent method of stormwater disposal. Of the 1208 ha discharging to Lake Richmond approximately 62 % was found to discharge directly via the piped/open drainage network without any compensation.

Almost all catchments discharging to the lake are conveyed at least in part through open drainage.

Table 15: Surface Water Catchment Overview

Total Catchment Area (ha)	1328
Total No. of Subcatchments	79
Subcatchment Classification Area (ha and % of total catchment)	
Compensated	458.5 ha (34.5 %)
Uncompensated	749.3 ha (56.4 %)
Infiltration	46.6 ha (3.5 %)
No Formal Drainage	74.2 ha (5.6 %)

5.3 Assessment of Catchment Land Use

Land use within each catchment is shown in **Map 3** and was accumulated into 9 main categories :

- Residential Lots : <400 m2
- Residential Lots : 401-600 m2
- Residential Lots : <601-730 m2
- Residential Lots : >730 m2
- Road Reserves : Local

- Road Reserves : Regional
- Parks and Recreation : Active (including School Ovals)
- Parks and Recreation : Passive
- Commercial/Industrial

These categories were selected to enable identification of areas of likely high nutrient and metal input to the catchment, with the breakdown of lot sizing based on categorisations used in the Department of Water's recent publication Survey of Urban Nutrient Inputs on the Swan Coastal Plain (2010).

A breakdown of land use within each sub catchment is presented in **Appendix 1**.

Table16 presents a summary of land use types in relation to sub-catchment classification types. The key findings are summarised as follows:

- Approximately 51.2% of the catchment is residential lots, the vast majority of which are greater in size than 600 m2.
- Roads and road reserves comprise approximately 26.3% of the total catchment area. This represents a typical percentage for an urban residential area.
- Parks and recreation areas (including school ovals) comprise approximately 17.2% of the catchment, the vast majority of which are active areas.
- Commercial and industrial areas comprise 5.4% of the catchment.

These results are further interpreted in subsequent sections of this report in the context of developing priority water quality management areas and developing key strategy actions.

Table 16: Land Use Areas by Sub-catchment Classification Type

Land UseType	Compensated	Uncompensated	Infiltrated	No Formal Drainage	Total
	Area (ha) and % of Total Catchment Area				
Residential Lots : <400 m2	15.1 (1.1%)	40.5 (3.1%)	3.2 (0.2%)	0.2 (0.0%)	59.1 (4.5%)
Residential Lots : 401-600 m2	28.7 (2.2%)	9.1 (0.7%)	14.0 (1.1%)	0.1 (0.0%)	51.9 (3.9%)
Residential Lots : <601-730 m2	135.1 (10.2%)	207.0 (15.6%)	4.3 (0.3%)	3.6 (0.3%)	350.0 (26.3%)
Residential Lots : >730 m2	74.4 (5.6%)	141.2 (10.6%)	0.5 (0.0%)	2.6 (0.2%)	218.7 (16.5%)
Road Reserves : Local	108.7 (8.2%)	161.6 (12.2%)	10.5 (0.8%)	3.1 (0.2%)	284.0 (21.4%)
Road Reserves : Regional	13.3 (1.0%)	23.6 (1.8%)	0.0 (0.0%)	27.6 (2.1%)	64.5 (4.9%)
Parks and Recreation : Active (including School Ovals)	66.0 (5.0%)	107.2 (8.1%)	14.1 (1.1%)	3.1 (0.2%)	190.3 (14.3%)
Parks and Recreation : Passive	0.0 (0.0%)	4.5 (0.3%)	0.0 (0.0%)	33.7 (2.5%)	38.2 (2.9%)
Commercial/Industrial	17.3 (1.3%)	54.5 (4.1%)	0.0 (0.0%)	0.0 (0.0%)	71.8 (5.4%)
Total	458.5 (34.5%)	749.3 (56.4%)	46.6 (3.5%)	74.2 (5.6%)	1328.6 (100%)

6.0 ICM Strategy

6.1 Overview

Integrated Catchment Management (ICM) is the process of coordinated planning, use and management of water, land, vegetation and other natural resources on a river or groundwater catchment basis. It involves the whole community of the catchment including landholders, businesses, residents, local government and State agencies (Swan River Trust 1999).

The development of the strategy and recommendations presented in this Chapter are based on an appreciation of the catchment and its existing land use, and is reflective of the absence of sufficient consolidated water quality information to currently identify water quality trends and pollutant sources.

The ICM strategy details a framework for determining priority areas for water quality management on the basis of existing and historical land use impacts, and provides a range of suitable measures which can be applied to these areas.

Recommendations for ongoing monitoring are also provided.

6.2 Minimising the Cost of Pollutant Removal

Over the years urban stormwater quality management in Western Australia has seen a shift from attempting to trap pollutants, to a more fundamental philosophy of prevention.

Within the Department of Water *Urban Stormwater Management Manual for Western Australia* (2004), a greater emphasis is provided on strengthening the use of non-structural controls and catchment management measures to reduce pollutant inputs.

This approach has been largely based on attempting to maximise environmental benefits while minimising pollutant removal costs, and has been achieved by :

- recognising the diffuse nature of pollutant application in urban areas and the benefits that can be achieved via source control measures such as education
- an appreciation of pollutant pathways and improved understanding of the role of shallow groundwater on the Swan Coastal Plain in defining the water quality of receiving environments such as wetlands
- identifying that the early lifecycle consideration of pollutants in land use and landscape planning can significantly impact environmental water quality outcomes.

The strategy recommended for Lake Richmond follows an approach of minimising the cost of pollutant removal. To achieve this the strategy focuses on :

- Identification of priority catchments
- Application of source and non-structural controls
- Recommendations for a continuing targeted water quality monitoring program prior to larger scale expenditure on structural control measures.

Implementation of comparatively lower cost non-structural water quality control techniques are considered vital to improving the water quality entering Lake Richmond and within Lake Richmond itself.

6.3 Determining Priority Water Quality Management Areas

In the absence of detailed water quality data for individual drains and sub-catchments, priority water quality management areas were determined using a process of map overlay techniques (Hollick 1993) based on the following key indicators for stormwater quality for each sub-catchment.

- **Nutrients (Diffuse Source)-**Estimated nutrient input rates (Total Phosphorus and Total Nitrogen) for each sub catchment based on existing land use and DoW (2010)
- **Metals/Other Pollutants (Diffuse Source) -**Percentage of roads with each sub-catchment and percentage of current commercial/industrial land
- **Potential Point Sources of Pollution-**Potential point sources of pollution

These indicators were then analysed to identify target areas for future water quality management using both structural and non structural controls.

6.4 Potential Diffuse Sources of Pollution

6.4.1 NUTRIENTS

NuBalance is a model developed by Hyd2o to assist in land use management planning and allows a quantitative estimation of nutrient input rates for a catchment based on a proposed or existing land use.

It calculates the total expected nutrient input rate (Total Phosphorus and Total Nitrogen) for a particular catchment or development area based on aggregating individual nutrient inputs from different land uses (residential lots, POS, road reserves, industrial and conservation areas) using a recent detailed analysis of median residential nutrient input rates as presented in the Department of Water publication Survey of Urban Nutrient Inputs on the Swan Coastal Plain (DoW, 2010).

Sample model input and output from NuBalance are shown in **Appendix 2**. NuBalance outputs demonstrate the relative composition of total nutrient application by land use type.

NuBalance was applied to each sub catchment to model existing land use and identify likely areas of high nutrient input. Nine land use categories as previously described were adopted.

Results are shown in **Appendix 1**, with estimated total nitrogen and phosphorus input summarised in **Maps 4 to 7** as a rated input unit per unit area (kg/ha/yr) and as a % of total annual input per sub-catchment. Summarising the results:

- With regard to TN, the highest nutrient input rates typically related to residential areas with predominately 600-730 m^2 lot sizes. Median input rates in these areas were typically in the range of 60-80 kg/ha/yr.
- Lower input rates of TN per hectare are estimated in the areas in close proximity to the lake where lot sizes are predominately greater than 730 m^2. Median input rates of 40-60 kg/ha/yr are estimated for these areas.
- The lowest TN input areas were identified as the commercial areas and areas where residential lots were <400 m^2 in size.
- With respect to TP, a similar thematic pattern was evident based on land use, with the highest median input rate of TP in excess of 5 kg/ha/yr.

The overall input rate for nutrients to the whole of the catchment is estimated as 55 kg/ha/yr for TN (73,000 kg/yr) and 11 kg/ha/yr (15,000 kg/yr) for TP.

As a comparative reference point, the Peel Harvey Water Sensitive Urban Design (WSUD) Local Planning Policy (Peel Development Commission, 2006), requires all future subdivisional developments to have nutrient input rates below the current average estimated catchment input rates of 15 kg/ha/yr (TP) and 150 kg/ha/yr (TN) to be considered environmentally acceptable.

These application rates compare to the following rates reproduced from DoW (2010) for rural activities :

- Dairy : 145 kg/ha/yr (TN) 26 kg/ha/yr (TP)
- Annual Horticulture (vegetables) : 143 kg/ha/yr (TN) 127 kg/ha/yr (TP)
- Beef Grazing : 86 kg/ha/yr (TN) 13 kg/ha/yr (TP)
- Horses : 70 kg/ha/yr (TN) 13 kg/ha/yr (TP)
- Cropping : 47 kg/ha/yr (TN) 8 kg/ha/yr (TP)
- Sheep : 35 kg/ha/yr (TN) 3 kg/ha/yr (TP)

6.4.2 METALS AND OTHER POLLUTANTS

To provide a qualitative assessment of other pollutants such as heavy metals, the proportion of major roads and commercial/industrial land within each catchment was identified. The use of these variables as indicators are based on the assumption that road and carparking area sediments provide a potentially significant source of heavy metals including Cu, Pb, and Zn.

Mapping of major roads and commercial areas as a percentage of each individual catchment area is shown in **Map 8**. This mapping highlights the central eastern area of the catchment including the Rockingham City Shopping Complex and the two major roads (Rae Road and Read St) as the areas where higher metal inputs are likely to occur.

Similarly to the findings for nutrients, lower input rates are estimated in the areas in close proximity to the lake.

6.5 Potential Point Sources of Pollution

Three types of potential point sources of pollution were identified as shown in **Map 9**. These include:

- Petrol Stations
- Non-sewered areas
- Water Corporation's Ocean Outlet Wastewater Pipe

It should be noted that these are identified as "potential" sites only.

With respect to the Water Corporation's Ocean Outlet Wastewater Pipe, this is located along the northern shoreline of Lake Richmond and it is understood Water Corporation propose a duplication of this pipeline in the near future. This pipeline is located above ground.

With respect to infill sewerage, based on mapping for the South Metropolitan Area contained on the Water Corporations website, it is understood only area Rockingham 25B remains unsewered within the catchment. This area's construction status is specified as deferred. This area of approximately 20 ha is located immediately adjacent to the southern boundary of the lake.

A review of the Department of Environment and Conservation's Contaminated Sites database indicate there are no known sites within the catchment.

6.6 Priority Catchments for Water Quality Management Based on Land Use

Based on the above analysis, priority areas for water quality management based on land use are identified in **Map 10** with consideration of both potential structural and non structural controls:

a) **Target Areas for Diffuse Nutrient Input Reduction (Non Structural)**: This identifies areas based on existing land use, and where the highest TP and TN input rates per unit hectare (kg/ha/yr) are expected to occur. This information can be used to target priority areas for non structural controls, such as education campaigns, and effectively represent areas where higher nutrient input reductions per unit area can be expected to be achieved.

b) **Target Areas for Construction/Retrofitting of Structural Controls**: This identifies the catchment areas of overall highest nutrient input (kg/yr) and/or high likely metal input which currently do not infiltrate and are conveyed to Lake Richmond. This identifies the priority catchments were the performance of existing structural controls should be assessed and water quality outputs monitored to determine targeted opportunities for water quality improvements.

c) **Target Areas for Infill Sewerage**: Identified as the remaining area within the Lake Richmond catchment which currently operates on septic tanks and is non-sewered.

Using the above screening process it should be noted that some of the catchment areas directly adjacent to Lake Richmond do not receive a priority rating in Map 10. This occurs as a result of the existing land use within these areas (eg. lot sizes) meaning that these areas are likely to have a lower nutrient input than other areas. However this is not to say that these areas don't require control, but land use density indicates the areas as less of a priority than other areas where higher metals and nutrient input is likely.

Control efforts for the catchments immediately adjacent to the Lake are still recommended in **Table 20** and should focus more on weed eradication, revegetation, and education such as demonstration projects as well as pamphlets and information nights for surrounding residents on the different issues potentially impacting on the Lake.

6.7 Best Management Practices

The Water Corporation are responsible for the maintenance of the main drainage network entering and exiting Lake Richmond. To manage pollution entering the drains the Water Corporation advocate for the use of non-structural controls more, over structural control options. In the long term, prevention through education is more cost effective than structural options and their on-going maintenance.

The use of non structural controls also coincides with the philosophy of prevention more so than structural controls which focus on trapping pollutants.

Structural and Non Structural Controls considered for the study area in this ICM include :

6.7.1 NON STRUCTURAL

- Street sweeping
- Maintenance of storm water network
- Manual litter collection
- Litter bin design, positioning and cleaning
- Road pavement repairs/resurfacing and road runoff

- Maintenance of gardens and reserves
- Building maintenance
- Stormwater management on industrial and commercial sites
- Capacity building programs for local government and stormwater industry
- Landowner training on stormwater management
- Community Participation in stormwater management
- Education campaigns for commercial and industrial premises
- Focused stormwater education for new estates

6.7.2 STRUCTURAL

- Stormwater Storage and Use
- Infiltration systems (lot to regional scales systems)
- Conveyance systems (living stream, bioretention systems)
- Detention systems (constructed wetlands, dry/ephemeral detention areas)
- Pollutant Control (gross pollutant traps, trash racks, hydrocarbon management systems)

Further details on each of the non structural and structural water quality controls above are presented in **Appendix 3** based on the Department of Environment *Stormwater Management Manual for Western Australia* (2004).

This ICM recommends a combination of both non-structural and structural techniques is adopted and annual review of the maintenance activities in relation to water quality management be established.

Specific recommendations for implementation of measures in relation to priority areas are presented in **Section 7**.

6.8 Improving Lake Richmond Surrounds

6.8.1 WEED MANAGEMENT

Weed management is based on identifying and controlling existing weeds and the prevention of their reintroduction. Weeds impact on wetland ecology by competing, restricting regeneration and recruitment of native plants, reducing feeding, breeding and shelter for native fauna and increase the fire risk with greater fuel load.

Control options should aim to minimise the detrimental Impacts on native biota and are best undertaken in conjunction with bushland restoration programs. Within the Lake Richmond Management Plan (2008) there is a detailed list of weed species and recommended control methods.

Weed control options can be summarised as follows:

CONTROLLING ECOSYSTEM DEGRADATION PROCESSES

Controlling ecosystem degradation processes that increase ecosystem vulnerability to weeds is often the most effective long-term method of weed control. By simply introducing water quality management options as discussed in Section 5.2 it can reduce ecosystem susceptibility to weeds.

PHYSICAL BARRIERS

Physical barriers such as kerbing between riparian vegetation and lawn areas can reduce the level of grass invasion into areas of native vegetation. Establishment of dense stands of vegetation and the use of mulch can also reduce the rate of weed invasion into the wetland.

MANUAL CONTROL (PHYSICAL REMOVAL)

Manual control is often the most expensive method of weed control as it can be very labour intensive, however, it is generally the most appropriate method where there are small infestations in largely native bush areas. It is particularly valuable for small infestations when chemical control is inappropriate and the resources are available. Described in more detail within the Lake Richmond Management Plan (2008), when undertaking manual weed control, the Bradley method should be used, and revegetation or assisted natural regeneration should be undertaken in conjunction with weed removal. Hand-pulling of weeds can be as time efficient as spraying where low numbers exist in a localized, well vegetated area of bush and in these situations should be given priority over herbicide spraying.

CHEMICAL CONTROL (HERBICIDE)

Herbicide application is often the most cost-effective method for weed control. A wide range of herbicides are available for different weeds and are detailed within Appendix 6 of the Lake Richmond Management Plan (2008).

6.8.2 REVEGETATION & HABITAT CREATION

Revegetation improves water quality, both directly and indirectly through a number of mechanisms including the uptake and filtering of both nutrients and pollutants, releasing oxygen from the root zone conducive to decomposition of organic matter, nitrogen transformation, and discouraging the release of phosphorus (Swan River Trust 2003a).

Vegetation is also critical to habitat creation and the level to which waterbirds utilise Lake Richmond. In determining which plants are suitable for establishment in and around the stormwater inlets and Lake Richmond, consideration has to be given to the native plants occurring in water gaining sites within the vegetation complexes surrounding Lake Richmond. The Water Corporation acknowledges that sedge planting along drains is the best way to reduce nutrients and improve water quality. However vegetation growth needs to be monitored to avoid blocking the drains.

Table 17 below indicates a list of appropriate sedge and rush species and their recommended position for planting. Further details relating to revegetation options are contained in the Lake Richmond Management Plan (2008).

The Water Corporation supports the strategy of native sedge plantings along drains to reduce nutrient inputs (Davies pers. comms. 24-09-08) but suggest that regular monitoring of vegetation growth is required to ensure drains do not become blocked.

Table 17: Recommended species for revegetating along drains (WRC, 2001)

	Water depth	
Species	**Above water level**	**Shallow water (<0.5m)**
Sedges		
Baumea juncea	X	x
Baumea preissii	X	x
Baumea rubiginosa	X	x
Carex appressa	X	
Dielsia stenostachya	X	
Eleocharis acuta	X	x
Gahnia decomposita	X	
Gahnia trifida	X	
Ficinia nodosa	X	
Lepidosperma gladiatum	X	
Lepidosperma longitudinale	X	
Rushes		
Juncus pallidus	X	
Juncus subsecundus	X	
Hypolaena exsulca	X	x
Hypolaena pubescens	X	
Loxocarya cinerea	X	
Meeboldina cana	X	
Meeboldina coangustata	X	
Meeboldina roycei	X	x
Meeboldina scariosa	X	x

Reproduced via Ecoscape (2008).

6.9 Water Quality Monitoring

The purpose of water quality sampling at Lake Richmond is to determine what levels of pollutants are entering the wetland and if these levels are going to have a deleterious impact on the overall water quality and biodiversity of Lake Richmond.

In order to achieve this, the six monitoring sites (LR1, LR2, EcoLR01, EcoLR02, EcoLR03, EcoLR04) should continue to be monitored. These are spread around the Lake, with a focus on areas where drains are entering and exiting the wetland. Two sites are also near the centre of the Lake, which should provide an overall picture of the water quality within Lake Richmond.

Monitoring should occur on an 'events based' approach. This would require paying particular attention to large rain events and sampling directly after these. One way to achieve this could be to conduct a monthly monitoring regime through these seasons, commencing after the first flush. During summer and spring a one-off seasonal monitoring would be sufficient. How long the monitoring will continue for will mainly be determined by the available personnel and funding, however it is recommended that at least three years of continuous data is collected for analysis to be meaningful.

Tables 18 below summarises the monitoring program. Details regarding specific sampling methods are contained in Ecoscape (2011). Please note that the number of monitoring events is a guide only and is at the discretion of the City to conduct what they feel is sufficient. Annual reporting is recommended with a full consolidated report of all results and historical data at the end of the program.

Table 18: Lake Richmond Ongoing Monitoring Program Implementation Plan

Task	Water Quality Parameters	Timing
Monitoring sites of six sites (LR1, LR2, EcoLR01, EcoLR02, EcoLR03, EcoLR04)	pH, EC, TDS, Salinity Colour (specify true/apparent) Chlorophyll a Turbidity Full Nutrients TRH CO3, HCO3, CL and SO4 Fluoride 14 Heavy Metals Cations/Anions balance	1 in Summer 1 in Spring 3 in Autumn 3 in Winter
Reporting	-	**Annually**

7.0 Management Recommendations

Table 19 provides a consolidated summary of all key recommendations previously listed in this plan. It should be noted that the recommendations in this plan do not reproduce actions and programs already routinely undertaken by council in the day to day management of stormwater systems, but focus on the key outcomes and priorities identified in the previous sections of this document.

Table 19: Lake Richmond ICM Recommendation Summary

Area of Application	Water Quality Control Recommendations	Key Stakeholders
	Staged Monitoring Program	
Lake Richmond	**Stage 1 : Ongoing Monitoring Program** (refer Table 18 for detail) Duration : Ongoing, with annual reporting and program review	CoR (Consulant)
Priority Water Management Areas & Groundwater	**Stage 2 :Monitoring to Identify Specific Pollutant Sources** Based on outcome of Stage 1, develop a more targeted monitoring program of inflow drains with a focus on the identified priority areas for water quality management to identify specific pollutant sources. It is recommended this program would also extend to the assessment of groundwater quality via installation of several shallow water quality monitoring bores within the catchment.	CoR (Consulant)
	Improving Immediate Surrounds of Water Richmond	
Lake Richmond Surrounds	**Weed Management** As detailed in Section 6.8.1 and the Lake Richmond Management Plan (2008)	CoR (Consulant, NEC)
	Habitat Creation As detailed in Section 6.8.2 and the Lake Richmond Management Plan (2008)	CoR (Consulant, NEC)
Lake Richmond Surrounds	**Stormwater Outlets** Consider opportunities for retrofitting improved outlet arrangements and water quality controls on outlets for existing local authority pipe outlet drains to Lake Richmond, and use these works with interpretive signage to provide demonstration sites for the public for improved water quality management initiatives for the lake.	CoR (Consultant), DoW,WC, NEC, DEC
	Non-Structural Controls	
Subcatchments 1-3, 5-8, 14 -15, 18-21, 23, 25-31, 36-37, 51, 68, 73, 76-77 & subcatchments immediately adjacent to Lake	**Target Areas for Diffuse Nutrient Input Reduction** Based on land use assessment these subcatchments represent areas where the highest TP and TN input rates per unit hectare (kg/ha/yr) are expected to occur. It is recommended an education campaign be designed and implemented. The education campaign should also extend to catchments immediately adjacent to lake Richmond due to their proximity to the lake.	CoR,DoW, NEC
Whole Catchment	**Capacity Building** Ensure distribution and access to stormwater information (such as New Waterways) and participation in stormwater management training programs for all City of Rockingham personnel with responsibilities in stormwater management.	CoR,DoW
	Review of Management Operations & Programs Conduct an annual review of all operations related to stormwater management to identify opportunities for improvements.	CoR
	Structural Controls (Nutrients)	

Subcatchments 21, 24, 31, 37, 51, 55, 78,	**Retrofit Opportunity Identification & Implementation** Conduct an audit of the identified subatchments for stormwater quality BMP retrofitting and prioritise potential future works. Recommended focus is on treatment of frequently occurring events through biofiltration and infiltration where possible. Construction of identified BMP to be undertaken only following implementation of the Stage 3 monitoring program and review of water quality data analysis outcomes.	CoR (Consultant), DoW,WC
	Structural Controls (Metals)	
Subcatchments 16-17,40,67,34	**Retrofit Opportunity Identification & Implementation** Conduct an audit of the identified subatchments for stormwater quality BMP retrofitting and prioritise potential future works. Construction of identified BMP to be undertaken only following implementation of Stage 3 monitoring program and review of water quality data analysis outcomes.	CoR (Consultant), DoW,WC
	ICMP Review	
Whole Catchment	**Review and Update ICMP** Conduct a review of the ICMP after 5 years, and update the strategy to reflect the outcomes of the monitoring programs and implemented works, and account for changes in stormwater best management practice in the preceding 5 year period..	CoR (Consultant), DoW,WC, NEC, DEC

CoR : City of Rockingham

DEC : Department of Environment and Conservation

DoW : Department of Water

NEC : Naragebup Environment Centre

WC : Water Corporation

LRMP: Lake Richmond Management Plan

8.0 Funding sources

There are a number of external sources of funding in the form of grants and employment and training programmes. Grants and potential sources of funding for works in the study area are identified in **Table 20**. The following are online resources for funding:

- Grants Directory: http://grantsdirectory.dlg.wa.gov.au/
- Grants Search: http://www.grantsearch.com.au/ (requires a subscription fee)

Funding and grants are generally only available for specific projects, often with conditions such as the need to be community organisations or source matching funding, and prospects for being awarded funding by the same organisation numerous times for a single site are slim. Thus external grants cannot be relied upon as a substitute for the long-term management of the environment managed by government departments with access to recurrent funds.

Table 20: Funding Sources

GRANT/ORGANISATION	WHO CAN APPLY?	AMOUNT	GRANT INFORMATION
ANZ Staff Foundation	Not-for-profit organisations Endorsed by the ATO as deductible gift recipients and Income Tax Exempt Charity	Small 1 year grants <$50,000 Major 3-5 year grants >$50,000	ANZ Trustess has various grant categories such as: • Small grants < $50,000 (single year) • Major grants > $50,000 (up to five years) • Invited grants • Special initiative grants Web:http://www.anz.com/personal/private-bank-trustees/trustees/granting/granting-programs/ ANZ Trustees: 1800 011 047
Australian Bird Environment Foundation (ABEF)	Anyone	Up to$5,000	BOCA accepts applications for financial assistance for projects pertaining to Australian native birds and their habitats from any person or institution (whether public or private) to: • undertake research and investigation, eg study of the needs of birds in their habitat • carry out voluntary conservation work, eg improve or extend habitat for birds • develop and execute education and information programs; • develop management plans or techniques. Application forms, together with supporting information, must be received no later than 31 May each year, and the Application must be completed and signed by the person or persons responsible for implementing the project. Web: www.boca.org.au E mail: admin@boca.org.au Phone: 03 9877 5342
Biodiversity Fund (DSEWPAC)	Local governments, land managers, State schools, community and NRM groups.	Various	The Biodiversity Fund will invest around $946m over the next six years to help land managers store carbon, enhance biodiversity and build greater environmental resilience across the Australian landscape. The Biodiversity Fund will invest in three main areas: • Biodiversity plantings • Protecting and enhancing existing native vegetation • Managing threats to biodiversity such as invasive species 2011-12 round one application is now closed, information on round two will be posted on the website soon: http://www.environment.gov.au/cleanenergyfuture/biodiversity-fund/index.html
Community Action Grants (DSEWPAC)	Community groups	$5,000-$20,000	Community Action Grants are a small grants component of the Australian Government's Caring for our Country initiative that aims to help local community groups take action to conserve and protect their natural environment. The grants are targeted towards established local community-based organisations that are successfully delivering projects to support sustainable farming and/or protect and enhance the natural environment. There are for steps required to apply. Please follow the instructions on this link: http://www.nrm.gov.au/funding/cag/how-to-apply.html

GRANT/ORGANISATION	WHO CAN APPLY?	AMOUNT	GRANT INFORMATION
Environmental Community Grants Program (DEC)	Local governments, individuals, community groups, not-for-profit organisations	Up to $500,000	This program provides grants to community projects which conserve, enhance or restore natural areas or values, as well as activities that raise public awareness of nature conservation at a local level. A total of $1.53 million is available annually across eight categories: • biodiversity conservation ($500,000) • sustainable catchment management ($300,000) • fauna rescue and rehabilitation ($50,000) • interpretation and sustainable recreation in natural areas ($180,000) • regional parks ($105,000) • Bush Forever ($75,000) • support for major conservation/environment organisations ($120,000) Applications close 4pm 2 April 2012. Website: http://www.dec.wa.gov.au/content/view/5135/1559/ E mail: grants@dec.wa.gov.au Phone: 9442 0300
Grants to Voluntary Environment and Heritage Organisations (GVESHO)	Environmental Community Groups	Up to $10,000	Funds provided through this program may be used to assist with administrative costs, such as salaries, office rental, gas, electricity, phone and other similar charges, essential office equipment, staff and volunteer training, photocopying and printing costs and travel costs on behalf of the organisation. Web: http://www.environment.gov.au/about/programs/gvesho/index.html E mail gvesho@environment.gov.au Phone (02) 6274 2422
Ian Potter Foundation	Organisations endorsed by the ATO as deductible gift recipients.	Up to $20,000 or more than $100,000 via expression of interest.	Have to be endorsed by the ATO as a deductible gift recipient. Environment & Conservation grants are of two types: • Research and other programs the promote sustainable agricultural practices • Landscape scale approach to protecting areas of high conservation value ($100,000 and over. Applications for $100,000 or more are received via an Expression of Interest process.) In addition, the Foundation supports smaller projects by recognising the important role played by volunteers and environmental organisations in increasing public understanding and awareness. Applications of up to $20,000 should be made on the Small Grants Application Form. Funding objectives and further information regarding both grant types is below. Please note that the Foundation will not fund grants between $20,001 and $99,999 in the Environment & Conservation program area. Web: http://foundation.ianpotter.org.au/environment-amp-conservation Application information: http://foundation.ianpotter.org.au/how_to_apply.html

GRANT/ORGANISATION	WHO CAN APPLY?	AMOUNT	GRANT INFORMATION
Indigenous Heritage Program (DSEWPAC)	Indigenous organisations or not-for-profit bodies, Individual Indigenous, local government authorities	$5,000-100,000	The Indigenous Heritage Program (IHP) is an ongoing competitive annual grants program which provides $3.645 million to support the identification, conservation, and promotion of heritage places important to Aboriginal and Torres Strait Islander people. Incorporated organisations can apply for projects up to $100,000 (GST exclusive). Individual applicants will generally be eligible for funding up to $5000. Applications for larger amounts may be considered where the applicant demonstrates special circumstances or a genuine requirement for additional funds. Eligible organisations may also apply for triennial funding up to $250,000 (GST exclusive) through one application, but with annual reporting on outcomes. Web: http://www.environment.gov.au/heritage/programs/ihp/index.html Phone: 1800 982 280
Litter Prevention Grants (Keep Australia Beautiful Council WA)	Local government, community groups, individuals and other organisations	Up to $10,000	The grant program encourages integrated litter prevention incorporating education, infrastructure and enforcement as key elements and which are consistent with the Keep Australia Beautiful Council's Litter Prevention Strategy for Western Australia. Closes 15 April 2012, no funding round in 2012-13. Contact the KAB Council on 6467 5169. Website: www.kabc.wa.gov.au
Lotterywest Grants Program	Local Governments, not-for-profit organisations	Up to $15,000	Typically a Lotterywest grant can contribute towards the cost of items or activities such as: • Equipment • Information technology • Vehicles • Community facilities • Buildings for organisations • Events • Projects • Research • Organisational development • Conserving and sharing heritage Web: www.lotterywest.wa.gov.au/grants E mail: grants@lotterywest.wa.gov.au Phone: (08) 9340 5270 or 1800 655 270
Mazda Foundation	Not-for-profit organisations Endorsed by the ATO as deductible gift recipients	Various	The Foundation currently has two priority areas for funding, the one which is relevant to this project is: • Projects aimed at the preservation of specific endangered flora and or/fauna Web: http://www.mazdafoundation.org.au/ E mail: info@mazdafoundation.org.au Phone: (03) 8540 1800

GRANT/ORGANISATION	WHO CAN APPLY?	AMOUNT	GRANT INFORMATION
Myer Foundation	Organisations endorsed by the ATO as Income Tax Exempt Charity	Various	The Myer Foundation aims to assist in the area of Sustainability and Environment with its Large Grants Program through the areas of: • Biodiversity • Northern Australia • Water. Web: http://www.myerfoundation.org.au/programs/overview.cfm?loadref=22 E mail: enquiries@myerfoundation.org.au Phone: (03)8672 5555
The Norman Wettenhall Foundation (NWF)	Community groups, NRM groups, educational institutions	Generally up to $10,000	The objectives of the Small Environmental Grants Scheme are to support Australian biodiversity projects that are concerned with one or more of the following: • monitoring and recording data • community education • community capacity building (training) • research and science The NWF has funded projects ranging from supporting local communities to maintain or restore habitat; to the production of education kits; and the publication and widespread dissemination of research information essential to species preservation. The NWF does not fund on-ground works, eg fencing, planting, weed control etc.. Web: http://nwf.org.au/grants/small-environmental-grants/ Contact: Elizabeth Mellick (Beth), Executive Director Email: beth@nwf.org.au Phone: (03) 5472 1316
SALP - Swan River Trust and Alcoa Landcare Program (Perth Region NRM)	Groups with ABNs (joint applications possible)	Up to $35,000 was awarded for individual grants in 2011	Alcoa and the Swan River Trust have supported the Landcare Program, ensuring community have accessible funding for rehabilitation and restoration work in the Perth metropolitan area, since its inception in 1998. Website: http://www.perthregionnrm.com/about-perth-region-nrm/funding.aspx E mail: enquiries@perthregionnrm.com Phone: 9374 3333
SGIO Community Grants Program	Community groups, not-for-profit organisations	One off grants from $500-10,000.	The SGIO Community Grants program helps to support organisations that are committed to initiatives that directly engage and educate the community through environmentally sustainable activities. Applications are open from 1-30 March each year. Website: www.sgio.com.au/grants Phone: 1300 306 496
Water for the Future	Anyone	Various	Through the Water for the Future initiative, the Australian Government is investing in a range of programs over 10 years to address four key priorities; taking action on climate change, using water wisely, securing water supplies and healthy rivers and waterways. Check the website for the various grants on offer: http://www.environment.gov.au/water/programs/index.html

GRANT/ORGANISATION	WHO CAN APPLY?	AMOUNT	GRANT INFORMATION
Westpac Foundation	Community groups , not-for-profit groups	Various	Our grant-making approach provides opportunity, right across the community. We fund local or national initiatives and new ideas or programs with a track record. Our approach falls under two categories – funding community and funding social enterprise and innovation. Web:http://www.westpac.com.au/about-westpac/sustainability-and-community/westpac-foundation/application-process/ E mail: westpacfoundation@westpac.com.au Phone: (02) 8253 0923

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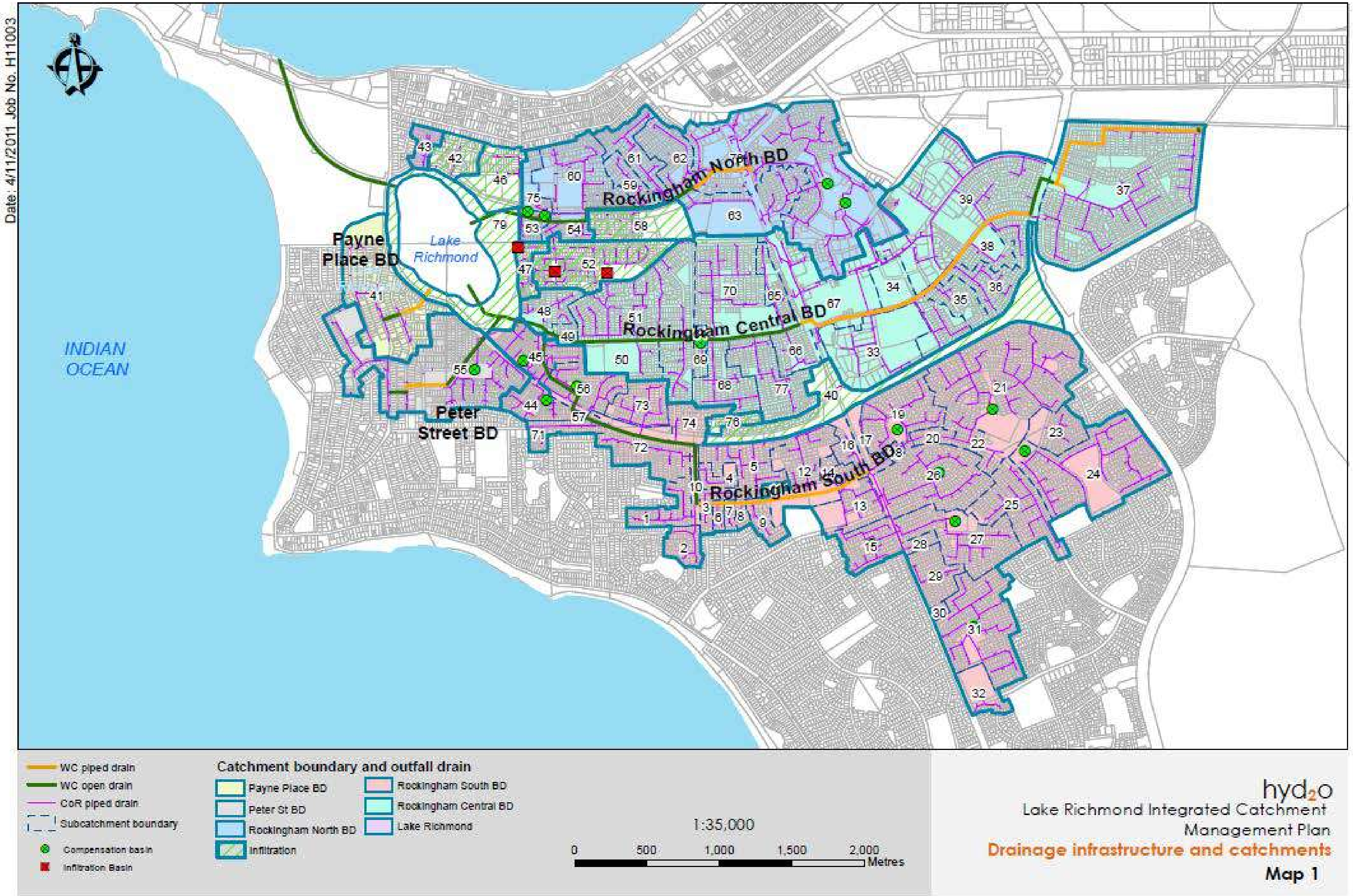
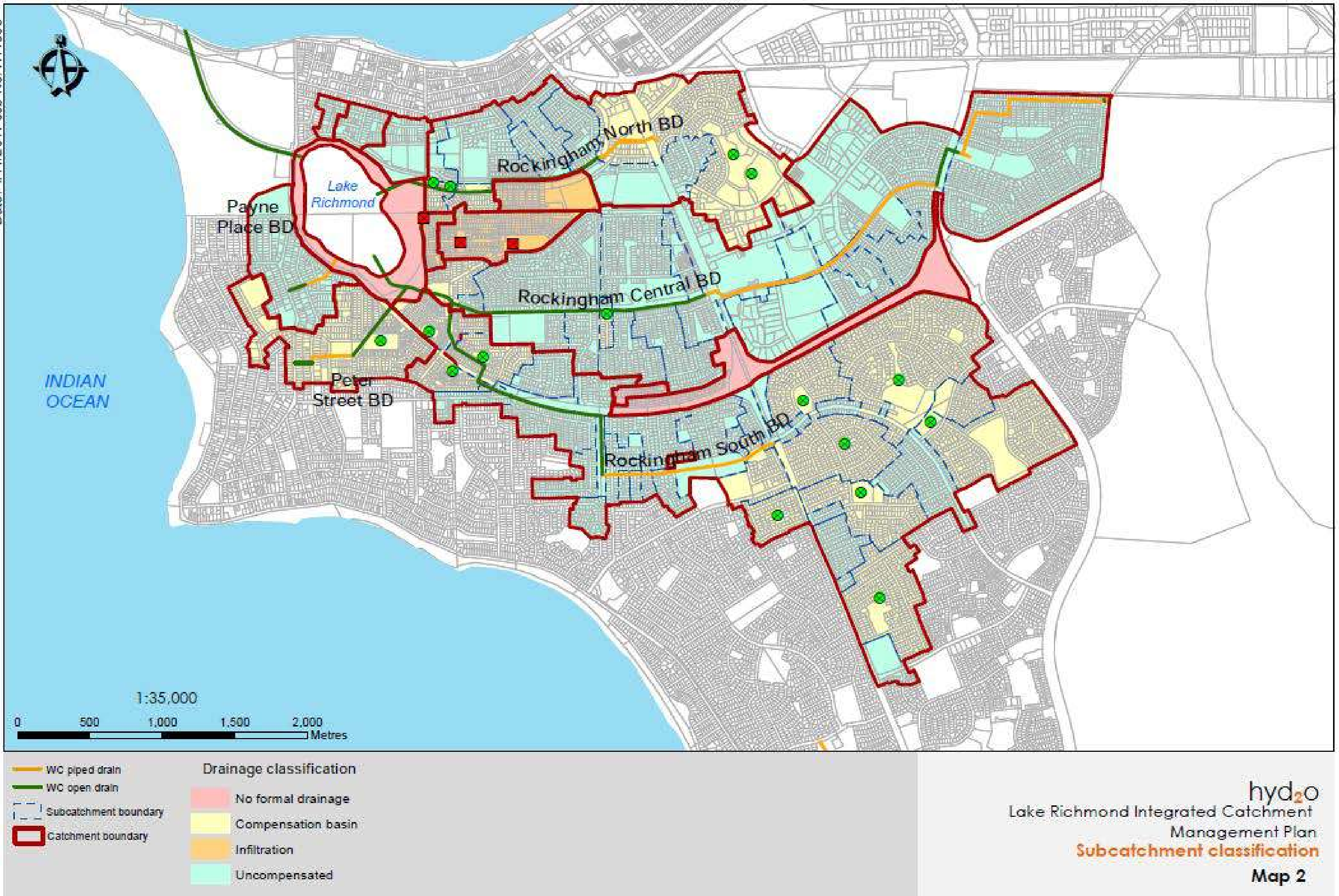
maps

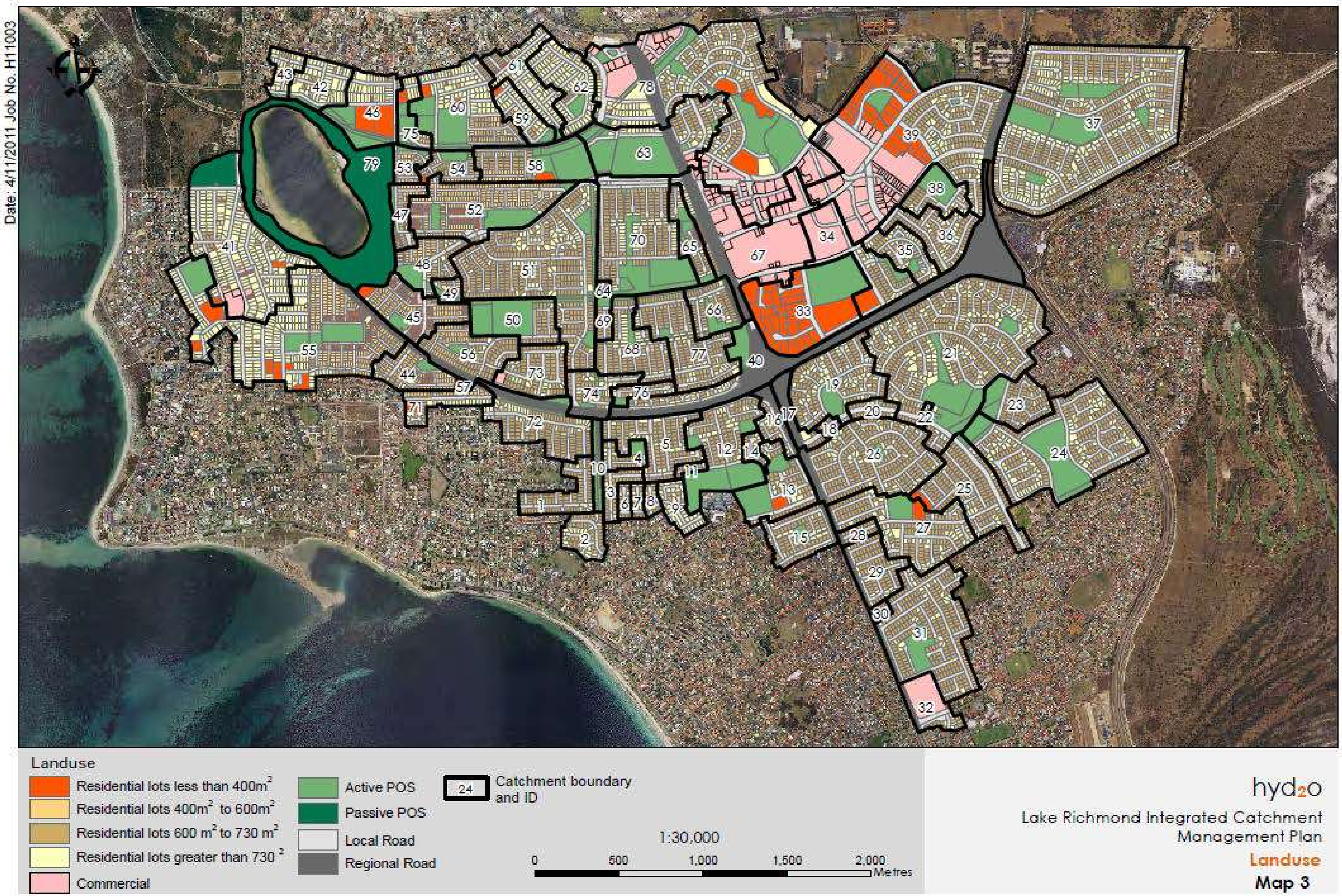
Map 1: Drainage Infrastructure and Catchments



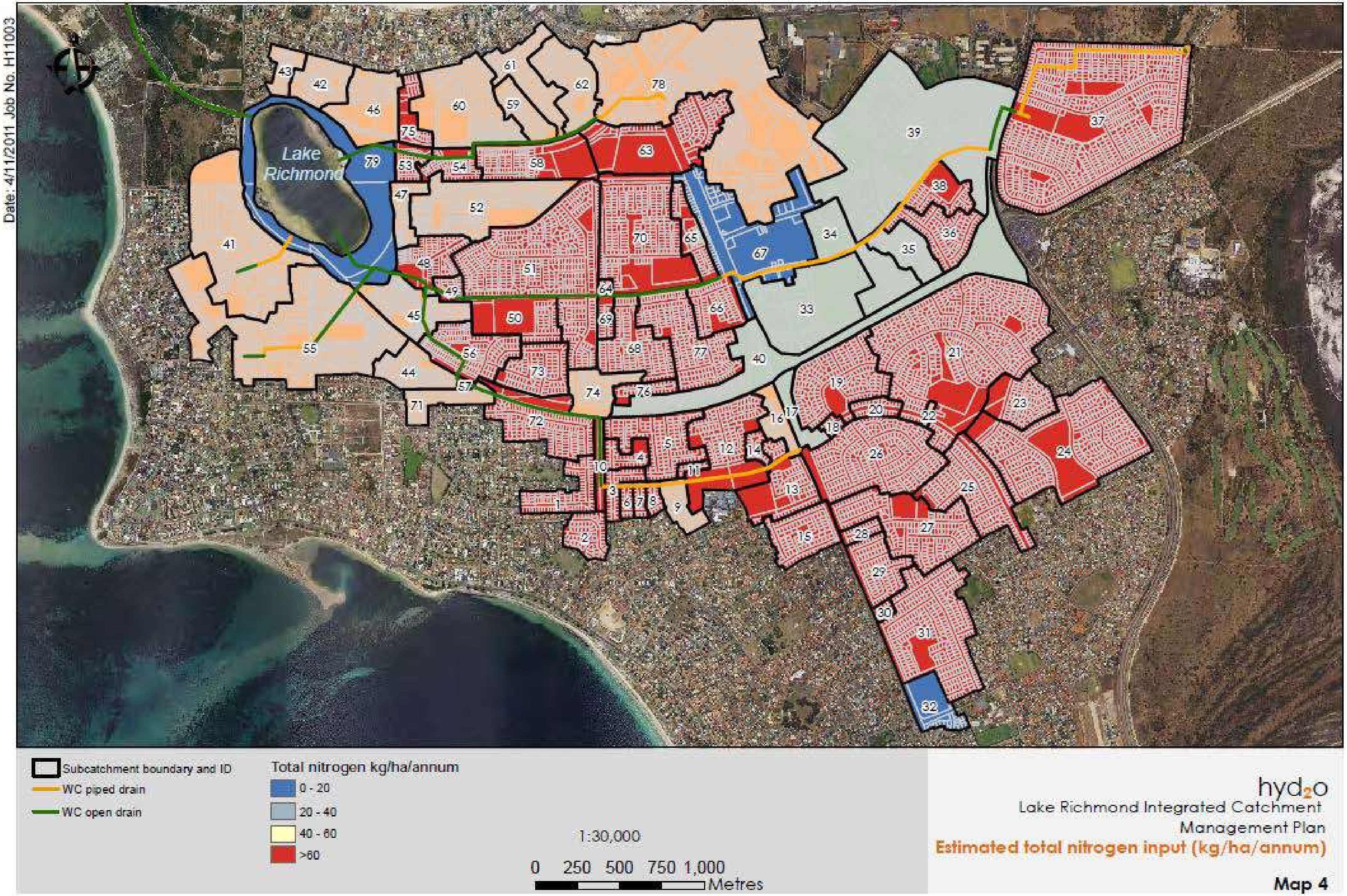
Map 2: Subcatchment Classification



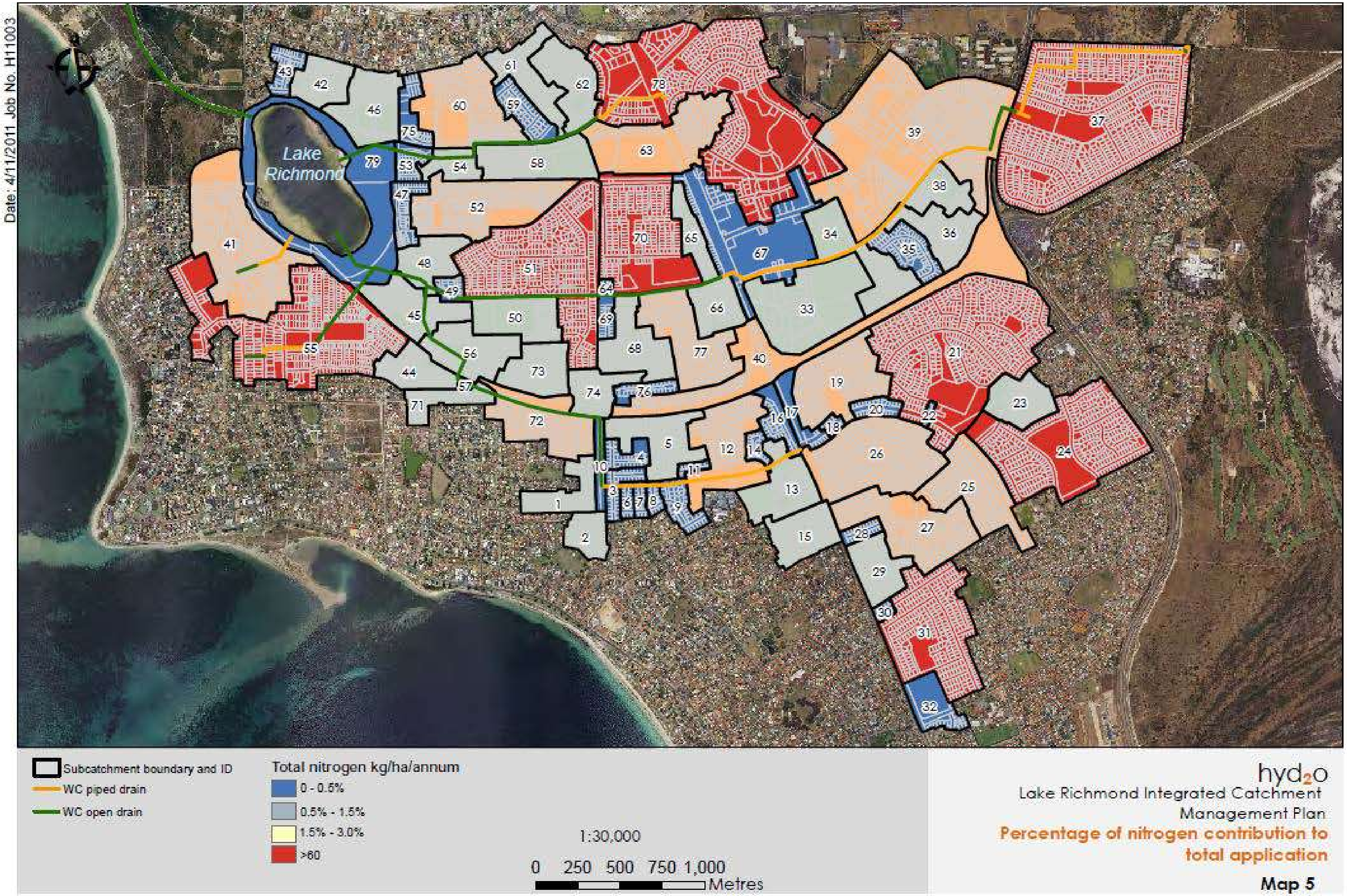
Map 3: Landuse



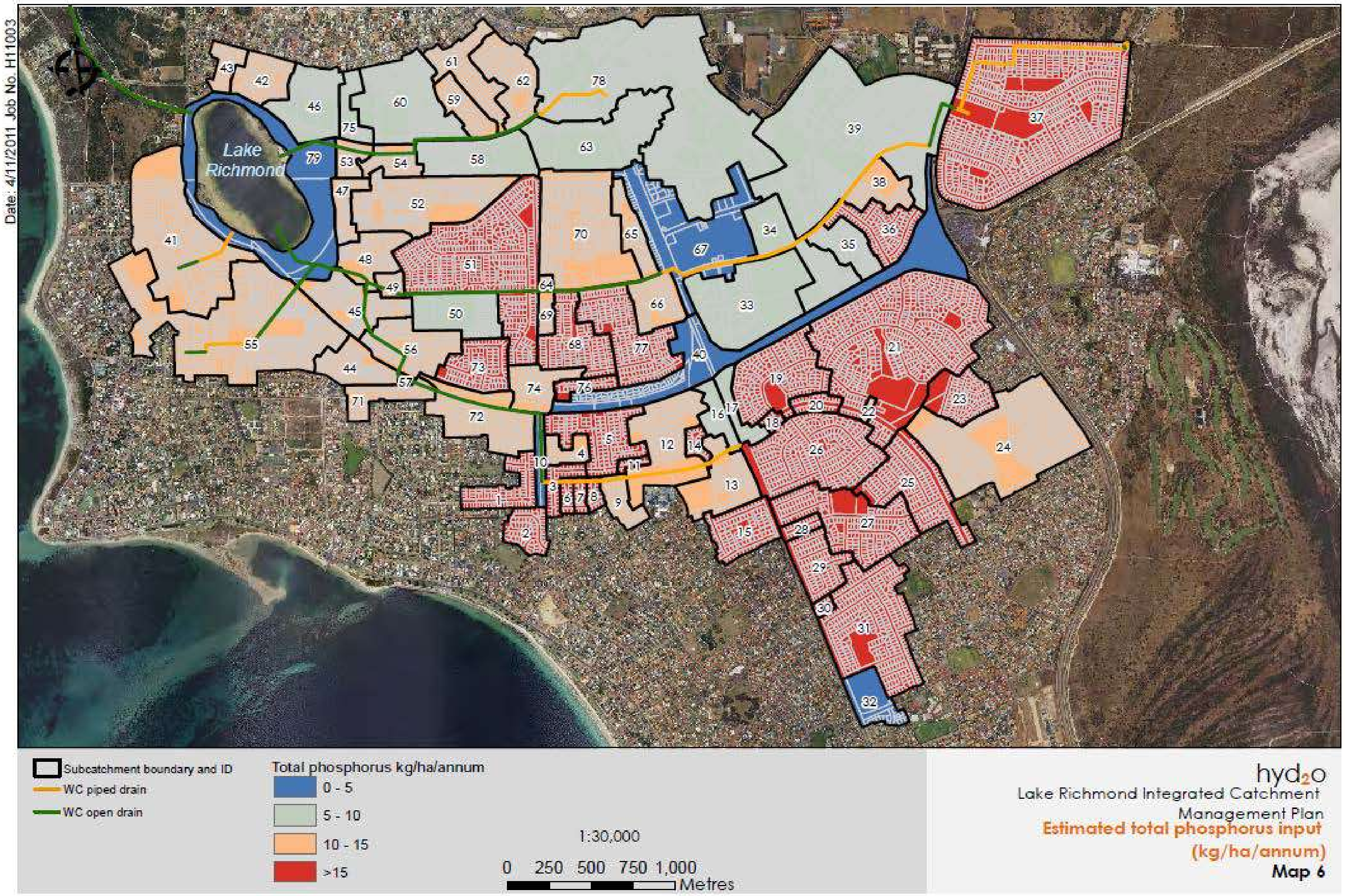
Map 4: Estimated Total Nitrogen input (kg/ha/annum)



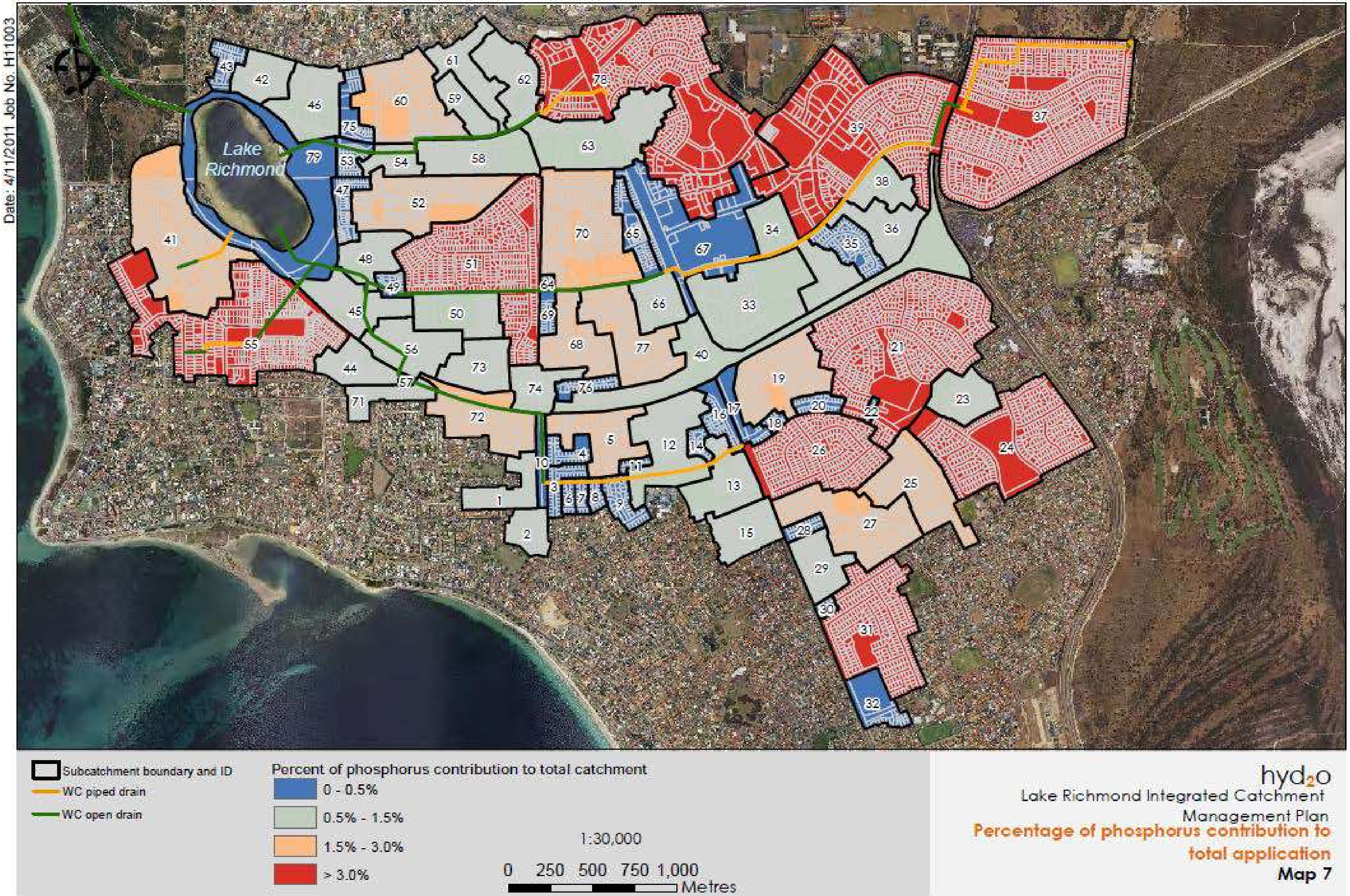
Map 5: Percentage of nitrogen contribution to total application



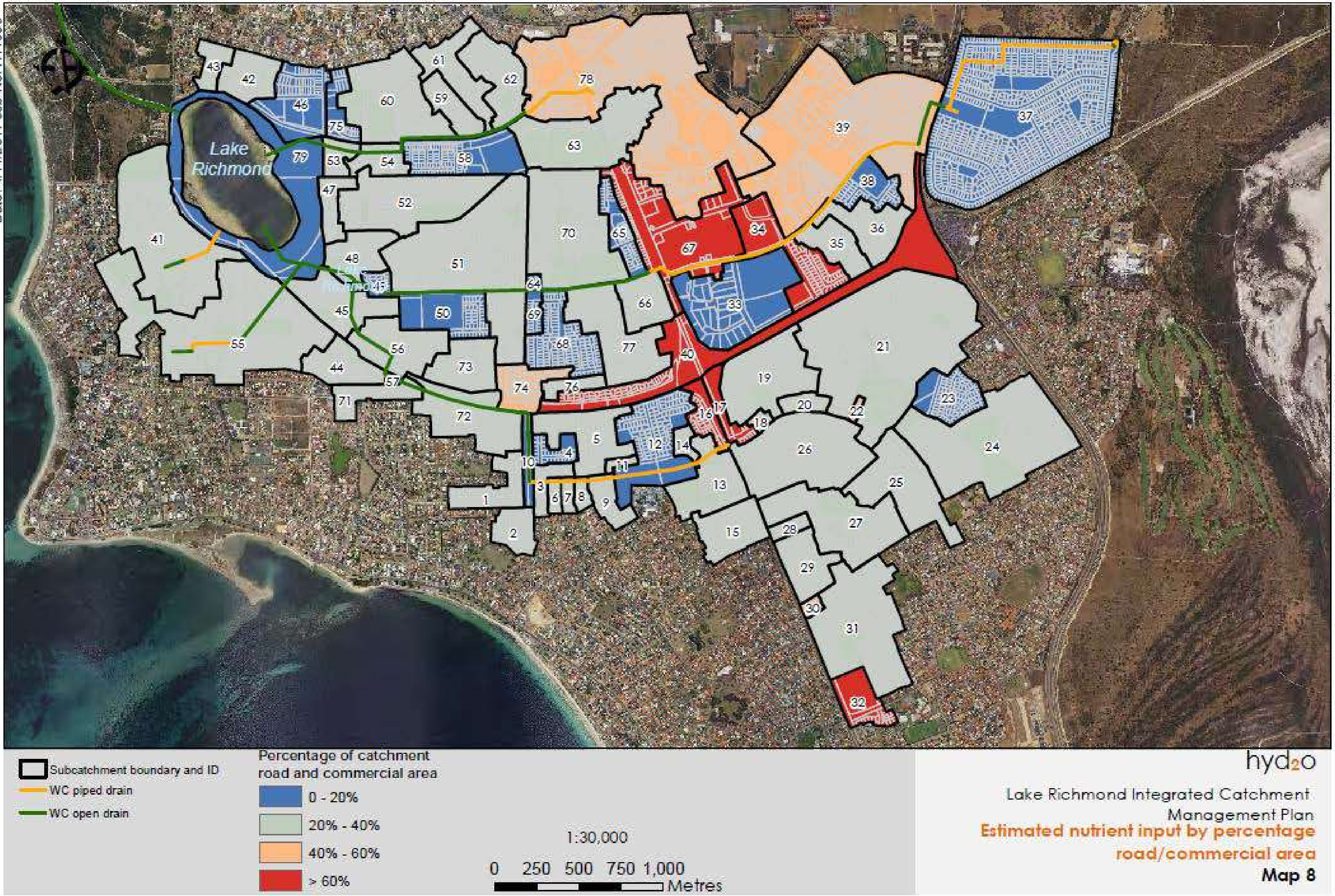
Map 6: Estimated Total Phosphorus input (kg/ha/annum)



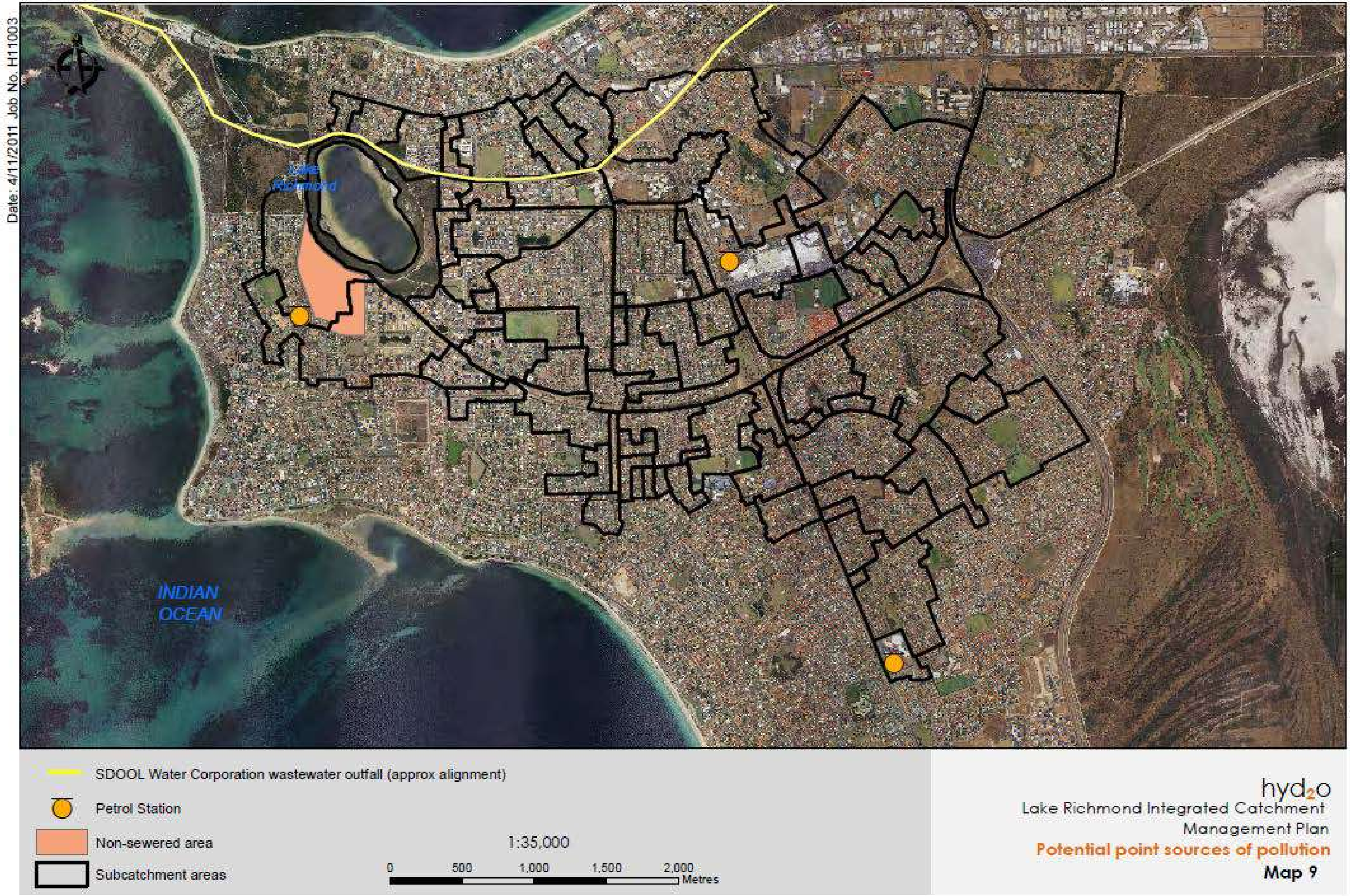
Map 7: Percentage of phosphorus contribution to total application



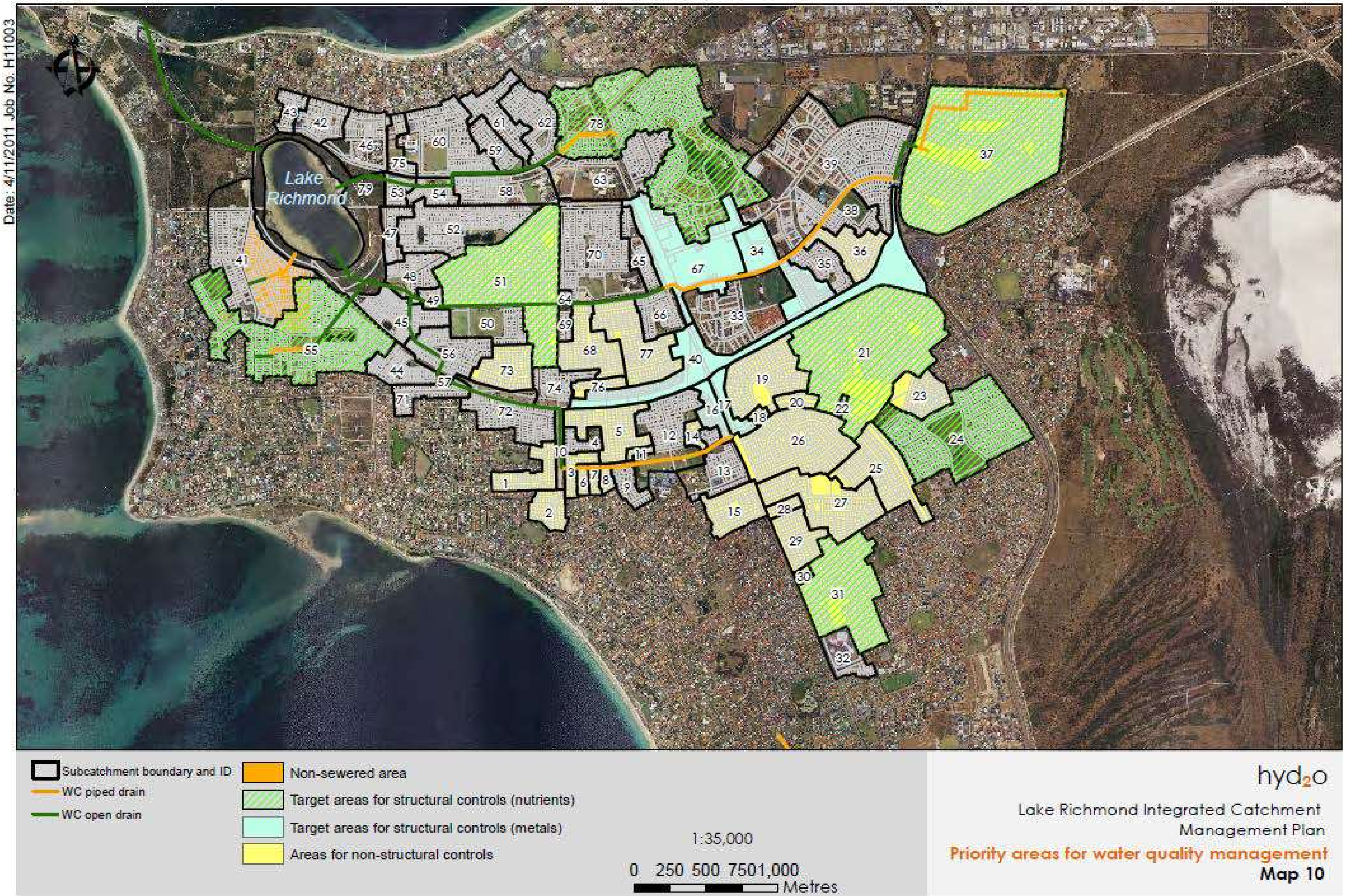
Map 8: Estimated Metals input by percentage road/commercial area



Map 9: Potential point sources of pollution



Map 10: Priority areas for management by land use



appendix one: Land Use Breakdown by Sub-Catchment

LAND USE BREAKDOWN BY CATCHMENT

Catch ID	Classification	Area (ha)	Residential Lots (ha)				Roads (ha)		POS (ha)		Indust/	Nutrient Inputs		
			<400 m2	400 to 600m2	600 to 730m2	>730m2	Local	Regional	Active	Vegetated	Comm (ha)	TN kg/yr	TP kg/yr	
1	uncom	8.67	0.00	0.04	5.88	0.46	2.27	0.00	0.01	0.00	0.00	635.2	165.2	
2	uncomp	6.17	0.00	0.01	2.92	1.55	1.66	0.00	0.01	0.00	0.00	412.8	105.5	
3	uncomp	3.94	0.00	0.02	2.34	0.50	1.06	0.00	0.02	0.00	0.00	276.9	71.3	
4	uncomp	3.85	0.00	0.05	1.59	0.60	0.74	0.00	0.87	0.00	0.00	273.4	56.2	
5	uncomp	14.35	0.00	0.13	7.96	2.06	4.11	0.07	0.02	0.00	0.00	971.9	250.2	
6	uncomp	1.73	0.00	0.00	0.89	0.39	0.43	0.00	0.02	0.00	0.00	120.6	30.6	
7	uncomp	1.70	0.00	0.00	0.76	0.50	0.42	0.00	0.03	0.00	0.00	115.4	29.0	
8	uncomp	1.76	0.00	0.00	0.76	0.53	0.44	0.00	0.03	0.00	0.00	117.9	29.7	
9	uncomp	5.16	0.00	0.01	0.36	3.40	1.37	0.00	0.02	0.00	0.00	290.8	70.9	
10	uncomp	4.09	0.00	0.00	0.01	0.00	0.00	0.00	4.08	0.00	0.00	300.5	10.9	
11	NFD	1.14	0.00	0.02	0.63	0.11	0.39	0.00	0.00	0.00	0.00	72.5	18.8	
12	uncomp	20.43	0.00	0.12	5.96	1.82	3.39	0.00	9.14	0.00	0.00	1418.8	216.5	
13	comp	13.67	0.59	0.06	3.74	1.63	2.94	0.29	4.43	0.00	0.00	851.3	145.3	
14	uncomp	2.21	0.00	0.05	0.84	0.68	0.64	0.00	0.00	0.00	0.00	139.8	35.5	
15	comp	10.99	0.00	0.15	5.10	1.39	2.90	0.65	0.80	0.00	0.00	709.8	165.8	
16	uncomp	5.32	0.00	0.03	1.11	0.92	1.16	2.10	0.00	0.00	0.00	244.8	48.7	
17	uncomp	4.71	0.00	0.01	0.63	0.36	0.43	3.28	0.00	0.00	0.00	187.3	26.7	
18	uncomp	1.25	0.00	0.00	0.64	0.15	0.46	0.00	0.00	0.00	0.00	75.7	19.6	
19	comp	20.84	0.00	0.03	8.32	5.05	5.59	0.00	1.86	0.00	0.00	1353.4	315.9	
20	uncomp	3.05	0.00	0.00	1.80	0.26	0.99	0.00	0.00	0.00	0.00	201.4	52.3	
21	comp	67.44	0.00	0.31	28.65	13.29	14.97	0.00	10.23	0.00	0.00	4658.3	1029.1	
22	uncomp	0.70	0.00	0.01	0.14	0.18	0.37	0.00	0.00	0.00	0.00	28.7	7.2	
23	comp	10.00	0.00	0.06	4.97	0.61	1.82	0.00	2.54	0.00	0.00	739.4	150.3	
24	comp	44.47	0.00	0.28	16.18	7.05	10.18	0.00	10.77	0.00	0.00	2973.8	588.5	
25	uncomp	20.08	0.71	0.14	10.94	2.21	5.74	0.00	0.35	0.00	0.00	1323.2	337.4	
26	comp	30.08	0.00	0.08	16.39	4.15	7.31	1.79	0.36	0.00	0.00	2050.0	512.2	
27	comp	23.91	0.83	0.08	10.03	4.81	5.63	0.43	2.10	0.00	0.00	1563.2	364.8	
28	uncomp	2.26	0.00	0.00	1.54	0.00	0.46	0.26	0.00	0.00	0.00	163.3	40.9	
29	uncomp	9.93	0.00	0.01	5.41	1.10	2.38	1.03	0.00	0.00	0.00	658.8	163.8	
30	uncomp	1.15	0.00	0.00	0.48	0.16	0.30	0.21	0.00	0.00	0.00	76.3	19.0	
31	comp	32.25	0.00	0.83	17.13	2.37	7.99	0.94	2.99	0.00	0.00	2228.4	522.5	
32	uncomp	7.75	0.00	0.13	0.83	0.24	1.32	0.84	0.00	0.00	4.40	137.2	29.9	
33	uncomp	28.39	16.89	0.01	0.00	0.42	3.18	0.00	7.89	0.00	0.00	1008.2	144.9	
34	uncomp	16.90	1.47	0.00	2.75	1.25	4.71	0.00	1.02	0.00	5.69	480.4	108.0	
35	uncomp	8.39	0.00	0.03	2.72	2.42	2.25	0.00	0.95	0.00	0.00	238.5	53.6	
36	uncomp	11.42	0.00	0.08	5.77	2.31	3.27	0.00	0.00	0.00	0.00	760.4	195.4	
37	uncomp	88.27	0.07	0.61	36.10	22.16	17.62	0.03	11.69	0.00	0.00	6206.2	1396.7	
38	uncomp	7.87	0.00	0.04	1.82	1.33	1.49	0.00	3.19	0.00	0.00	520.1	81.1	
39	uncomp	74.53	12.46	0.38	11.88	5.45	19.19	2.67	1.42	0.00	21.07	2114.6	512.9	
40	NFD	35.98	0.19	0.12	1.45	1.95	2.03	27.63	2.61	0.00	0.00	1308.8	112.8	
41	uncomp	39.85	1.20	0.92	0.99	20.16	9.68	0.06	0.44	4.54	1.86	1741.6	419.3	
42	uncomp	8.86	0.04	0.25	0.07	5.52	2.36	0.00	0.63	0.00	0.00	485.8	108.6	
43	uncomp	4.33	0.04	0.14	0.28	2.54	1.05	0.00	0.27	0.00	0.00	250.9	57.4	
44	comp	9.11	0.67	3.76	0.58	0.47	2.44	0.60	0.60	0.00	0.00	513.3	116.2	
45	comp	13.51	2.83	4.69	0.25	0.00	4.05	0.57	0.89	0.00	0.22	602.3	136.1	
46	uncomp	14.70	3.83	0.05	0.35	3.80	2.12	0.00	4.55	0.00	0.00	745.7	116.9	
47	infiltration	5.29	0.39	2.41	0.12	0.00	1.69	0.00	0.68	0.00	0.00	291.5	62.7	
48	comp	9.65	0.04	2.74	1.67	0.49	2.56	0.00	2.15	0.00	0.00	613.3	121.2	
49	uncomp	2.36	0.00	0.37	0.52	0.28	0.36	0.00	0.83	0.00	0.00	168.5	29.5	
50	uncomp	12.84	0.01	0.00	2.77	0.11	1.12	0.00	8.83	0.00	0.00	936.1	98.1	
51	uncomp	49.02	0.19	0.47	25.74	7.13	10.95	0.00	4.55	0.00	0.00	3509.2	831.5	
52	infiltration	25.67	2.23	9.42	1.78	0.43	6.73	0.00	5.08	0.00	0.00	1496.4	298.1	
53	comp	3.94	0.00	1.12	0.89	0.09	1.20	0.00	0.65	0.00	0.00	245.7	52.2	
54	comp	5.77	0.18	1.12	2.11	0.00	1.20	0.00	1.15	0.00	0.00	404.3	85.6	
55	comp	58.74	5.74	9.58	1.99	17.91	13.14	2.15	8.20	0.00	0.02	3204.3	656.7	
56	comp	13.97	0.07	3.54	4.25	0.38	3.29	1.66	0.79	0.00	0.00	888.0	204.0	
57	comp	0.55	0.00	0.25	0.00	0.09	0.16	0.04	0.00	0.00	0.00	31.2	7.5	
58	infiltration	15.65	0.61	2.16	2.38	0.09	2.12	0.00	8.30	0.00	0.00	1066.8	139.4	
59	uncomp	6.78	0.28	0.05	0.56	3.20	1.94	0.00	0.74	0.00	0.00	360.0	77.5	
60	uncomp	24.80	0.81	2.15	2.02	6.33	5.63	0.00	7.85	0.00	0.00	1465.6	242.4	
61	uncomp	11.61	0.18	0.05	0.93	6.89	3.20	0.00	0.37	0.00	0.00	640.7	151.8	
62	uncomp	13.36	0.29	0.27	0.40	7.88	3.29	0.00	1.22	0.00	0.00	746.9	163.9	
63	uncomp	25.84	0.00	0.00	3.45	3.28	3.88	1.77	12.76	0.00	0.69	1580.4	185.2	
64	uncomp	0.79	0.01	0.00	0.26	0.15	0.10	0.00	0.27	0.00	0.00	57.2	10.3	
65	uncomp	6.83	0.29	0.36	1.43	1.12	1.15	0.00	2.48	0.00	0.00	449.0	74.5	
66	uncomp	8.75	0.01	0.01	3.75	0.66	1.30	0.96	2.05	0.00	0.00	607.9	117.5	
67	uncomp	33.66	0.52	0.00	0.59	0.62	5.31	6.00	0.31	0.00	20.32	316.3	37.2	
68	uncomp	14.30	0.03	0.12	7.42	2.59	2.81	0.00	1.33	0.00	0.00	1050.7	248.9	
69	comp	2.55	0.00	0.00	1.30	0.00	0.48	0.00	0.77	0.00	0.00	187.9	36.4	
70	uncomp	33.58	0.01	0.10	11.98	3.61	7.83	0.00	10.05	0.00	0.00	2224.9	409.7	
71	uncomp	6.82	0.52	1.13	1.09	1.99	1.84	0.25	0.00	0.00	0.00	380.8	94.3	
72	uncomp	19.71	0.04	0.00	7.74	2.68	3.60	2.86	2.79	0.00	0.00	1270.2	263.0	
73	uncomp	10.90	0.03	0.00	5.73	1.70	3.02	0.00	0.00	0.00	0.41	705.9	182.1	
74	uncomp	8.28	0.02	0.04	2.83	1.30	2.11	1.24	0.74	0.00	0.00	476.9	102.3	
75	uncomp	5.29	0.51	0.58	0.00	1.18	0.74	0.00	2.27	0.00	0.00	319.9	44.0	
76	NFD	3.36	0.05	0.01	1.56	0.57	0.69	0.00	0.48	0.00	0.00	237.1	53.2	
77	uncomp	19.99	0.05	0.11	11.27	3.10	4.37	0.00	1.09	0.00	0.00	1459.8	359.1	
78	comp	87.08	4.17	0.05	11.53	14.58	20.85	4.14	14.70	0.00	17.06	3550.2	693.4	
79	NFD	33.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.69	0.00	0.0	0.0	
	Totals	1328.56	59.12	51.95	349.96	218.75	283.96	64.52	190.31	38.23	71.75	73291.2	15323.3	
	% of Total		4.5%	3.9%	26.3%	16.5%	21.4%	4.9%	14.3%	2.9%	5.4%	55.2	11.5	kg/ha/yr

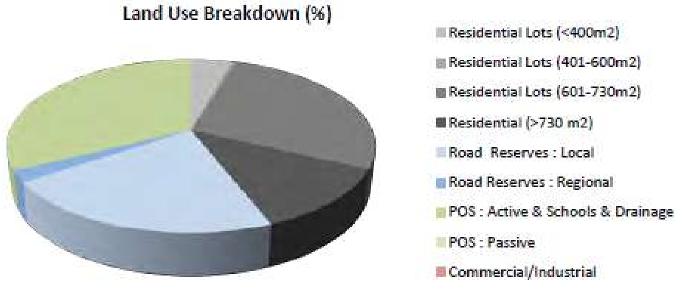
appendix two: NuBalance Nutrient Balance Model Output

NuBalance

Urban Nutrient Input Balance Calculator

	kg/yr	kg/ha/yr
Total Phosphorus	145.3	10.6
Total Nitrogen	851.3	62.3

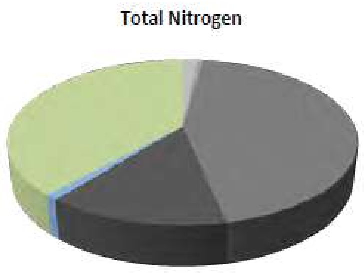
Catchment Name	Sample Catchment Only : Catchment		
Area	13.67	ha	
Land Use Breakdown (%)			
Residential Lots (<400m2)	4%		
Residential Lots (401-600m2)	0%		
Residential Lots (601-730m2)	27%		
Residential (>730 m2)	12%		
Road Reserves : Local	21%		
Road Reserves : Regional	2%	40%	assumed nutrient application area within regional road reserve
POS : Active & Schools & Drainage	32%		
POS : Passive	0%		
Commercial/Industrial	0%	100%	Total

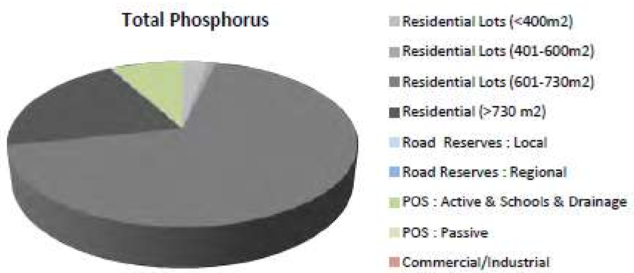


Median Application Rates (kg/ha/year)	TN	TP	Data/Source Comment
Residential Lots (<400m2)	23.5	6.9	Survey of Nutrient Inputs on the Swan Coastal Plain (DoW,2010)
Residential Lots (401-600m2)	91.2	22.8	Survey of Nutrient Inputs on the Swan Coastal Plain (DoW,2010)
Residential Lots (601-730m2)	101.0	26.4	Survey of Nutrient Inputs on the Swan Coastal Plain (DoW,2010)
Residential (>730 m2)	74.2	18.0	Survey of Nutrient Inputs on the Swan Coastal Plain (DoW,2010)
Road Reserves : Local	0.0	0.0	Verge application already included in DoW (2010) values for lots
Road Reserves : Regional	73.4	2.6	Via JDA (2002) based on City of Armadale application rates
POS : Active & Schools & Drainage	73.4	2.6	Via JDA (2002) based on City of Armadale application rates
POS : Passive	0.0	0.0	No nutrient application assumed
Commercial/Industrial	0.0	0.0	No nutrient application assumed

Note : median lot application rates include fertilisers and pet waste

Total Catchment Application (kg/year)	TN	TP
Residential Lots (<400m2)	13.9	4.1
Residential Lots (401-600m2)	5.1	1.3
Residential Lots (601-730m2)	377.8	98.8
Residential (>730 m2)	121.0	29.4
Road Reserves : Local	0.0	0.0
Road Reserves : Regional	8.5	0.3
POS : Active & Schools & Drainage	325.0	11.5
POS : Passive	0.0	0.0
Commercial/Industrial	0.0	0.0
Total (kg/yr)	851.3	145.3





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appendix three: Non structural controls and Structural controls

Non Structural Controls

STREET SWEEPING

Street sweeping is widely used in urban areas to reduce the accumulation of litter, leaves and coarse sediment from roads and footpaths. It is undertaken to improve aesthetics, public safety and stormwater quality. Street sweeping as a stormwater quality BMP is an attractive option for many local authorities, as it is already in use, and roads, car parks and footpaths account for approximately 70% of impervious urban areas. There are many types of sweeping equipment, with new technologies recently emerging that have the potential to collect a high proportion of fine sediments, unlike their predecessors. Street sweeping has most benefit in specific circumstances, such as focusing on pollution 'hot spots' rather than routinely sweeping all streets, and coordinating street sweeping with other maintenance activities and events, such as after a street parade.

It is recommended that street sweeping be coordinated with other maintenance activities and events. For example, targeted street sweeping may be undertaken after:

- resurfacing works on a roadway;
- unloading of materials in an industrial or commercial area; or
- a community event or major sporting event.

Recommendation for street sweeping are summarised below from the Department of Water (2004):

- resources for sweeping should target 'hot spots' in particular locations of point source contamination.
- identify priority pollutants that could be collected by street sweeping (e.g. leaves from deciduous trees upstream of a Lake Richmond) and priority locations where these pollutants may accumulate
- street sweeping should be undertaken after a long dry period such as midsummer, when larger loads of material have accumulated on impervious surfaces and there is the potential for this material to be flushed into Lake Richmond after the first major rainfall
- the catchments surrounding Lake Richmond that have a high percentage of deciduous trees should be swept during/after the autumn leaf fall
- sweeping frequency should be increased during the wet season, as rainfall is a significant pollutant vector
- inspect areas before sweeping to determine the need and likely effectiveness, and after sweeping to broadly determine its value
- ensure that records are kept of the quantity and composition of collected material, as well as the cost, so that the cost-effectiveness of the sweeping program can be improved over time

- keep up to date with new street sweeping technology and ensure new equipment maximises the capture efficiency for pollutants of concern
- street sweeping would be beneficial prior to the scouring of new water mains or at the end of the day around a construction site where sediment has tracked on to the road
- ensure routine maintenance programs that have a need for street sweeping (such as road repair works) include street sweeping as part of their procedures
- advise the community of street sweeping schedules and encourage people to remove vehicles from the street so that the sweeper can access the kerb
- install temporary parking restrictions to gain access to the kerb in areas that are heavily trafficked
- ensure street sweepers do not discharge any solid or liquid waste to the drainage system
- discourage the washing of footpaths and flushing of kerbs unless necessary for safety reasons. Where flushing is necessary, investigate opportunities to trap the stormwater for subsequent disposal (e.g. to a grassed area) or filter it prior to discharge to stormwater
- where mechanical sweeping equipment has limited access to an area, hand sweeping is recommended.

MAINTENANCE OF STORM WATER NETWORK

Maintenance of the stormwater drainage network includes inspection, cleaning and repair of open and piped drains, pits, treatment devices, detention basins and outfall structures. This network needs to be regularly cleaned to maintain its performance. Drainage features such as infiltration pits/soak wells and detention basins can provide ‘hot spots’ for accumulation of gross pollutants and contaminated sediments with high concentrations of heavy metals, hydrocarbons and nutrients. Regular cleaning of the stormwater drainage network provides an opportunity to remove pollutant loads that would otherwise enter receiving water bodies after heavy rainfall. Drains with accumulated pollutants may also overflow, leading to localised flooding and erosion, as well as risks to human safety and constructed assets. Open drains and basins can provide habitat for aquatic fauna and birds. Maintenance of these areas may need to include protecting their environmental values and minimising disturbance to vegetation.

This management practice is applicable to all areas with stormwater drainage systems, but is particularly relevant where the system has an increased risk of pollutant accumulation (e.g. due to flat grades or the existence of nodes in enclosed drainage systems where pollutants can accumulate). In general, drainage networks that have a high proportion of open drains and detention basins provide a greater opportunity for the capture of contaminants than equivalent enclosed systems.

Maintenance of open drains, detention basins and infiltration basins is a significant issue as it can affect the export of contaminants from some drainage catchments. Some recommendations are provided below summarised from the Department of Water (2004) and thought to be relevant to protecting Lake Richmond on the maintenance practices of this non structural control method:

Inspection and maintenance

- identify pollutant 'hot spots' or point sources, where large quantities of pollutants of concern regularly accumulate in the drainage system
- focus on those parts of the stormwater drainage network with relatively flat grades or low flows, as pollutants tend to accumulate in these areas
- undertake regular inspections of 'hot spots' to assess whether pollutants are accumulating
- inspect all stormwater drains and detention basins at least once a year, preferably just prior to the wet season
- adjust the maintenance frequency of the drainage network to suit pollutant accumulation rates and seasonal conditions. Flexibility of the maintenance regime is required given the uncertainty with accumulation rates and rainfall patterns
- prepare an inspection program that assigns inspection tasks, frequencies and responsibilities

Pollutant removal operations

- work in dry weather, when the drainage facility is dry or during low flow conditions. This will reduce the volume of material that will require disposal
- do not disturb the banks of the drain, unless they are eroded and need stabilisation
- determine if there are any sensitive flora or fauna in the vicinity of the drainage network during maintenance and establish precautions to protect these when undertaking maintenance works. Records should be kept by maintenance staff of any area that requires special maintenance procedures (e.g. an area where maintenance activities need to be scheduled around months when birds nest in the area)
- remove sediment, litter and weeds from the drainage asset without altering its design invert level. This is particularly important in areas where nutrient-rich base flow enters open drains in summer months and transports these nutrients to sensitive waterways and wetlands, such as Lake Richmond. All effort should be made to minimise the deepening of open drains and detention basins.
- analyse a representative sample of the sediment before it is removed from the drainage asset. In most urbanised catchments, removed sediment will contain high levels of nutrients and will often contain high levels of heavy metals and hydrocarbons (Oldmeadow & Watkins 2004; Swan River Trust 2003b). Analysis will determine if the sediment is suitable for use as a soil amendment, if it can be disposed on-site, or if it is contaminated and requires disposal at a landfill

- when maintaining detention basins, be aware that the highest levels of contaminants are usually found in sediments closest to the outlet (Oldmeadow & Watkins 2004; Swan River Trust 2003b)
- sediments removed from the drainage asset should not be left alongside the drain or basin where it can erode and re-enter the drainage system.

Mowing and other types of mechanical maintenance

- firstly ensure the proposed works are necessary. The vegetation may appear unsightly, but maybe providing a soil stabilisation role, habitat to valuable fauna and shading of the water column
- under no circumstances should vegetative matter (e.g. grass clippings, removed weeds) enter the water in the drainage asset, or be placed in locations where they could be blown or washed into the drainage asset. It is best to remove vegetative matter and litter from the site
- when maintaining recreational areas alongside open drainage channels or detention basins, try to maintain a buffer zone of at least 10 metres where no fertilisation of lawns and gardens occurs. This strip should consist of suitable native plant species. Where possible, bank-side vegetation regimes should be designed to shade water in the drainage asset
- where appropriate, maintain firebreaks along drainage easements in accordance with local government requirements.
- The existence of non-native annual grasses along the top of the banks can be a matter of concern because such vegetation provides little shading and a poor buffer, requires regular mowing, can block drainage inlets and can contaminate the waterway following maintenance (e.g. from cut material entering the water column). Where a grassed landscape is preferred (e.g. for aesthetic reasons), it is recommended that conventional grasses be replaced with native perennial grasses, where practicable.

Herbicides for weed control

- herbicides should only be used after examining all other alternatives, (e.g. physical removal of weeds, biological control, planting of native species that can out-compete weeds species, or planting of species that will shade out weed species and help lower the water temperature in the drainage asset). The Water and Rivers Commission Water Note 22 *Herbicide Use in Wetlands* provides guidance on minimising the risk of herbicide use to aquatic ecosystems. Frogs in particular have been found to be sensitive to most herbicides, however some products have been developed that are far less toxic to frogs
- all practical attempts should be made to avoid herbicides entering water in drainage assets (e.g. avoid spraying in windy conditions)
- be careful that weed control activities do not generate an erosion problem (e.g. along the banks of open drains). To minimise this risk, consider planting native species two weeks after spraying the weeds

- the service provider undertaking spraying activities must have knowledge of the weed species and the best time to spray.

MANUAL LITTER COLLECTION

The manual collection of gross pollutants (especially litter) in locations where it may be blown or washed into the stormwater drainage network or directly into water bodies is a common management practice, particularly in urban areas and along main roads. Collections are typically undertaken by staff from government agencies (e.g. in 'hot spots', such as along the road corridor in commercial areas), volunteers during 'clean-up days', the private sector in relation to their own premises (e.g. around commercial and industrial sites) and sectors of the community that sponsor an area. This management practice is often implemented for aesthetic reasons. However, there is evidence that a regular manual litter collection program can significantly reduce the loads of pollutants entering water bodies via the stormwater drainage network. The practice can, in some circumstances, be used to provide an opportunity to raise the public's awareness of stormwater pollution.

This management practice is applicable where gross pollutants (particularly litter) are accumulating in locations that are easily accessed by maintenance teams or volunteers. It is particularly relevant where these pollutants have a high risk of entering the stormwater drainage system. Some recommendations summarised from the Department of Water (2004) are provided below:

- identify areas where litter accumulates
- identify the areas where there is a high risk of litter entering the stormwater management system or directly into Lake Richmond
- develop a suitable maintenance regime (including collection frequency, collection methods, personnel, health and safety etc.)
- develop a monitoring plan to determine the effectiveness of the regime
- explore opportunities to raise awareness of stormwater pollution and littering during the cleanup activities. For example, signage can be used to explain the purpose of cleanup activities, and large volumes of collected waste can be used as a graphic reminder of the quantities of litter that are generated in the region
- place a strong emphasis on maintaining safety standards. For example, manual litter collectors may find hazardous substances (e.g. syringes) and volunteers may have limited training. Specialist 'sharps containers' and associated instructions/training should be provided
- in areas where the collected litter includes a high percentage of potentially recyclable items (e.g. glass and plastic bottles), the collected waste should be sorted into recyclable and non-recyclables.

LITTER BIN DESIGN, POSITIONING AND CLEANING

The design, location and maintenance regimes surrounding public litter bins (and accompanying recycling facilities) can facilitate litter control, particularly in public spaces in urban areas and potential litter 'hot spots' in non-urban locations (e.g. roadside rest areas). Caution is needed, as this management practice should not be considered in isolation from the local context in which it will be applied or from supporting measures (e.g. signage, public participation and enforcement). Strategies that are considered to be effective in reducing local littering in public places include placing bins in locations that are convenient to the public, designing bins to catch the attention of the public, keeping observable litter to a minimum (e.g. through frequent collections), providing signage, designing public open space to minimise areas that are hidden from public view and involving the community in litter management initiatives.

This management practice is suitable for public spaces in urban areas and potential litter 'hot spots'. It is particularly relevant where litter has a high risk of entering the stormwater drainage system or water body such as the picnic area along the north side of Lake Richmond, or if the receiving water body hosts environmental values that would be threatened by the discharge of litter in stormwater such as the sedgeland and thrombolite communities at Lake Richmond. The following recommendation for reducing littering in public places have been summarised from the Department of Water (2004) Stormwater Management Manual:

- place litter and recycling bins in locations that are convenient and accessible to the public e.g. picnic areas, along recreation paths, public open spaces.
- undertake site assessments to identify the bins used the most, particularly if they are near stormwater management systems and/or Lake Richmond. These bins will require an increased level of inspection
- bin designs should catch the attention of the public and should be easily identifiable
- decisions made regarding the size of bins should seek to minimise the required emptying frequency while discouraging illegal dumping
- Typically, bins should be emptied before they reach 75 - 80% full. The service provider that undertakes bin emptying should be responsible for clearing up unconfined litter within a specified radius of the bin and the frequency of bin emptying can vary due to usage but as a general guide for park bins a weekly emptying is suitable
- Involve the community in litter management initiatives.

ROAD/PAVEMENT REPAIRS/RESURFACING AND ROAD RUNOFF

Activities to repair potholes and degraded footpaths and resurface roads have the potential to contaminate stormwater. Substantial amounts of pollutants are generated during daily roadway use, which can threaten the health of local water bodies by contributing heavy metals, hydrocarbons, sediment, gross pollutants and nutrients. The risks to stormwater quality include discharges of hydrocarbons during road resurfacing work (e.g. from a spill), discharge of sediments, heavy metals and hydrocarbons from road surfaces, bitumen overspray during road resurfacing activities, alkaline slurry from concrete cutting activities and wastewater from the washing of machinery and tools. Specific management practices need to be applied to minimise these risks, such as planning maintenance activities, modifying road resurfacing and footpath maintenance practices, managing spills and sweeping. Strategic planning and employing good road and bridge maintenance practices are efficient and low-cost means of minimising contamination of stormwater runoff and reducing the risk of environmental harm to the receiving environment.

This management practice is applicable to all areas with roads, car parks and footpaths, and includes sealed and unsealed surfaces. It is particularly relevant in steeply sloping catchments with a high proportion of directly connected impervious surfaces and sensitive receiving waters. Improving the quality of stormwater runoff from road surfaces is usually a priority in urban areas, given the significant load of stormwater pollutants that can be generated from road runoff, and the efficiency of traditional drainage systems in transporting this load to receiving waters. While the potential for environmental harm from road runoff is often significant, there can be a high degree of variability in the quality of this runoff.

Recommendations from the Department of Water (2004) have been summarised below:

Site preparation and planning

- where there is the threat of material entering side entry pits during maintenance activities (e.g. road base, aggregate, or bitumen), install temporary inlet filters
- ensure material such as packing sand, cement, gravel, crushed rock and excavated material is stockpiled away from any drainage paths and covered to prevent erosion
- resurfacing activities should not occur when rainfall is imminent or occurring
- pavements should be repaired in sections to reduce the spillage of paving materials during the repair of potholes and worn pavement.

Bitumen and resurfacing works

- do not carry out bitumen spraying in windy conditions
- place only the required amount of screenings on the bitumen
- ensure loose aggregate is swept up at the completion of works

- use pollution prevention techniques such as drip pans and absorbent materials for all paving machines to limit leaks and spills of paving materials
- consider the use of porous asphalt when replacing surfaces, to reduce the volume of stormwater runoff and associated pollutant loads.

Concrete Work

- undertake concrete mixing and clean-up operations in a designated area that is capable of containing wastewater. Small amounts of wastewater can be allowed to evaporate or infiltrate into the soil
- ensure a contingency measure is in place to prevent any spilt material from entering the drainage network when using concrete pumps
- allow concrete waste and slurry to set before disposal off-site
- prevent wastewater from concrete cutting, brick cutting, or grinding activities from entering the stormwater system
- remove any cover material and formwork from the site once concrete has cured.

MAINTENANCE OF GARDENS AND RESERVES

The maintenance practices applied to grassed areas and gardens can have a significant potential impact on stormwater and groundwater quality. Potential pollutants include nutrients, sediment, pesticides, wastewater from washing machinery (e.g. mowers), and organic matter (e.g. grass clippings). Possible impacts include eutrophication and elevated levels of turbidity in receiving waters, leading to a variety of adverse impacts on aquatic flora and fauna. The focus should be on best management practices relating to plant selection and landscaping design, nutrient and irrigation management, lawn mowing, top dressing and pruning, and pest management. The objectives are to minimise pollutants leaving the site via stormwater or shallow groundwater, minimise adverse impacts on the site's hydrology, minimise the use of fertilisers and irrigation water, maximise water and nutrient recycling and, where possible, save time and money on maintenance practices.

The following management practices and recommendations are particularly relevant to areas of open space that drain into sensitive receiving waters such as Lake Richmond that is under pressure from nutrient inputs. It is also relevant to areas of open space situated close to Lake Richmond such as the picnic area on the northwest edge of Lake Richmond. They are also particularly relevant to areas that are subject to erosion; subject to intense rainfall events that may generate surface runoff; subject to intensive maintenance practices (e.g. golf courses) or areas that have soils with poor moisture and nutrient retention capabilities.

Plant selection and landscaping design

- plant local native species. This will reduce the risks of grass cuttings, deciduous leaves, nutrients and pesticides entering water bodies. Local native plants require less irrigation and maintenance (e.g. little or no nutrient or pesticide application) than exotic species and provide habitat and food for native fauna

- where local native species are not planted
  - minimise the use of deciduous plants as deciduous plant drop all of their leaves over a short period and decompose quickly, which can result in an excessive release of nutrients into water bodies
  - minimise the amount of grassed/lawn areas
  - minimise the extent of water-consuming planting
  - Apply the basic principles of hydro-zoning (grouping plants on the basis of having similar water requirements) to planting design
  - Match the plants to the soil type
- maximise the use of water conserving elements and techniques, such as using mulches, ground covers and porous paving instead of lawn.

Nutrient management

For turf and grassed areas, use the guidelines provided by DEP & WRC (2001) to determine each area's fertilisation requirements. This process involves visual inspection of the turf; regular analysis of leaf tissue, soil and water; consideration of the grass species, turf and grass use, weather patterns, ground temperatures, air temperatures, water availability, sunlight intensity and soil conditions; the use of catalysts (where necessary) to convert soil nutrients to a form that can be utilised by plants; synchronising the application of fertiliser with the needs of the plant; and adopting the principle of frequently applying small amounts of fertiliser. DEP & WRC (2001) also provides guidance on calculating fertiliser application rates, and specific factors that should be considered when determining nitrogen and phosphorus application rates. Some recommendations from DEP &WRC (2001) and WAWC (2004) include the following:

- when applying nitrogen to sandy soils on the Swan Coastal Plain, the quantity of nitrogen applied in any one application should not exceed 40 kg/ha
- where phosphorus is being applied, special consideration must be given to the level of available phosphorus in the soil; the Phosphorus Retention Index (PRI); and the results of leaf tissue analysis
- when determining a suitable fertilisation regime, recognise that reducing the amount of water used on gardens and lawns will also reduce the need for fertilisation
- where 'fertigation' is used to supply plants with soluble nutrients in irrigation water, care is needed to frequently apply very small amounts of nutrients to the plants at a rate at which the roots can take up most, if not all, of the nutrients. This is necessary to minimise the percentage of nutrients that move past the root zone and enter shallow groundwater, as well as the cost of fertilisation. Fertigation is ideally suited for the soils of the Swan Coastal Plain that have a poor capacity to retain nutrients. It has the advantage that the fertilisers are only

applied when water is required (not in winter) but it has the disadvantage that it requires accurate irrigation systems to avoid areas of over and under application of nutrients

- use slow-release fertilisers where possible
- avoid using fertilisers in areas where runoff can result in the fertiliser entering drainage systems or directly into Lake Richmond
- if fertiliser is required, apply in spring or early autumn (September, October, November, March and April).
- apply fertiliser often and in small amounts during the spring and early autumn period
- applying organic matter or soil amendment to the upper 15 cm of sandy soils can produce multiple benefits. These include the slow release of nutrients, and the retention and recycling of soil moisture and nutrients
- while fertilisers are usually applied immediately before watering, extreme care must be taken to ensure that this watering does not generate runoff or leachate to shallow groundwater
- where possible, establish a buffer zone at least 50 metres wide between fertilised areas and water bodies
- where drainage channels flow through fertilised areas, apply the principles of water sensitive design to establish a 'treatment train' within the drainage corridor (e.g. by using controls such as unfertilised buffer zones, swales, wetlands, ponds, stormwater recycling, etc.).

Irrigation management

- ensure that if irrigation systems are in place that they are water efficient (e.g. drip or trickle systems, sprinklers that produce large droplets, sprinklers with matched precipitation rates, high-quality controllers that have the ability to run separate watering programs for lawn and garden areas, and rain sensors that can be used to prevent irrigation after summer rain storms)
- ensure the design, sensors and settings used for automated irrigation systems do not produce surface runoff from the area being watered or from adjacent impervious surfaces
- determine the necessary amount of irrigation with due consideration of grass growth rate, soil type, daily evaporation rate, wind effects, soil temperature and available soil moisture (DEP & WRC, 2001). This can be achieved with modern soil moisture and air sensing devices such as tensiometers, soil moisture sensors, relative humidity measuring devices and wind velocity detectors. Alternatively, recommended irrigation frequencies for the application of 10 litres/m2 of water for different types of 'watering zones' can be obtained from the Water Corporation's website (www.watercorporation.com.au)
- seek to recycle nutrient–rich shallow groundwater and/or stormwater from the site
- visually check irrigation systems every week 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 to improve water retention, smother weeds and prevent erosion

- where required, apply soil wetting agents to overcome hydrophobic soil conditions and enhance infiltration of irrigation water
- use soil amendments to improve the water retention capacities of soils where appropriate
- where nutrient-rich wastewater is used as a source of irrigation water, it is particularly important to control application rates so that surface runoff and shallow groundwater contamination does not occur. A comprehensive monitoring and evaluation program should be established to ensure that this objective is achieved.

Pest management

The most effective pest control methods are often a combination of non-chemical and chemical control methods (DEP & WRC, 2001). Where chemical pest control methods need to be used, less hazardous products (e.g. Roundup Biactive®) or target-specific chemicals should be used for control of nuisance/disease vector insects, rather than pesticides that are a greater threat to aquatic systems, such as diazinon and chloropyrifos. The less hazardous chemical pesticides must still be used with the best practice precautions applied to other chemical pesticides.

Recommendations to reduce the risks from pesticides as discussed by the Water and Rivers Commission (2000) document include:

- apply according to the label's recommended rate
- do not apply pesticides when rain is occurring or imminent
- do not spray pesticides on windy days
- where possible, wipe or inject pesticides to avoid spray drift
- if possible, spray when surface water levels are low
- do not apply pesticides when there is a high risk of impact to vulnerable stages of fauna development. For example, avoid the period from egg lay to dispersal of junior frogs into the surrounding area – this period varies, but is generally between late autumn and early spring
- mix in a coloured dye so that you can see which areas have been sprayed
- avoid using surfactants in the pesticides, as frogs are particularly sensitive to surfactants (Water & Rivers Commission 2001).
- if disposal of unwanted pesticides and/or pesticide containers needs to be undertaken, consultation should occur with operators of local waste disposal/treatment facilities to identify options for reuse or disposal.

Lawn mowing, top-dressing and pruning

- Remove litter and debris before mowing
- close cropping during mowing is not recommended, as it provides an opportunity for accelerated erosion and increases the area's irrigation requirements. As a general rule, no more than 33% of the grass leaf area should be removed during one mowing event

- where possible and where there is not a risk of cuttings entering adjacent water bodies, grass cuttings should be left on the lawn after mowing
- where grass cuttings are collected, they should be composted and reused as fertiliser
- compost should be stored in areas where stormwater and/or groundwater will not be contaminated
- grass cuttings should not be 'thrown' from the mower blades onto hard surfaces (e.g. roads) or into adjacent water bodies. If some cuttings are inadvertently deposited on roads or footpaths, they should be collected by 'dry' methods (e.g. sweeping) at the completion of mowing activities
- cuttings should not be blown or swept onto the road or into water bodies or the stormwater system
- in areas adjacent to roads with a kerb and channel, coordinate activities such as mowing or pruning with street cleaning operations
- mowing equipment is commonly hosed down after use at a particular location to prevent the transfer of weeds between mowing sites. Where this is done, the rinse water can be infiltrated into the soil. Under no circumstances should this rinse water be directed to the stormwater system
- only use top-dressing to even out bumps and hollows in the lawn, and then only use special topdressing mixes which contain organic matter (WAWC 2004). A vegetated buffer should be maintained between the top-dressed area and stormwater drains or water bodies. In addition, topdressing should not occur when intense and/or prolonged rainfall is likely.

BUILDING MAINTENANCE

Building maintenance practices such as washing of buildings and paved surfaces, sandblasting, painting, rendering and graffiti removal generate contaminated wastewater that is a potential threat to the stormwater system and can be acutely toxic to aquatic biota in the receiving water body. Once construction is completed, pollutants in runoff from roofed areas and paved surfaces may continue to enter stormwater after every rainfall event. These pollutants include flaking paint containing heavy metals, nitrogen from atmospheric deposition, litter from the building's footpaths, hydrocarbons and heavy metals from the building's roadways and nutrients from fertilised lawns and garden beds. Management practices can be applied during building maintenance and post-construction stages to minimise the risk of stormwater and groundwater pollution and, to a lesser extent, minimise the volume of stormwater discharge. The Department of Environments *Urban Stormwater Management Manual for Western Australia* (2004) guidelines includes procedures for the proper storage, use and disposal of hazardous and non-hazardous wastes, techniques to prevent wastewater from entering the stormwater system and recommendations for inspection and maintenance of stormwater-related structures.

Management practices can be applied during building maintenance and post-construction stages to minimise the risk of stormwater and groundwater pollution and, to a lesser extent, minimise the volume of stormwater discharge. These management practices are applicable to building maintenance in all areas in particular catchments with a sensitive receiving water body.

Some recommendations are provided below summarised from the Department of Water (2004) and thought to be relevant to protecting Lake Richmond:

Building maintenance activities

- a waste management hierarchy should be adopted when undertaking building maintenance activities. For example, first explore options that do not generate wastewater (e.g. painting over graffiti rather than removing it); then 'dry' methods (e.g. paint scraping with debris being swept up); then methods that involve little risk of stormwater discharge (e.g. spot application of solvents to remove graffiti using an absorbent ground sheet); then options that generate large amounts of relatively innocuous wastewater (e.g. high-pressure hoses that wash a building but do not remove paints)
- methods that generate large amounts of relatively hazardous wastewater (e.g. chlorinated washwaters from washing buildings with moulds) should be used only when other options are not available
- these types of maintenance activities should not be used in wet weather or when rainfall is imminent
- used solvents and excess paint should be managed as 'hazardous waste'. Accordingly, liaise with local waste management firms and the operators of local waste management disposal/treatment facilities to identify opportunities for recycling and appropriate disposal options
- where washing is necessary and wastewater contains only non-hazardous contaminants in particulate form, direct wastewater to an infiltration area.
- where infiltration of wastewater is not possible, remove the suspended material by allowing sedimentation (e.g. building 'check dams' along the roadside channel using sandbags) and/or filtration (e.g. using filters made of geofabric on drainage inlets).
- another filtration option is to build several 'socks' approximately 50 centimetres long, which are made of geofabric filled with crushed aggregate. These can be placed on hard surfaces between the source of the wastewater and the drainage inlet
- ensure paint or solvent leakages cannot enter the stormwater system
- treat a paint spill in the same manner as a 'chemical spill'
- use a ground cloth/sheet to collect dust and paint residue during scraping, sanding and painting activities
- clean water-based paint equipment where residue cannot enter the stormwater system

- clean oil-based paint equipment where the liquid waste material can be collected and disposed of as hazardous waste
- avoid spray painting outdoors on windy days
- where painted buildings are being washed and there is the likelihood of lead or mercury additives in the paint, wastewater should be directed to sewer (in accordance with an approved Industrial Waste Permit) or taken to a hazardous waste treatment facility by a licensed contractor
- where washing building walls with soap, either discharge wastewater to a landscaped area, to sewer (in accordance with an approved Industrial Waste Permit), or to a waste treatment facility via a licensed waste transport contractor
- where washing building walls without soap and where lead-based paint is not likely to be present in the wastewater, direct wastewater to landscaped areas where possible, or if this is not possible, filter the wastewater to remove coarse sediment particles prior to its discharge to stormwater
- dispose of collected solids as non-hazardous solid waste.

Maintenance of the building's stormwater-related structures

- regularly inspect and maintain all structural stormwater treatment, retention or infiltration devices
- a maintenance and repair plan should be developed that clearly outlines inspection and maintenance frequencies, procedures for the disposal of wastes, equipment requirements, health and safety requirements
- inspect and, where necessary, maintain the site's in-ground stormwater network (at least annually)
- inspect and, where necessary, maintain the building's drain inlets, spouting and downpipes (at least twice per year).

STORMWATER MANAGEMENT ON INDUSTRIAL AND COMMERCIAL SITES

Industrial and commercial premises have significant potential to pollute stormwater, for example, through poor control of industrial processes or inadequate facilities for waste disposal. The transport, handling and storage of goods and wastes can also result in the contamination of stormwater. Improving practices that potentially impact on stormwater and groundwater at these premises is a priority for water resource protection. Recommended pollution prevention practices include identifying and assessing stormwater-related risks on the site, developing management plans or procedures to manage the identified risks and training all staff to undertake their roles in relation to these management plans/procedures.

Pollution prevention and other management activities for stormwater management are applicable to most commercial and industrial sites. Site-specific risks should be identified and appropriate management practices should be designed for the site. Recommendations for keeping workplaces clean and minimising the risk of accidents/incidents have been summarised below from the Department of Water (2004):

- ensure surfaces that drain to stormwater are regularly cleaned using 'dry' methods
- only undertake washing, degreasing and cleaning activities in dedicated wash-down bays where the wastewater can be collected and prevented from mixing with stormwater. This includes vehicle washing using biodegradable detergents
- maintain machinery/vehicles to minimise the risk of leaks and store such machinery in cleaned areas so that regular inspections can quickly identify any discharges
- use spill trays under work areas where spills could occur
- control airborne sprays so those surfaces that generate or convey stormwater are not contaminated
- where possible, loading and unloading should take place in a covered area away from the vicinity of stormwater drains. Stormwater should be directed away from loading and unloading areas
- ensure staff training includes safe material handling and storage procedures to minimise the risk of a spill
- in consultation with staff, industrial and commercial businesses should develop and communicate an Emergency Response Plan to manage spills. One of the primary objectives of this plan is to ensure that spills do not leave the site via stormwater drains
- ensure sites are equipped with suitable emergency spill equipment and absorbents and train staff on their use
- clean up of spills should be immediate, automatic and routine in industrial premises, no matter how small. Under no circumstances should spills be washed away with water or buried on-site.

CAPACITY BUILDING PROGRAMS FOR LOCAL GOVERNMENT AND STORMWATER MANAGEMENT INDUSTRY PROFESSIONALS

Capacity building is a holistic approach to knowledge building and transfer, which fosters professional skill development, competency, innovation and confidence. Capacity building is also a means to facilitate network building, linkages and training for continuous improvement. Providing people with the information and skills they need to make better decisions is an essential part of promoting best practice stormwater management.

Stormwater-related capacity building programs can be run at a variety of scales, from a program that covers a small local government area to one that covers an entire State. Recommended steps to developing a stormwater-related capacity building program include:

- Develop a scope for the program by identifying the capacity building requirements for the target audience. For example, specialist market researchers may be engaged to survey the

target audience (through methods such as focus groups, workshops and phone surveys) to identify current levels of stormwater knowledge and awareness, training and development needs, barriers to change, potential education and networking opportunities, including existing communication networks. Examples of the target audience can include:
  - elected members (particularly in small to medium-sized local government)
  - senior managers in local government, State government and relevant water service providers
  - town planners, engineers, ecologists, architects, landscape architects and staff responsible for the maintenance of stormwater assets
  - the construction and stormwater management industries (both in government and the private sector)
  - local catchment groups, industry associations and other existing communication networks, where applicable
- use the information gathered from the scoping step to identify key project areas
- develop project plans for each of the key project areas. These plans should detail how major projects will be delivered (e.g. training events, information registers, websites and guidelines), including details such as the target audience, objectives, expected outputs, expected outcomes, method of evaluation, timing and responsibilities
- implement these project plans
- communicate with stakeholders throughout this process. Opportunities for communication include newsletters (paper and electronic), websites, workshops and travelling 'road shows' where stakeholders are; introduced to the capacity building program; new projects can be advertised (e.g. upcoming training events or guidelines); and new products can be explained
- evaluate the program. An approach to monitoring and evaluation should be planned at the beginning of the program's development and executed throughout its delivery.

Landowner training on stormwater management

This best management practice typically involves intensive training for volunteer residents to provide information on alternative lawn and garden care practices. These programs may focus on source controls, with the aim of minimising stormwater pollution, particularly with respect to nutrients. Programs may address water conservation, plant selection (e.g. growing local native plants or plants that require less water and fertiliser), fertiliser use, weed and pest management, irrigation practices, stormwater and shallow groundwater reuse, composting and soil amendment. These programs are applicable to all areas, particularly areas with sandy soils that have low nutrient and moisture retention capabilities; areas draining to sensitive water bodies or water bodies that are under stress from nutrient inputs; drinking water catchments; areas with large gardens and lawns; and areas subject to erosion (e.g. due to steep slopes).

These programs are applicable to all areas, however they are particularly applicable in situations such as; areas with sandy soils that have low nutrient and moisture retention capabilities; areas draining to sensitive water bodies (e.g. wetlands and waterways with conservation values, or catchments that are under stress from nutrient inputs); drinking water catchments; areas where gardens are close to water bodies; areas with large gardens and lawns; and areas subject to erosion. Some recommendations are provided below that have been summarised from the Department of Water (2004):

- investigate using proven behaviour changing techniques, such as commitments/goal setting, prompts (to address forgetting), develop social norms and incentives to train and educate landowners
- engage the community. It may be advantageous for programs to address a range of sustainable living issues, e.g. stormwater management, water conservation, water sensitive gardening, waste minimisation and energy efficiency.

COMMUNITY PARTICIPATION IN STORMWATER MANAGEMENT

Stormwater related community participation programs seek to engage the community so that they understand the nature of the problem and can participate in the development and implementation of solutions. Community members, given support and time, can quickly build knowledge and positively contribute to the formulation of new and sustainable approaches to stormwater management. This best management practice fosters ownership of stormwater related problems by the local community. A participatory approach can be applied to common stormwater related activities, such as the development of a stormwater management plan or program to protect the health of a local waterway. Encouraging public participation in decision-making is a 'bottom-up' approach that has been shown to more effectively change people's behaviour than traditional 'top-down' education methods. The technique can be applied to common stormwater related activities such as the development of management plans; education/participation programs (e.g. programs within a catchment to protect the health of a local waterway or wetland and anti-litter campaigns within a commercial district); and specific activities such as stormwater drain stencilling and clean-up activities.

These recommendations aim at increasing the focus on public participation in urban stormwater management (e.g. involving the community in deliberative decision-making processes), as opposed to traditional community education approaches (e.g. distribution of education materials).

- investigate the potential of developing stormwater management plans for each identified catchment or as a whole area that adopts a participatory approach. For example, awareness could be raised in the community then volunteers could be sought to participate in development of the plan. Participation techniques could include
    - select a group, representative of the community
    - deliberate and agree on priority issues to be manage

- o jointly develop sustainable solutions.

EDUCATION CAMPAIGNS FOR COMMERCIAL AND INDUSTRIAL PREMISES

This best management practice includes industry-specific training and environmental accreditation programs to increase the uptake of environmental management and cleaner production techniques. Many industrial and commercial premises have a significant risk of contaminating stormwater and shallow groundwater due to the type of activities they undertake (e.g. fuel and chemical storage associated with automotive repair industries). For education campaigns involving commercial or industrial premises, care must be taken to specifically tailor messages to a particular target audience. While the approach needs to be tailored, the recommended procedure of firstly surveying the target audience, designing the campaign (involving the target audience where possible), delivering the campaign and finally evaluating the campaign is generic. To maximise the effect of the campaign, the complementary use of site assessments, incentives (e.g. positive recognition, assistance) and disincentives (e.g. penalties) should also be considered.

These campaigns or programs are applicable to all commercial and industrial areas. However, they are particularly applicable where areas are draining into sensitive water bodies such as Lake Richmond. Some recommendations are provided below that have been summarised from the Department of Water (2004) Storm Water Management Manual:

- education and participation programs should be applied on a priority basis.
- Undertake an investigation to determine those premises that pose the greatest risk to the health of Lake Richmond
- develop campaigns that specifically tailor messages to a particular target audience (i.e. based on the type of business or industry sector). To maximise the impact of the campaign, consider complementary use of site assessments, incentives (e.g. positive recognition, assistance) and disincentives (e.g. penalties)
- understand the knowledge and attitudes of the target audience, as well as the context in which they conduct their work
- undertake community surveys to help identify critical pieces of information, such as the need to develop education materials in several languages, the need to address specific knowledge gaps or attitudes, and the need to deliver educational messages in a form that is compatible with the work environment of the target audience
- undertake campaigns that will take a ‘participatory approach’ and seek to involve the target audience in the design and delivery of the campaign. Campaigns that are able to enhance the participatory element of the program are generally more successful than those that rely upon traditional forms of education
- design educational materials for commercial and industrial premises. These may include; posters, flyers, checklists, brochures, fact sheets, guidelines, magnets, calendars, caps, T-shirts, drain stencils, procedures, training materials (e.g. videos), signs, etc

- investigate the usefulness of educational events, such as training sessions, trade displays and field days (to highlight best management practices and technologies), and free lunches or barbecues (where educational messages are communicated)
- investigate the use of incentives to change behaviours. These could include; promotional give-aways (e.g. spill clean-up kits, signs, Tshirts), free educational events (as described above), recognition in the local media, awards schemes with associated publicity, cash grants, assistance from environmental specialists (e.g. to conduct site assessments and recommend solutions to identified problems), listing in a 'green business directory', licence fee reductions and free waste disposal.

FOCUSED STORMWATER EDUCATION FOR NEW ESTATES

The employment of a developer-funded Stormwater Management / Environmental Officer for a large residential estate/ land development has great potential and should be considered as part of the development's overall stormwater management plan. The Local Government Officer (LG Officer) would play a role during the construction stage to ensure that best practice stormwater management techniques are implemented. This could include educating builders and sub-contractors while they are on-site and helping to maintain the integrity of structural controls, such as infiltration systems, during construction. The LG Officer could also monitor construction practices and erosion and sediment controls. The role could be valuable in educating residents on water sensitive management practices at the building stage, when there is the greatest potential to adopt measures such as waterwise and fertilise wise gardening (e.g. through plant selection) and the reuse of shallow groundwater or roof water. There is also have a role during post-construction in educating new landowners about sustainable practices for washing cars, car maintenance (e.g. changing oil), composting, disposing of animal wastes, disposal of swimming pool discharges, bin washing and how to keep materials, such as lawn clippings and sediment, out of the stormwater management system. The LG Officer could help establish an ongoing environmental group for the catchment area and run community education and participation events. The role could be broadened to include education on all aspects of sustainable living, for example energy efficiency, waste minimization and litter management.

These recommendations are valuable in protecting infiltration systems during construction and educating residents on water sensitive management practices at the building stage, when there is the greatest potential to adopt measures such as waterwise and fertilise wise gardening, and the reuse of shallow groundwater or roof water. Recommendations summarised from the Department of Water (2004) Stormwater Management Manual include:

- develop a local environmental group (e.g. staff from the group may be funded by the developer and/or local government), which would help to build expertise and skills in the area

- engage the community to address a range of sustainable living issues, e.g. stormwater management, water conservation, water sensitive gardening, waste minimisation and energy efficiency.

Structural Control Methods

STORMWATER STORAGE AND USE

Stormwater retention and on-site usage is a part of integrated water cycle management in the urban setting. This best management practice is sometimes referred to as stormwater harvesting. Stormwater retention and use within an urban catchment has the potential to mitigate the impacts of urban development on flow regimes and provide an alternative non-potable water supply source. Capturing stormwater at-source and preventing runoff from small rainfall events also has the benefit of preventing the risk of this runoff picking up and transporting pollutants as it flows through the urban landscape.

Stormwater retention mechanisms include:

- rainwater storage devices, including rainwater tanks;
- below-ground rainwater/stormwater storage units and media filled storage tanks;
- raingardens, including roof gardens and small bioretention gardens;
- stormwater sculptures and water features; and
- managed aquifer recharge (MAR).

RAINWATER STORAGE AND USE

At the lot scale, rainwater storage tank systems are an effective way of capturing stormwater for non-potable use (such as garden watering, toilet flushing, in washing machines and for car washing) and therefore helping to conserve scheme drinking water supplies.

- when designing rainwater storage system consideration is required of the intended uses of the water and the water quality
- rainwater storage tanks should be fitted with a first flush device or filter sock to limit the transfer of contaminants into the rainwater tank that may have built up between storm events
- if collecting roof water, roof gutters should be installed and well maintained. It is recommended that gutter guards or screen mesh be used on buildings to reduce the amount of debris entering the storage tank and minimise the need for maintenance. Leaf diverters are also an important feature in roof water systems
- the harvested rainwater should be used for the purpose identified at the planning stage of Best Management Practice (BMP) selection
- the location of the storage infrastructure will be dependent on aesthetic and space requirements for the chosen device
- the discharge of overflow water should be via overland flow or to an infiltration system
- the required capacity of a rainwater storage system will depend on the water use of the premises, as well as the rainfall and roof area. In areas with a scheme water supply available, roof water tanks with capacities of 1–5 kL are generally sufficient for domestic use. Smaller tanks can also provide water conservation benefits.

MANAGED AQUIFER RECHARGE

Managed aquifer recharge (MAR), also known as artificial recharge, is the infiltration or injection of water into an aquifer (EPA 2005). The water can be withdrawn at a later date, left in the aquifer for environmental benefits, such as maintaining water levels in wetlands, or used as a barrier to prevent saltwater or other contaminants from entering the aquifer. As the water infiltrates or is injected into the soil, natural biological, chemical and physical processes may assist in removing pathogens, chemicals and nutrients from the water, and thus improve water quality.

Recommendation relating to implementation and design of MAR systems include:

- compile an inventory of existing environmental values attributed to the groundwater system, such as drinking water, aquatic ecosystem values and primary industries. This should provide design objectives for planning the MAR system and identify the location of existing bores, their intended uses (e.g. monitoring, public open space irrigation) and groundwater dependent ecosystems (phreatophytic vegetation, caves, wetlands and waterways). As the aquifer may already be providing beneficial uses to others, quality, quantity and flow requirements of these users need to be considered in the aquifer selection
- each MAR proposal must identify potential pollution sources within the catchment and plan risk management strategies, including pollution contingency plans
- detailed hydrologic investigations must be carried out as part of the MAR design process, including identification of ecological water requirements (EWRs) sufficient to maintain and protect groundwater dependent ecosystems under drying climatic conditions
- controls should be incorporated to shut down an injection pump or valve if any of the parameters determined for the project exceed the criteria for the environmental values of the aquifer
- ongoing monitoring should be conducted including monitoring of water levels in valuable groundwater dependent ecosystems
- a monitoring system should be designed to ensure that any treatment system is performing as expected, and that MAR is not causing any adverse impacts to the receiving aquifer.

INFILTRATION SYSTEMS

Infiltration best management practices consist of systems where the majority of the stormwater is infiltrated to the ground, rather than discharged to a receiving surface water body. Infiltration systems cover a wide range of application scales (lot to regional) and include infiltration basins and trenches, soakwells and pervious pavements. Infiltration can also be simply achieved through the provision of a soil surface or vegetated area allocated for this purpose, for example by directing roof runoff to a garden bed.

Infiltration Basins and Trenches

Two primary infiltration systems used at larger scales are infiltration trenches and infiltration basins. Soil types, surface geological conditions and groundwater levels determine the suitability of infiltration systems. Recommendations for design include the following:

- these devices should not be placed in loose Aeolian wind-blown sands. However, well-compacted sands are suitable.
- infiltration devices should not be sited in rock or shale, although site specific permeability should be investigated as some limestone and sandstone permeability can be comparable to medium clays
- soils must be sufficiently permeable to ensure that collected runoff can infiltrate quickly enough to reduce the potential for flooding and mosquito breeding
- root barriers may need to be installed around sections of infiltration systems that incorporate perforated/slotted pipes or crate units where trees will be planted, to prevent roots growing into the system and causing blockages
- infiltration is not recommended for stormwater collected at industrial and commercial sites that have the potential to be contaminated
- stormwater runoff should not be conveyed directly into an infiltration system, but the requirement for pre-treatment will depend on the catchment.

More detailed design considerations can be seen in the Department of Water (2004) *Stormwater Management Manual for Western Australia*.

Soakwells

An alternative method for infiltration is using soakwells. These systems are used widely in Western Australia as an at-source stormwater management control, typically in small-scale residential and commercial applications, or as road side entry pits at the beginning of a stormwater system. Soakwells consist of a vertical perforated liner, with stormwater entering the system via an inlet pipe at the top of the device.

Design considerations for soakwells are similar to those for other infiltration systems. Recommendations include:

- consider the following prior to installation; soil type and stability, topography, separation to groundwater, setback to buildings and pre-treatment to remove sediment, litter and other pollutants
- maintenance is required for efficient operation and to reduce the risk of mosquito breeding, including regular inspection and cleaning to prevent clogging by sediments and litter.
- undertake pre-treatment BMPs to reduce the maintenance requirements by preventing sediments and litter from entering the system.
- install temporary bunding or sediment controls to prevent road/carpark soakwells from being clogged with sediment/litter during road and housing/building construction temporary.

Pervious Pavement

Permeable/porous (collectively termed pervious) paving can be used as an alternative to traditional impervious hard surfaces, such as roads, carparks, footpaths and public squares. Bitumen, concrete and other hard surface areas (such as paving surrounding buildings) are typically impermeable and result in high runoff rates during a storm event. This runoff can be reduced by interspacing permeable material, such as lawn or pebbles, between widely spaced impermeable pavers, or by installing porous paving.

As with other infiltration systems, designing pervious pavement systems requires consideration of the site conditions and potential contamination of the receiving groundwater environment. Other recommendations regarding the design of pervious pavements include the following:

- it is not recommended to use pervious pavement systems in areas with slopes greater than 5% or high wind erosion rates
- soils that feature a rising water table, saline conditions, dispersive clay or low hydraulic conductivity are not suitable for pervious pavement
- regularly vacuum sweep pervious pavement systems to prevent clogging by fine sediment and maintain porosity
- consider the use of sediment traps and vegetation filter strips to prevent sediment entering the system
- pervious pavement should be used for low volume parking and roads with light vehicle use
- to prevent pervious pavement from being clogged with sediment/ litter during road and housing/building construction, temporary bunding or sediment controls should be installed.

CONVEYANCE SYSTEMS

Natural and rehabilitated living streams, bioretention systems and swales are increasingly playing a role in stormwater management, providing conveyance of runoff and an opportunity for water quality improvement and detention and retention of flows. These conveyance systems are being applied locally to newer development areas and can also be retrofitted to existing development areas to replace existing steep sided trapezoidal drains and to rehabilitate degraded waterways. In developed urban areas, these systems are also used to supplement or, where feasible, replace piped drainage.

If designed correctly, these conveyance systems can provide aesthetic, recreational and conservation values in the urban environment.

Swales and Buffer Strips

A vegetated swale is a broad, shallow channel with vegetation covering the side slopes and base. Vegetation can range from grass to native sedges and shrubs, depending on hydraulic and landscape requirements. The treatment efficiency of swales is variable for different pollutants and swales may not provide sufficient treatment on their own to meet water quality objectives. However, when used as part of the overall stormwater management system, swales are a useful at-source and in-transit water quantity management tool, whilst providing initial treatment for water quality outcomes.

Buffer strips are areas of vegetation through which runoff passes while travelling to a discharge point and are therefore aligned perpendicular to the direction of flow. They reduce sediment loads by passing a sheet flow of shallow depth through vegetation. The vegetation acts to slow the flow and trap coarse sediments. Buffer strips typically require uniformly distributed flow, such as sheet flow that comes off a road, car park or other impervious area. Buffer strips also can be applied around other structural BMPs, such as living streams and constructed wetlands.

When designing and implementing swales and buffer strips the following should be considered:

- it is important to ensure flow velocities along a swale are kept sufficiently low to avoid scouring of vegetation and collected pollutants. Typically, the slope is considered to be most efficient between 1% and 4% to ensure that velocities do not scour the channel or compromise public safety, whilst at the same time limit ponding at low flows
- where the longitudinal slope exceeds 4%, riffles along swales should can help to distribute flows evenly across the swale as well as reduce velocities. The riffles maximise the retention time within the swale, further decreasing the velocities and better promoting particulate settling
- vegetated swales can be used for water quality treatment wherever the local climate and soils permit the establishment and maintenance of a dense vegetative cover. The principal selection criteria for swales should address the function of conveyance and ensure that the system has features that will maximise treatment objectives and habitat and aesthetic values
- undertake pre-treatment for swales including litter traps at point source inlets and buffer strips parallel to the top of the banks to pre-treat sheet flows entering the swale
- locate swales in areas that are most effective, such as within public open space or within the centre medians or verges of roads
- swales should not be located within residential verges if other options are available, due to maintenance and safety issues, as well as the need to provide driveway crossings
- traffic movements along the swales should be prevented.

Bioretention Systems

Bioretention systems can be classified as either pervious or impervious. Pervious bioretention systems refer to systems that promote direct infiltration into highly permeable surrounding soils post-treatment. Impervious bioretention systems describe systems in low permeability soils where treated surface runoff cannot be effectively infiltrated and is therefore conveyed out of the system via a subsoil or base drain.

Considerations and recommendations for selecting bioretention systems include the following:

- the following should be understood prior to implementing bioretention systems; the catchment areas to be treated; the slope at the location of the system and of the catchment that drains to it; soil and subsurface conditions; and the depth of the annual maximum groundwater level
- bioretention systems should ideally be used at or close to source to treat small catchments When used to treat larger catchment areas, they tend to clog
- bioretention systems can be used in a greenfields development or retrofitting scenario
- bioretention systems can be applied in almost any soils, since they are designed with runoff percolating through a constructed bed of soil and then returning to the stormwater system. However, it is also possible to design a bioretention system to function like an infiltration system, where runoff percolates into the native soil below the system
- traffic management measures should be put in place to protect the vegetation and prevent compaction of the bioretention system.

Living Streams

Urban waterways are increasingly being recognised for their potential value as multiple use corridors that provide additional benefits to the traditional channel hydraulic objectives. A living stream achieves multiple outcomes, including creating a healthy ecosystem, improving water quality, conveying floodwaters and creating an attractive landscape feature for the residential community.

This management practice is typically appropriate in areas with degraded natural streams and where there is opportunity to modify existing trapezoidal open drains with significant flows in areas of proposed development. Living streams have also been applied to replace sections of piped drainage, particularly as pre-treatment to a receiving water body. Construction of living streams is suitable for ephemeral, as well as permanent, water regimes.

Selecting the location and alignment for living streams is largely dictated by the natural terrain and established flow paths, and in some instances by other planning considerations (e.g. infrastructure requirements). Recommendations for design include the following:

- revegetate around the stream to prevent erosion and improve water quality
- use indigenous species, however grass strips can also be effective
- deciduous species should not be planted as they contribute a significant amount of leaf matter to the organic load over one season and also provide less ecological value. The leaves of deciduous species are also softer and degrade faster than the leaves of native plants, releasing nutrients into the waterway
- design the invert of living streams so as to not intersect the groundwater table. In areas where this is not feasible and the living stream channel intersects the regional groundwater table, groundwater level and water quality investigations should be undertaken to better define the

interaction between the waterway (flow, quality) and groundwater, and provide guidance to the design process

- conduct hydraulic assessments (modelling) if retrofitting of open drains in urban areas is required, or if any changes to existing drain inverts such as meandering or channels is required to ensure the existing flood capacity of the drain is maintained and flood levels are not adversely affected by the works.

DETENTION SYSTEMS

Detention best management practices consist of a range of systems in which stormwater is primarily detained (rather than infiltrated) and water then discharged to a receiving environment. The primary detention system types include constructed wetlands, dry/ephemeral detention areas and on-site detention systems. While the primary function of these systems in many cases is peak flow attenuation and flood protection of downstream environments, in the case of constructed wetlands detention is utilised together with biological processes for pollutant removal.

Dry/Ephemeral Detention Areas

Dry/ephemeral detention areas are landscaped areas formed by simple dam walls, by excavation below ground level or by utilisation or enhancement of natural swales or depressions. These areas primarily serve to capture and store stormwater to prevent excessive runoff and channel erosion in receiving environments, and as areas to remove particulate-based contaminants and sediment. The following recommendations relate to the design and implementation of this system:

- target pollutants should be identified to guide the design of the detention area, as well as site and economic constraints
- dry/ephemeral detention areas should be designed to not alter groundwater levels, which could result in flooding or exposing ASS
- dry/ephemeral detention areas must be designed to minimise the risk of mosquito breeding.

Constructed Wetlands

Constructed wetlands are vegetated detention areas that are designed and built specifically to remove pollutants from stormwater runoff. Constructed wetlands differ from constructed lakes, which are defined as constructed, permanently inundated basins of open water, formed by simple dam walls or by excavation below ground level (Department of Water, 2004).

Constructed wetlands are particularly useful where stormwater contains high concentrations of soluble material that is difficult to remove with other treatment methods. Depending on their design, constructed wetlands can also serve to attenuate larger storm events and reduce peak flows, offsetting the changes to flow frequency relationships caused by increased catchment imperviousness, and protecting downstream environments from erosion and flooding. Constructed wetlands also increase flora and fauna habitat in already urbanised catchments where many natural wetlands have been cleared, drained or filled. They also provide passive recreation opportunities and can provide opportunities for educational and scientific studies.

Before the commencement of site investigations or the design process, the following should be considered:

- establish objectives for the constructed wetland. Objectives can include environmental benefits (such as water quality improvement, detention and erosion control), habitat value (enhancing biodiversity and conservation) or aesthetic and recreational values
- identify the hydrologic regime of the constructed wetland as it has a significant impact on its ability to assimilate nutrients.
- investigate the water quality of the inflow (surface and groundwater), as this determines the size of the wetland and influences the design. Large wetlands are more successful at removing sediment and the nutrients attached to sediment, while wetlands with alternating bed depths are more suitable for removing dissolved nutrients by the nitrification/denitrification process and biofilm growth
- ensure that the soils at the proposed site for a constructed wetland have sufficient water retention characteristics and are able to promote wetland plant growth, particularly during the dry season
- by using the existing site contours this can reduce potentially costly earthworks involved in construction
- consider the potential of mosquito and midge breeding if the wetland is poorly designed.

POLLUTANT CONTROL

The pollutant control devices discussed are litter and sediment management systems (e.g. gross pollutant traps, trash racks, etc.) and hydrocarbon management systems (e.g. oil-water separators). These systems typically operate as one component of an overall stormwater management treatment train protecting the receiving environment. These pollutant control devices are often used where land constraints prohibit the use of other BMPs, or as pre-treatment to other BMPs, such as constructed wetlands.

Litter and Sediment Management

Litter and sediment management (LSM) systems are primary treatment measures that retain gross pollutants by physical screening or rapid sedimentation techniques. Gross pollutants generally consist of litter, debris and coarse sediments.

Through the implementation of water sensitive urban design (WSUD) in stormwater management, the requirement for LSM devices has been significantly reduced, particularly due to the focus on retention of stormwater at-source and ‘disconnecting’ pollutant transport pathways. Non-structural control methods, such as litter collection programs, strategic bin design and placement, sediment controls on construction sites, street sweeping and minimising the use of deciduous plants in streetscape landscaping, also have significant potential to reduce litter and sediment inputs to the stormwater system.

However, LSM systems still have a role to play in stormwater management to complement nonstructural controls and as pre-treatment to other measures, such as constructed wetlands and bioretention systems, where upstream characteristics warrant their use.

LSM systems can be aesthetically unobtrusive as they require a relatively small footprint and can be situated below ground. They are suited for retrofitting to an existing piped drainage system, particularly in highly urbanised areas, and targeting specific problem areas with high loads of gross pollutants. Use of these systems assists in preventing blockages of drains and other conveyance based systems.

There are six commonly used LSM systems in Australia. These range from at-source treatment for the upper reaches of catchments (e.g. side entry pit traps) to those intended for slow-moving waterways (e.g. litter booms) further down the catchment. The six LSM include the following:

- **side entry pit traps** are baskets fitted below the entrances to stormwater systems from road and carpark gutters. When stormwater passes through the basket into the side entry pit, material larger than the basket mesh (typically 5–20 mm) is retained. This material remains in the basket until it is cleaned out during required regular maintenance
- **litter control devices** are baskets sitting below the entry point of the inlet pipe. Water entering the baskets flows out through the openings, while debris larger than the pore size is retained. As debris builds up, it reduces the pore sizes, allowing smaller material to be caught
- **trash racks** consist of vertical or horizontal steel bars, typically 40–100 mm apart, fitted across stormwater channels or inlet and outlet pipes to receiving water bodies. When water passes through the trash rack, it retains material larger than the bar spacing. As material builds up behind the rack, finer material may also be collected
- **gross pollutant traps (GPTs)** typically consist of a sediment trap with a weir and trash rack at the downstream end. Flows enter a large typically concrete lined basin and are detained in the basin by a weir, decreasing flow velocities and encouraging sedimentation. The trash rack collects debris from flows overtopping the weir. GPTs servicing small catchments can be located below ground. These devices typically use a series of underground chambers, weirs, screens or baffles to control flows and trap sediments. An alternative below-ground system is a continuous deflective separation (CDS) device, which operates by diverting the incoming flow of stormwater and pollutants into a chamber that has a circular screen that induces a vortex to keep pollutants in continuous motion, preventing solids from ‘blocking’ the screen. The secondary flows induced by the vortex concentrate sediment in the bottom of the unit. Water passes through the screen and flows downstream

- **floating debris traps**, or litter booms, are made by placing partly submerged floating booms across waterways to trap highly buoyant and visible pollutants such as plastic bottles. The booms collect floating objects as they collide with it. Newer designs use floating polyethylene boom arms with fitted skirts to deflect floating debris through a flap gate into a storage compartment. Floating booms are not suited to fast moving waters. Additionally, the traps miss most of the gross pollutant load because only a small fraction of gross pollution remains buoyant for a significant length of time
- **sediment basins** may be concrete lined, or built as more natural ponds excavated from the site soils and stabilised with fringing vegetation. The basins consist of a widening and/or deepening of the channel so that flow velocities are reduced and sediment particles settle out of the water column. Macrophytes planted in and around the basin will assist in minimising the risk of sediment re-suspension. A pervious rock riffle or weir at the outlet may also assist filtering the water and preventing the conveyance of sediment downstream. Sediment basins are often used as pre-treatment to remove coarse sediment prior to flow entering a constructed wetland system.

When determining whether to use LSM systems, the following should be considered:

- the principal design objective of LSM systems is to achieve a balance between the impact on the discharge capacity of the drainage system, the trapping efficiency of the unit and the capital and maintenance costs
- the selection and positioning of LSM systems need to be strategic as these devices can be expensive to install and maintain
- the design of LSM systems must also consider that previously trapped material may be remobilised when high inflows causing turbulence or overflows occur
- vegetation can be used to disguise the LSM system, as well as prevent easy access to the structure.

HYDROCARBON MANAGEMENT

The primary aim of hydrocarbon pollution management is to provide at–source containment through the implementation of appropriate structural measures. Non-structural techniques, such as raising the awareness of operators or imposing heavy fines for illegal discharges, are also useful preventive measures. Compliance with control requirements incorporated into building approvals and industry operating licences, as well as pollution discharge inspection and monitoring, help to better regulate the principal sources of contamination. Guidelines to the implementation and consideration of managing hydrocarbon pollution include the following:

- use oil-water separators in retrofit situations to provide some water quality treatment at a lot scale, particularly for small industrial or commercial lots where larger BMPs are not feasible due to site constraints

- separators are best used in commercial, industrial and transportation type land uses (i.e. impervious areas that are expected to receive high sediment and hydrocarbon loadings, such as carparks and service stations)
- oil-water separators cannot be used for the removal of dissolved or emulsified oils such as coolants, soluble lubricants, glycols and alcohols
- only rainfall runoff that may contain hydrocarbons (e.g. runoff from carparks or areas adjacent to fuel pumps) should enter the oil-water separator that is part of the stormwater treatment system
- runoff that is relatively clean (e.g. roof runoff) should be managed separately to minimise the volume of stormwater that requires a high level of treatment
- oil-water separators installed to treat stormwater runoff at industrial or commercial sites should not be used to collect and treat wastewater or fluids from chemical or petroleum spills
- evaluate any maintenance and disposal issues
- higher residual hydrocarbon concentrations in trapped sediments cause maintenance and residual disposal costs associated with oil-water separators to be higher than other BMPs
- proper disposal of trapped sediment, oil and grease is required as trapped material is likely to have high concentrations of pollutants and might be toxic
- ease of access for maintenance and inspection is required, in particular, lids should be kept as lightweight as practical
- oil-water separators should be designed and constructed as offline systems only
- it is recommended that the contributing area to any individual inlet be limited to approximately half hectare or less of impervious surface.