Government of Western Australia

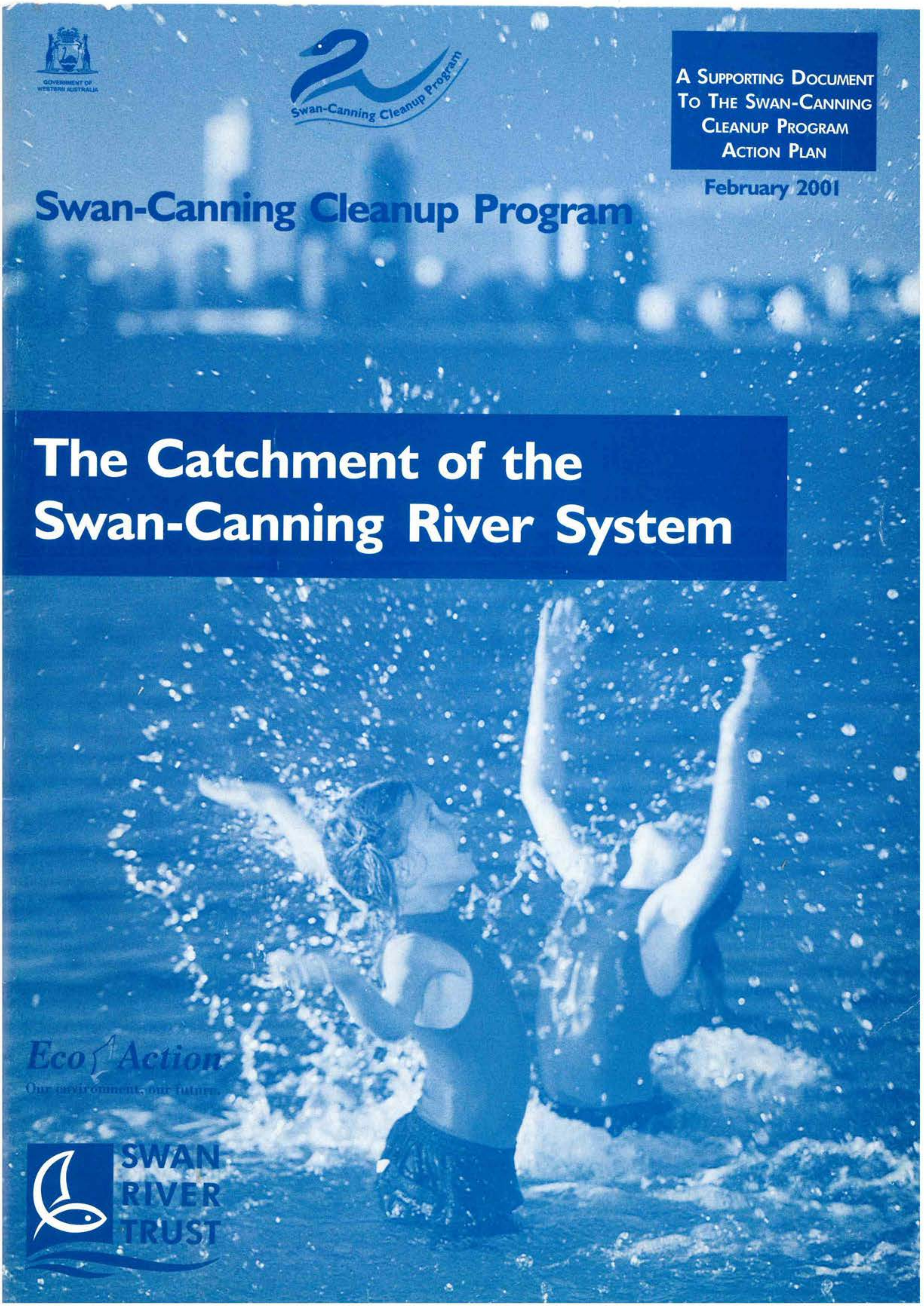
Swan-Canning Cleanup Program

A Supporting Document To The Swan-Canning Cleanup Program Action Plan

February 2001

Swan-Canning Cleanup Program

The Catchment of the Swan-Canning River System



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Swan-Canning Cleanup Program

The Catchment Of The Swan–Canning River System

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Information compiled in 1997, published February 2001

WATER AND RIVERS COMMISSION

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Summary

The Swan and Canning River System (SCRS) is one of the most vitally important natural resources of the Perth Metropolitan Region and yet the health of the SCRS has been on the decline for many years. This situation is primarily due to high nutrient loads in several of the watercourses draining the catchment area.

A Catchment Management Technical Advisory Committee (shortened to Catchment Advisory Committee or CAC) was formed in 1996, under the auspices of the Swan–Canning Cleanup Program (SCCP) Task Force, to develop catchment action recommendations for the SCCP Action Plan. The strategic aim of the CAC is *to foster the coordinated and sustainable use of the catchments in the SCRS*. Hence, the purpose of this report is to place in perspective the problems of the catchment area and, in keeping with the aims of the SCCP, to outline a management strategy designed to overcome them.

The focus of the report is on the coastal plain (ie. the hinterland of the Perth Metropolitan Region) which is a relatively small component of the greater Swan-Avon catchment, which has an area in excess of 120,000 km^2. However, sight is not lost of the fact that the Swan-Avon catchment has one of the largest river systems in Western Australia. The Avon River contributes 60% of the flow, but the amount of water discharged varies greatly from year to year due to variations in the time of onset, duration and intensity of rainfall.

A large number of water quality studies have been undertaken to assess the health of the river system. The rural catchments of Ellen Brook and the Avon River are the major contributors of nutrients, between them carrying, on average, approximately 37 tonnes of phosphorus (P) and 324 tonnes of nitrogen (N) per year. Approximately 70% of the P load is contributed in the winter months from rural catchments, when low-lying fertilised pastures become waterlogged. In contrast, 24% (17.5 tonnes) of the total P load and 21% (155 tonnes) of the total N load enters the SCRS via urban drains. Urban pollution loads of toxic substances such as copper, cadmium, lead, chromium and zinc have been of concern but, generally speaking, industrial point sources of pollution appear to be under control.

In the last decade, the amount of P being exported from sub-catchments such as Bennett Brook, Blackadder Creek, Bayswater and Bannister Creek has noticeably declined. Both improvements and declines in water quality have been detectable in the case of Ellen Brook and the Southern River catchments. However, there has been no consistent improvement in the water quality in sub-catchments such as the Mills Street Main Drain.

Although all catchment matters are interrelated, the report briefly outlines the range of catchment management issues that confront managers of the SCRS. In the rural catchments these issues include, but are not necessarily limited to, agricultural activities such as grazing enterprises, horticulture, turf farming and intensive livestock operations. Issues such as soil erosion, nutrient shedding, rural housing, river regulation, fire management, loss of habitat, riparian zones and biodiversity are described, as well as concerns about aquaculture, soil testing procedures and interbasin transfers of water. In urban catchments the issues described include non-point source pollution, point source pollution, high-density housing, run-off from parklands, recreation areas and roads, water use, unsewered and sewered areas, wastewater overflows, dewatering operations, solid waste disposal, drain maintenance, weed encroachment, urban growth, habitat fragmentation, soil erosion and sedimentation.

The report also draws attention to a number of organisational issues that appear to have hampered effective management of the catchment. These include EPP water quality targets, the lack of accountability, legislative powers and interagency cooperation. The type of support needed by rural and urban volunteer groups is also perceived to be lacking. Hence, in order to bring about behavioural change within directly affected communities, attention is drawn to the need to share the burden of what is termed "Integrated Catchment Management" (ICM) and for networking among practitioners.

Attention is then drawn to the options available for improving land and water management in the catchment of the SCRS. In the rural catchments these options range from fertiliser management to soil amendment, fire management, riparian management, nutrient uptake by tree cropping, nutrient stripping, recycling, wetland creation and restoration, land

capability assessment and catchment management planning. In the urban catchments similar options apply but others, such as Water-Sensitive Urban Design, land drainage planning, cluster housing, wetland protection and the establishment of multi-use corridors, are also highlighted. A number of engineering options (or intervention techniques) are emphasised, including the use of compensation basins, the retrofitting of existing drainage systems, groundwater interception, deep sewerage of residential and industrial areas, and chemical intervention. Finally, attention is drawn to the type of policy options that are available to improve the health of the catchment. These include a variety of fiscal measures, the reviewing of town planning schemes and the opportunity for making catchment management a truly cooperative venture.

In its concluding sections, the report emphasises that the SRT's intention to establish a strong foundation for effective catchment management requires long-term commitment, great determination and large sums of money to see the process through to completion. In an area as complex as the catchment of the SCRS this statement is particularly true and, for this reason, the Task Force is advised to "think locally".

Another of the conclusions drawn by the CAC is that the provision of a legally enforceable basis for achieving the goals of the SCCP, in the form of an Environmental Protection Policy (EPP), is vital. Without such powers being available to show that the government is serious about achieving the goals of the SCCP, and without a mechanism in place to 'persuade' farmers to adopt a non-regulatory approach to catchment management, the CAC considered that *the risk of the SCCP and its objectives failing is high.* At the same time, because they are designed to *encourage* rather than *require* conservation efforts, the CAC contends that a combination of fiscal measures and community involvement approaches to catchment management stand the best chance of success.

With regard to the control of phytoplankton blooms and poor water quality in the SCRS, the CAC maintains that the ultimate, long-term solution will depend on the extent to which nutrient export from the catchment can be effectively controlled. The CAC considers that this can only be achieved by *reducing fertiliser inputs, increasing nutrient uptake and changing landuse within the catchment area* and, to this end, offers **eight recommendations**. The recommendations concerned are that:

- The four sub-catchments of the SCRS that were recently contributing the largest nutrient load to the estuary are initially targeted by the SCCP as the main focus for the development of catchment management plans. The catchments concerned are the Ellen Brook catchment, the Southern–Wungong River catchments, the Bayswater Main Drain and the Upper Canning catchment.
- The approach to management in the catchment should be directed at '*source management*' by means of a participative planning process. The latter will require the introduction of an innovative program of economic incentives to change landuse in specific high-risk areas; to reduce fertiliser inputs; to increase precipitation uptake; and to restore a natural run-off pattern in the catchment.
- For the purpose of joint decision making, the views and aspirations of all stakeholders should be accommodated and balanced accordingly. The process involved will require the creation of an Interdepartmental Catchment Management Forum and a Catchment Management Liaison Unit, as well as requiring that the five Technical Advisory Committees of the SCCP work more closely together. Every possible form of assistance will also need to be given to the formation of ICM Groups and to their ongoing support.
- The existing landuse controls in the catchment of the SCRS are improved by undertaking a systematic review of Metropolitan and Town Planning Schemes to ensure that they are environmentally sustainable and incorporate nutrient reduction principles. It is recommended that a Statement of Planning Policy is prepared for the SCRS and, if need be, that the *Environmental Protection Act 1986* is utilised to delegate powers to an agency (such as AGWEST) to regulate fertiliser use and landuse.
- A fiscal approach to management is adopted by actively developing servitude and/or foreshore management agreements with landowners in high-risk areas, and that a consistent regulatory definition of the lands affected be agreed to.

- Urgent consideration is given to the appointment of experienced resource managers to fill the position of catchment coordinators, and to developing an environmental indicator program at a farm level to detect trends in catchment condition. It is suggested that local Councils that are not yet involved in the SCCP are invited to participate and that all local Councils are provided with the funds needed to appoint environmental officers. It is also suggested that a definitive set of management guidelines, based on water sensitive design principles, be prepared for the rural catchments of the SCRS.
- With a view to better exercising control over nutrient ingress into the SCRS, further research is undertaken with the aid of both State and NHT funding. The projects concerned include quantifying the nutrient balance in the urban catchments; quantifying the sediment yield from each of the major catchments; quantifying fertiliser usage on turf farms, parks and gardens in high-density residential areas; developing ecotoxicology testing; evaluating the significance of historical landfill sites, and of contaminated sites in industrial areas as contributors to pollution; and conducting an audit on the economic costs of management without adequate buffer zones in the major catchments of the SCRS.
- Any statutory limits for nutrient inputs from the catchment of the SCRS include nitrogen and not just phosphorus, particularly in light of the opportunity to set nutrient limits as part of the recently gazetted Swan–Canning EPP.

Four-point Action Plan summary

1. Support Integrated Catchment Management to reduce nutrient inputs

- Strengthen Integrated Catchment Management in the Swan–Canning catchment and support ICM groups.
- Develop and implement catchment management and farm plans and manage drain inputs to reduce nutrients.
- Raise awareness and provide support to enable the participation of landholders, catchment and river groups, local government and the broad community in catchment and river management.
- Improve government coordination and support.

2. Improve planning and landuse management to reduce nutrient inputs

- Use statutory mechanisms including regulations, by-laws, town planning schemes and statements of planning policy to modify landuse practices and prevent or relocate polluting activities.
- Develop and adopt Best Management Practices to reduce nutrient inputs in current land management practices and in all future developments, re-developments and stormwater drainage schemes.
- Use economic and regulatory mechanisms to encourage catchment, wetland and river foreshore management for nutrient reduction.

3. Modify river conditions to reduce algal blooms

- Develop and implement river manipulation and remediation techniques to reduce algal blooms in the Swan–Canning system.

4. Monitor river health, fill critical gaps in knowledge and report progress to the community

- Adopt recommended water quality targets for the freshwater tributaries of the Swan–Canning system until the year 2005 and use this to assess performance of the Action Plan.
- Undertake investigations to fill critical gaps, monitor the river conditions and produce a "State of the Swan–Canning system" report every five years.
- Report progress regularly to the community and ensure opportunities for feedback and for involvement in the adoption and implementation of the Action Plan.

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1. Overview of Swan–Canning coastal plain catchment

The Swan and Canning River System (SCRS) is one of the most vitally important natural resources of the Perth Metropolitan Region. In its lower reaches the estuary is the scenic and recreational heart of Perth and is claimed in certain circles to be '*the cleanest river of any capital city in the world*' (Anon, 1996a). In reality, the health of the SCRS has been on the decline for many years and there is no room for complacency in this regard. The regular appearance of algal blooms in the upper reaches of the Swan Estuary, due to high nutrient loads in several of the rivers draining the catchment area and the large volumes of gross pollutants in the form of litter and debris, serve to illustrate the point. In 1995, for example, field staff of the Swan River Trust (SRT) removed 123 tonnes of domestic rubbish, 347 tonnes of weed, 253 tonnes of floating debris and 12 tonnes of dead fish from the waterways and foreshore areas (Anon, 1996a).

The purpose of this report is to place in perspective the problems of the coastal catchment area and, in keeping with the aims of the Swan–Canning Cleanup Program (SCCP), to outline a management strategy designed to overcome them. The report concentrates on coastal plain issues because SCCP is only focussed on the coastal plain, where a range of urban and semi-rural landuses directly impact on water quality. A number of State and Federal programs have been established to address issues in the greater Avon catchment, for example Natural Heritage Trust (NHT) initiatives and the *Western Australian Salinity Action Plan*. While there are a number of common issues and solutions relevant to both catchments, this report deals primarily with landuse effects within close proximity to the coastal plain.

The first draft of the report was completed in July 1997. However, this report was later reviewed and significantly updated, and was finalised in April 2000.

1.1 Biophysical characteristics

1.1.1 Extent

The catchment of the SCRS is 2,100 km^2 in size. However, it occupies only 1.74% of the Swan-Avon catchment which is approximately 120,500 km^2 in extent and is one of the largest river systems in Western Australia (**Figure 1**).

The catchment of the SCRS extends from Lennard Brook near Gingin in the north, to the Mundaring dam on the Helena River in the east, to the Wungong and Canning dams in the Armadale area in the south. The catchment can be divided into five geographically distinct subregions. These are the Ellen Brook catchment; the Hills catchments; the Southern River/Wungong Brook catchment; the Gnangara and Jandakot Mounds and the urban areas surrounding the lowermost reaches of the Swan Estuary (**Figure 2**).

1.1.2 Geology and geomorphology

The catchment of the SCRS is formed almost entirely of depositional material, either from fluviatile or aeolian activity (McArthur & Bettenay, 1974). The main geomorphic elements of the area (**Figure 3**) lie sub-parallel to the coastline and reflect events that took place two million years ago when sea level fluctuations caused the coastline to change position several times. These elements comprise:

- *The Spearwood Dune System* (or Coastal Limestone Formation)- a core of aeolionite with a hard capping of secondary calcite (lithified dunes), overlain by variable depths of yellow or brown siliceous sand.
- *The Bassendean Dune System* (or Coastal Sand Plain Formation)- a series of low hills of highly permeable bleached (or white) siliceous sand, interspersed with extensive areas of poorly drained soils or seasonally waterlogged flats (palusplains).

- *The Pinjarra Plain* (or Guildford Formation)- an area of unconsolidated alluvium (riverine deposits) lying at an altitude of approximately 40m above sea level at the foot of the Darling Scarp. Variable soils (clay to deep sands), generally characterised by poor drainage.
- *The Darling Scarp (or Ridge Hill Shelf)*- a narrow, highly dissected strip of country (altitude: 80 -200m above sea level) forming the foothills of the Darling Plateau, that slopes westward and is characterised by a residual laterite on the surface.
- *The Darling Plateau*- a gently undulating area of Precambrian gneisses and granites, overlain by laterite ridges with sands and gravels in shallow depressions. The Plateau is intersected by both major and minor valleys containing tributaries of the Swan River, such as Susannah Brook, Jane Brook and the Helena River.

1.1.3 Soils

Broadly speaking, the major soil types associated with the catchment of the SCRS (**Figure 4**), are:

- Deep, well-drained, grey sandy soils (e.g. Bassendean and Southern River formations).
- Poorly-drained, shallow sands (e.g. Yanga and Beermullah formations).
- Gravelly and sandy soils (e.g. Forrestfield formation) on laterised foothills of Darling Scarp.
- Red and yellow earths of the Darling Scarp which, lying on steeply sloping land, are major silt sources in the catchment.
- Medium-textured duplex soils characterised by deep yellow sands over a relatively impermeable clay layer (e.g. Guildford formation).
- Alluvial soils along major watercourses and sandy silts deposited along creek lines (e.g. Swan formation of red earths and duplex soils).
- Swamp deposits comprising dark grey/black, highly acidic, peaty clays with low permeability and high organic content. Characteristically flood prone, but highly prized as horticultural soils.

The sandy soils of the Bassendean, Southern River, Yanga and Beermullah formations are naturally extremely infertile. They also have very low capacities to retain nutrients applied in fertilisers.

Fertiliser nitrogen (N) is usually applied in the ammonium form as ammonium sulphate, ammonium nitrate or urea. In well aerated sandy soils, the conversion of ammonium-N to nitrate-N is very rapid and may be almost complete within only a few hours in soils under horticulture (McPharlin *et al.*, 1995b). Nitrate-N is not retained (absorbed) by soil constituents and is, therefore, available for leaching by rainfall or over watering. The rate of loss of nitrate-N from the topsoil is probably very similar for all the sandy soils of the Swan Coastal Plain.

The sandy soils of the Swan Coastal Plain vary in their capacity to retain fertiliser phosphorus (P), which depends on the concentration of iron and aluminium oxides. The grey to white Bassendean sands have very low concentrations of these oxides and, therefore, have almost zero phosphorus retention capacity. The phosphorus retention index (PRI) test (Allen & Jeffery, 1990) was developed in Western Australia specifically to differentiate the P retention capacities of sandy soils.

The PRI of unfertilised sandy soils on the Swan Coastal Plain varies from less than 0.5 for Bassendean sands (very low phosphorus retention capacity) to 8-10 for Spearwood sands (moderate phosphorus retention capacity).

There is another factor that diminishes the overall phosphorus retention capacity of sandy soils of the SCRS catchment. This factor relates to increases in the rate of leaching of phosphorus relative to sandy subsoils, of similar PRI, from other areas of the state. The level of accumulation of phosphorus normally increases over time by a factor of 5-10 times compared with initial estimates based on the PRI test. However, subsoil sands on the Swan Coastal Plain increase phosphorus accumulation over time by only a factor of 1.5-2 times (McPharlin & Jeffery, unpublished).

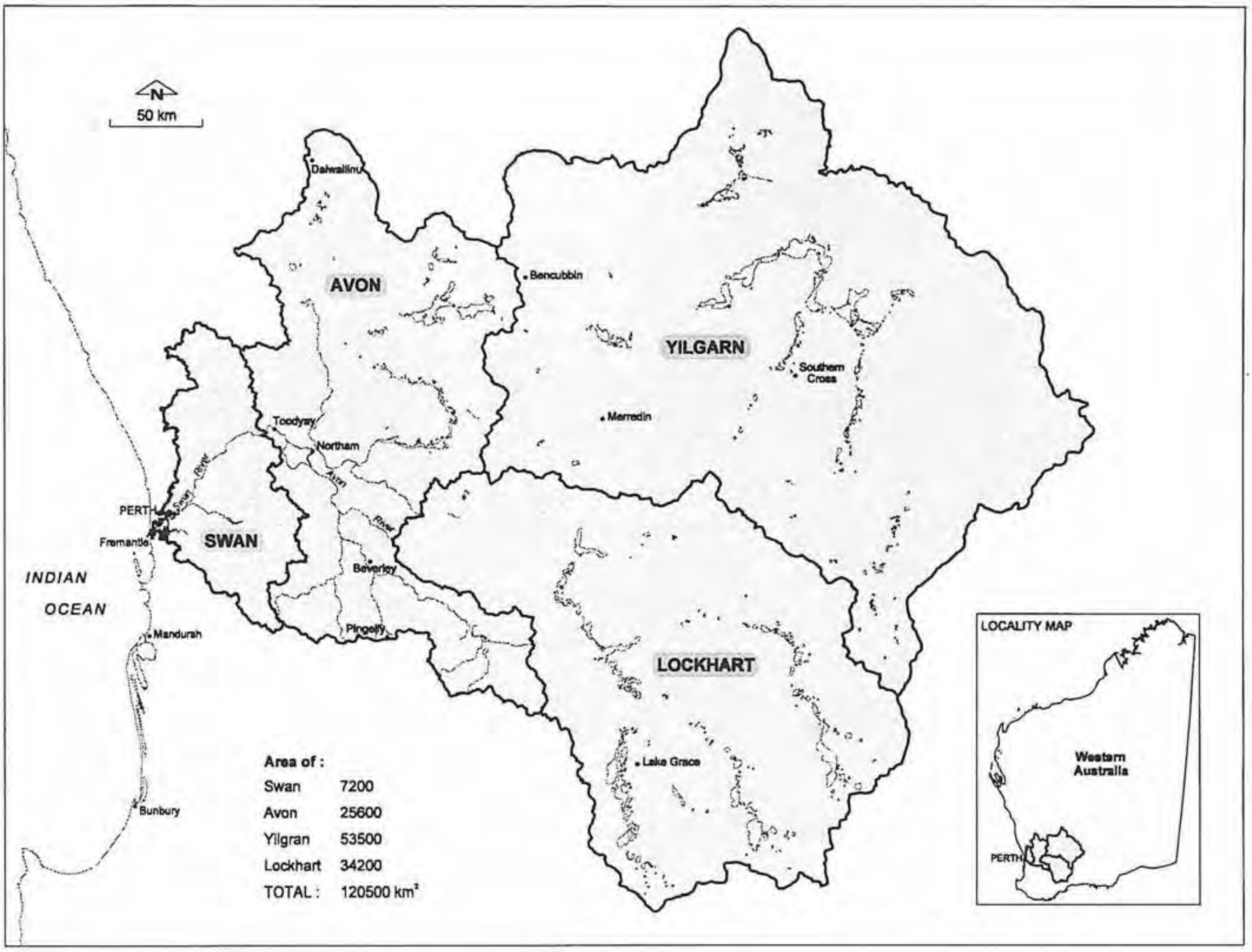

Figure 1: The catchment of the Swan/Avon River System

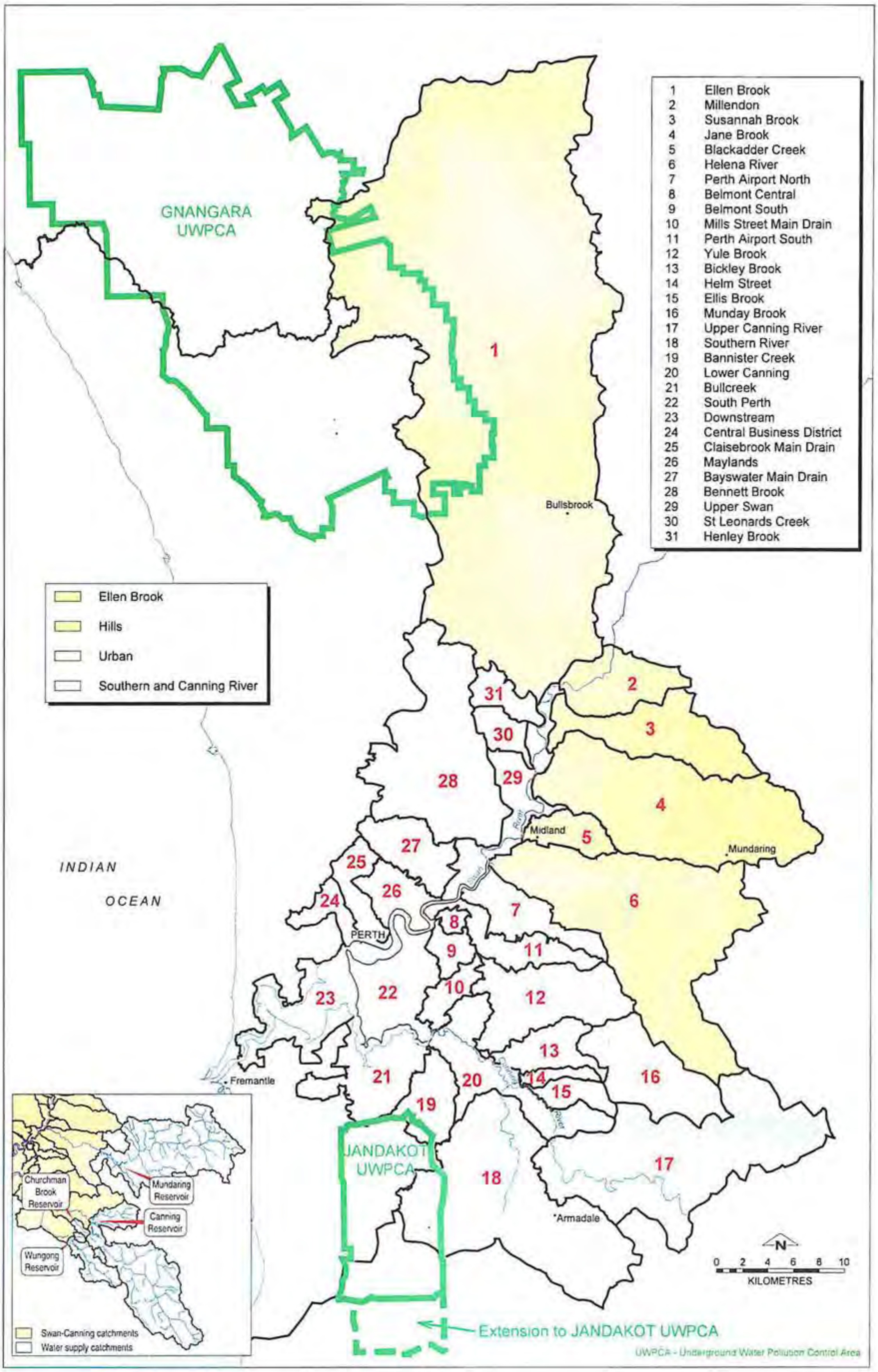

Figure 2: The sub-catchments of the Swan–Canning River System

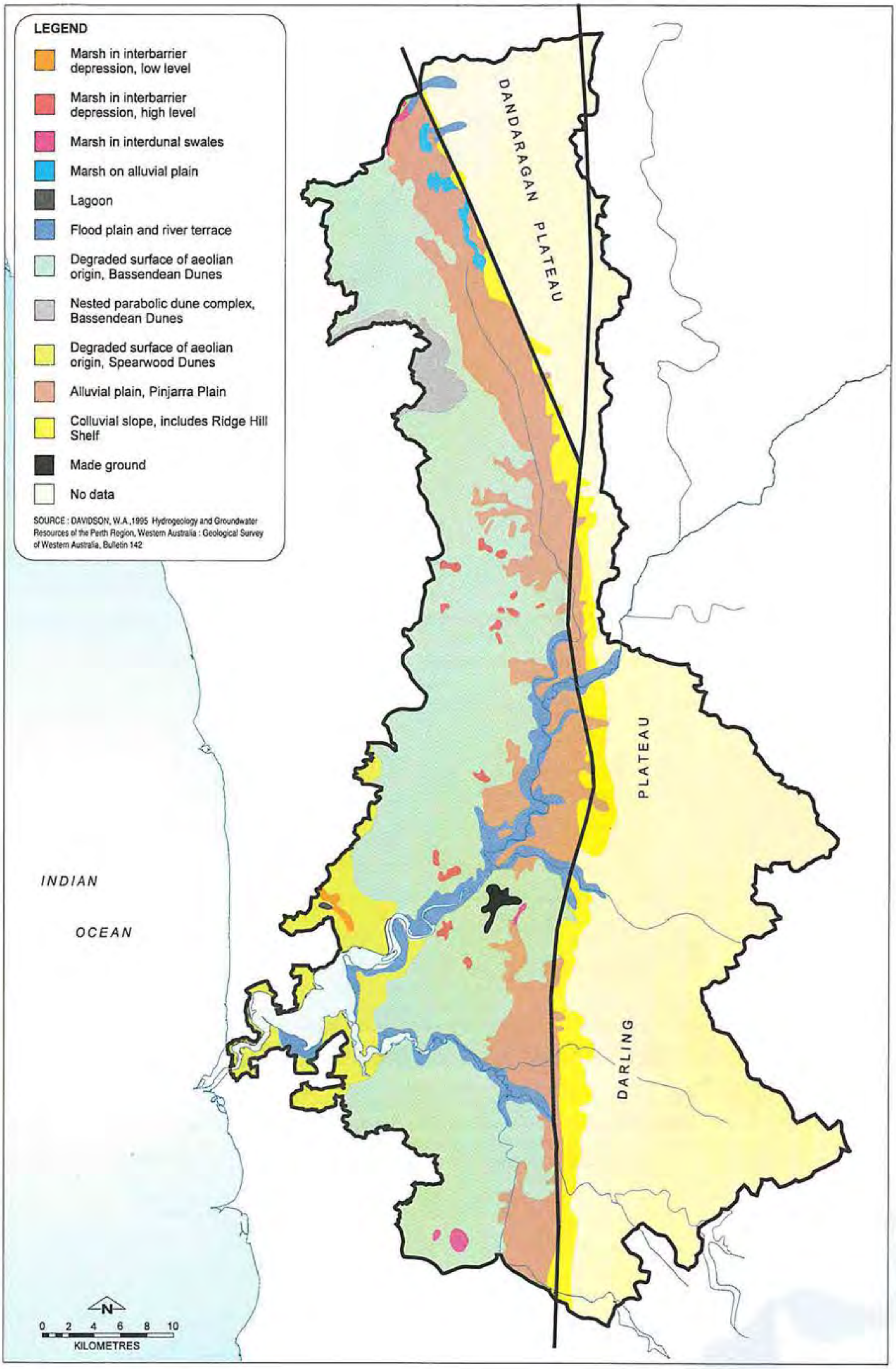

Figure 3: Geomorphology of the study area

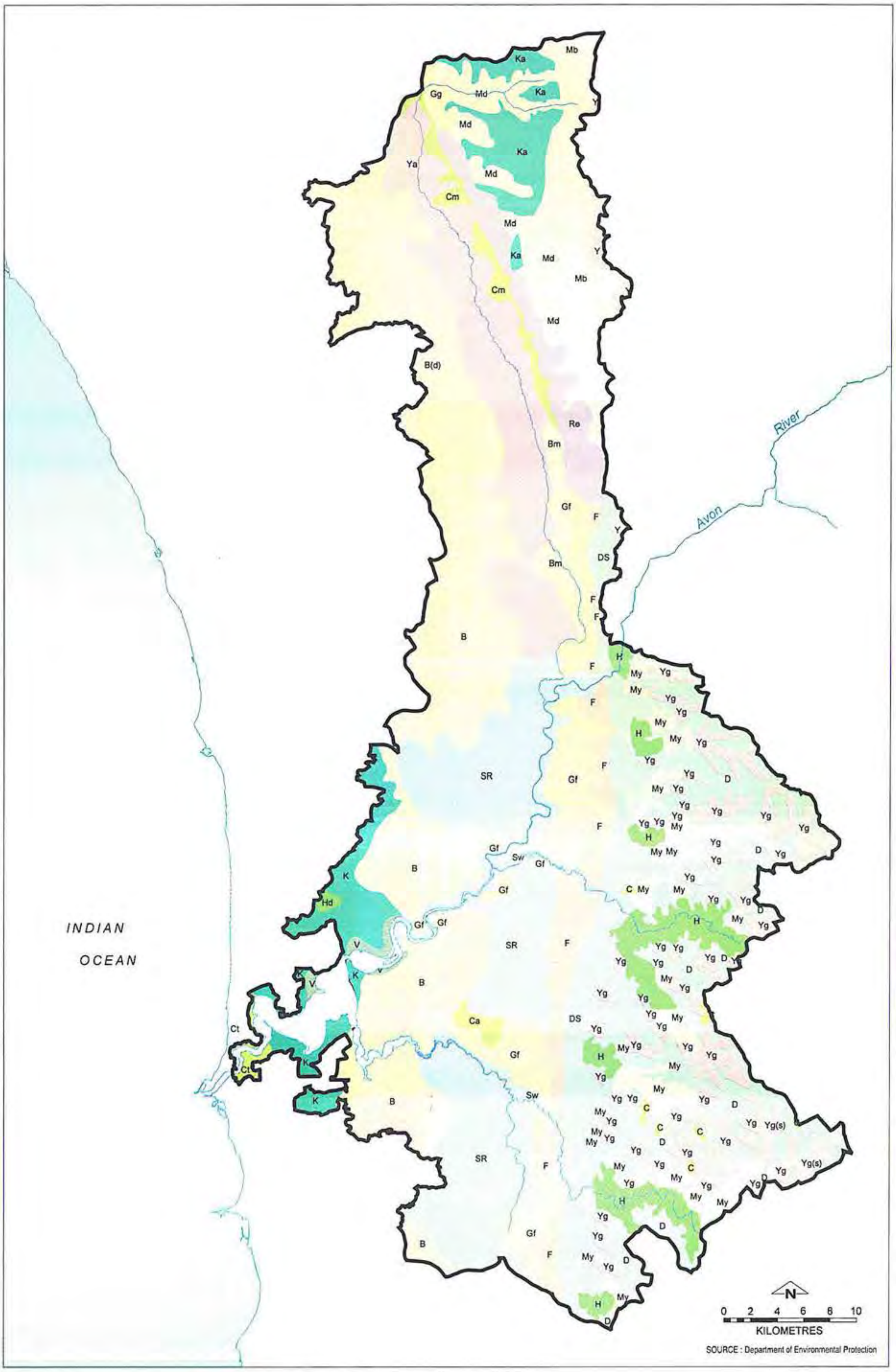

Figure 4: Major soil types of the study area

Soil Type and Description

A	AVON: Narrow sandy terraces floors.
Ab	ABBA: Poorly drained plain with medium\textured deposites; yellow duplex soils and\some shallow sands over bog iron ore.
B	BASSENDEAN: Sand plains with low dunes\and occasional swamps; iron or\humus podzols.
B(d)	BASSENDEAN: Sand plains with low dunes\and occasional swamps; iron or\humus podzols with areas of complex\steep dunes shown by B(d).
Ba	BALINGUP: Incised valleys; red and yellow\earths and duplex soils on slopes;narrow\alluvial terraces; swampy floor(s).
Bi	BINDOON: Steep irregular slopes with\shallow red and yellow earths and\much rock outcrop
Bm	BEERMULLAH: Poorly drained plain; saline\and solonetzic soils
Bo	BOOTINE: Poorly drained plain; large\permanent lakes with intervening red and\brown sandy benches; also some\solonetzic soils
Br	BROCKMAN: Narrow terraces floor with red\earths and brown alluvial soils.
Bt	BRIDGETOWN: Very deeply incised vallyy of\the Blackwood River; shallow red and yellow\earths and rock outcrop on slopes; narrow\all
C	COOK: Hills rising above general plateau level;\mainly mantled by laterite but with some rock outcrop.
Ca	CANNINGTON: Poorly drained plains with\calcareous substrate; yellow duplex\soils with minor areas of red and\black clays over limes
Cc	CATTERICK: Valleys of the south-eastern part\of the plateau; yellow duplex soils and red\earths on slopes; narrow alluvial terrace.
Cd	CALADENIA: Low dunes of yellow sand\with intervening discrete round swamps.
Ck	COOLAKIN: Valleys of the eastern part of the\plateau; sandy and gravelly duplex soils on the\slopes; narrow valley floors; some roc
Cm	COONAMBIDGEE: Gently sloping fringe to\the Dandaragan Plateau; deep grey sands.
Co	COLLIE: Gently undulating landscape\dominated by durecrust
Cr	CARDIFF: Broad shallow swampy depressions\dominated by grey sands.
Cs	CARTIS: Gently sloping fringe to the Blackwood\Plateau: grey or yelllow sands with some\gravels.
Ct	COTTESLOE: Low hilly landscape with\shallow brown sands over limestone
Cu	CULLALA: Aeolian sandplain with some\low dunes; occasional swamps.
D	DWELLINGUP: Gently undulating landscape with\duricrust on ridges; sands and gravels in shallow\depressions.
Da	DARRADUP: Sandy terraces and flanking\sandy slopes of the Blackwood River.
Dp	DARDANUP: Alluvial fans with dark brown\loamy soils.
DS	DARLING SCARP: Very steep slopes with\shallow red and yellow earths and much\rock outcrop.
F	FORRESTFIELD: Laterised foothills of the\Darling Scarp dominated by gravelly and\sandy soils.
G	GOONAPING: Shallow upland valleys with grey\sands and some swamps.
Gf	GUILDFORD: Flat plain with medium textured\deposites; yellow duplex soils.
Gg	GINGIN: Gently sloping irregular scarp;\mainly red sandy soils with associated small\areas of red duplex soils and shallow black\cl
H	HELENA: Very deeply incised valleys with\steep rocky slopes and some shallow red\or yellow earths.
Hd	HERDSMAN: Peaty swamps associated\with Bassendean and Karrakatta\units.
Hr	HESTER: Narrow plateau remnants with duricrust\and gravels flanked by gravelly duplex soils.
J	JARRAHWOOD: Minor valleys with gravelly\and sandy slopes and a narrow sandy\terrace.
K	KARRAKATTA: Undulating landscape with\deep yellow sands over limestone.
Ka	KARAMAL: Gently undulating landscape\dominated by deep yellow sands; some\gravels on ridges.
Ki	KINIGIA: Gently undulating divides with\duricrust
Lo	LOWDON: Steep irregular slopes with\shallow red and yellow earths and duplex\soils; rock outcrop; gently sloping\apron at base.
M	MUNGALA: Plains dominated by shallow\black clays on marl; some red and\brown sandy rises and occasional bog\iron ore.
Mb	MOGUMBER: Gently undulating landscape;\duricrust and gravels on crests and grey\sands in broad shallow depressions.
Md	MOONDAH: Valleys with deep red and yellow\brown sands; occasional swamps.
Ml	MUMBALLUP: Terraced floor of the Preston River;\red earths and duplex soils and brown alluvial\soils.
Mn	MICHIBIN: Moderate slopes with yellow\duplex soils and some rock outcrop.
Mo	MOORE: Sandy terraces and slopes\of the Moore River as it traverses the\Coastal Plain and adjacent Dandaragan\Plateau.
Mp	MUNGARDUP: Broad depressions with sandy\yellow duplex soils on slopes; swampy\floors.
Mu	MUJA: Minor valleys with gravelly slopes\and sandy swampy valley floors(s).
My	MURRAY: Deeply incised valleys with red\and yellow earths on slopes; narrow\alluvial terraces.
No	NOONING: Terraces floors of Upper\Brockman River;yellow duplex soils and\sandy deposites; some swamps.
Pn	PINDALUP: Valleys of the central part of the\plateau; gravelly duplex soils on slopes; some\rock outcrop; grey sands
Pn(s)	PINDALUP: Valleys of the central part of the\plateau; gravelly duplex soils on slopes; some\rock outcrop; grey sands
Pr	PRESTON: Major valleys with sandy and\gravelly slopes; red earths and duplex soils\on valley floors.
Q	QUINDALUP: Dunes and beach ridges\composed of calcareous sand.
Re	REAGAN: Gently sloping scarp dominated\by yellow or grey sands; some\duricrust and gravels.
Sp	SERPENTINE RIVER: Poorly drained plain\with fine textured alluvial soils.
SR	SOUTHERN RIVER: Sandplain with low\dunes and many intervening swamps; iron\and humus podzols
Sw	SWAN: Alluvial terraces with red earths\and duplex soils.
V	VASSE: Poorly draines plains with variable\undifferentiated estuarine and marine\deposits.
W	WILLIAMS: Terraces with yellow duplex soils.
Wg	WILGA: Flat or gently undulating divides with grey\sands; some swamps.
Wn	WANNAMAL: Aeolian sandplain with low\sand dunes; extensive swamps.
Y	YALANBEE: Gently undulating landscape dominated\by fine gravels; some duricrust on ridges.
Ya	YANGA: Poorly drained plain with grey\sandy benches and intervening swamps;\also areas of bog iron ore
Yg	YARRAGIL: Valleys of the western part of the\plateau; sandy gravels on the slopes; orange\earths in swampy floor(s)
Yg(s)	YARRAGIL: Valleys of the western part of the\plateau; sandy gravels on the slopes; orange\earths in swampy floor(s) - VALLEY FLOORS
Yo	YOONGARILLUP: Plains with low ridges and\swales;shallow yellow and brown sands\over marine limestone.

1.1.4 Hydrology

Despite the large size of the Swan-Avon catchment, the annual water discharge is low because east of the Darling Scarp rainfall rapidly decreases and much of the inland catchment receives less than 400 mm of rain each year. The typical discharge from the river system in a year of average rainfall is 400–500 million cubic metres (Hillman, 1985). The inflow from groundwater comprises another 20 million cubic metres per year (Appleyard, 1992). The Avon River contributes 60% of the flow (Hamilton, 1996) but the amount of water discharged varies greatly from year to year due to variations in the time of onset, duration and intensity of rainfall (Spencer, 1956; Sharma & Hughes, 1985). During a period of above average rainfall (e.g. 1974) the mean annual run-off can increase to 1474 million cubic metres whereas, in a period of low rainfall, it can diminish to as little as 102 million cubic metres (Hillman, 1985).

The average rainfall of 800 mm/year on the coastal plain is the primary source of recharge, but the quantity of run-off derived from influences such as the recharge from septic tanks, is also considered to be significant (Gerritse *et al.*, 1990). In summer and autumn, which are the critical months for algal blooms, almost 100% of the input is attributable to groundwater discharges (Appleyard, 1992). Urban drains contribute 16% of the total annual flow from the catchment (Henderson & Jarvis, 1995).

Due to the gently undulating or flat topography and the widespread occurrence of poorly drained soils, the catchment of the SCRS is characterised by an extensive and complex network of rivers, streams and drains (**Figure 5**). For example, in the 27 km^2 catchment of Bayswater Main Drain alone, the drainage system consists of a network totalling 215 km of drains which were installed by the Water Authority of Western Australia (Water Corporation) as long ago as 1958 to facilitate the establishment of septic tanks in the area (Klemm & Switzer, 1994). The environmental implications of expanding the network of drains in urban areas are discussed more fully in Section 1.3.

1.1.5 Native vegetation/habitat types

Substantial parts of the catchment of the SCRS have been severely modified by agricultural activities and urbanisation. Consequently, relatively little of the original plant and animal communities remain except perhaps on parts of the Darling Scarp (**Figure 6**). Irrigated and dryland agriculture as well as urbanisation has left little uncleared land in the flat areas in the eastern part of the coastal plain, but the dune systems in the west of the coastal plain have extensive natural woodlands.

Broadly speaking, the dryland habitats (or 'bushlands') comprise remnants of tuart (*Eucalyptus gomphocephala*) woodland associated with the Spearwood Dune System; scrub vegetation on the Bassendean dune areas (characteristically co-dominant woody assemblages of *Banksia menziesii*, *Banksia ilicifolia*, *Banksia attenuata*, Sheoak (*Casuarina fraseriana*) and woody pear (*Xylomelum occidentale*); and heath, forest and woodland comprised of jarrah-marri (*Eucalyptus marginata and Eucalyptus calophylla*, respectively) alliances on both the Pinjarra plain and the Darling Plateau.

Approximately 200,000 ha (70%) of the wetlands on the Swan Coastal Plain have been destroyed by landfill and drainage (Riggert, 1966; Halse, 1989; Balla, 1994). Most of those that remain occupy low-lying depressions in the Bassendean dune system. The major cover of woody vegetation peripherally is scattered paper-bark gum (*Melaleuca parviflora*) with a dense ground cover of sedges and rushes (Semeniuk *et al.*, 1990). However, towards the western-edge of the Pinjarra Plain where the soils are very fine-textured and seasonally flooded, the dominant vegetation is dense, low scrub consisting of several different paperbark (*Melaleuca*) species (McArthur & Bettenay, 1974).

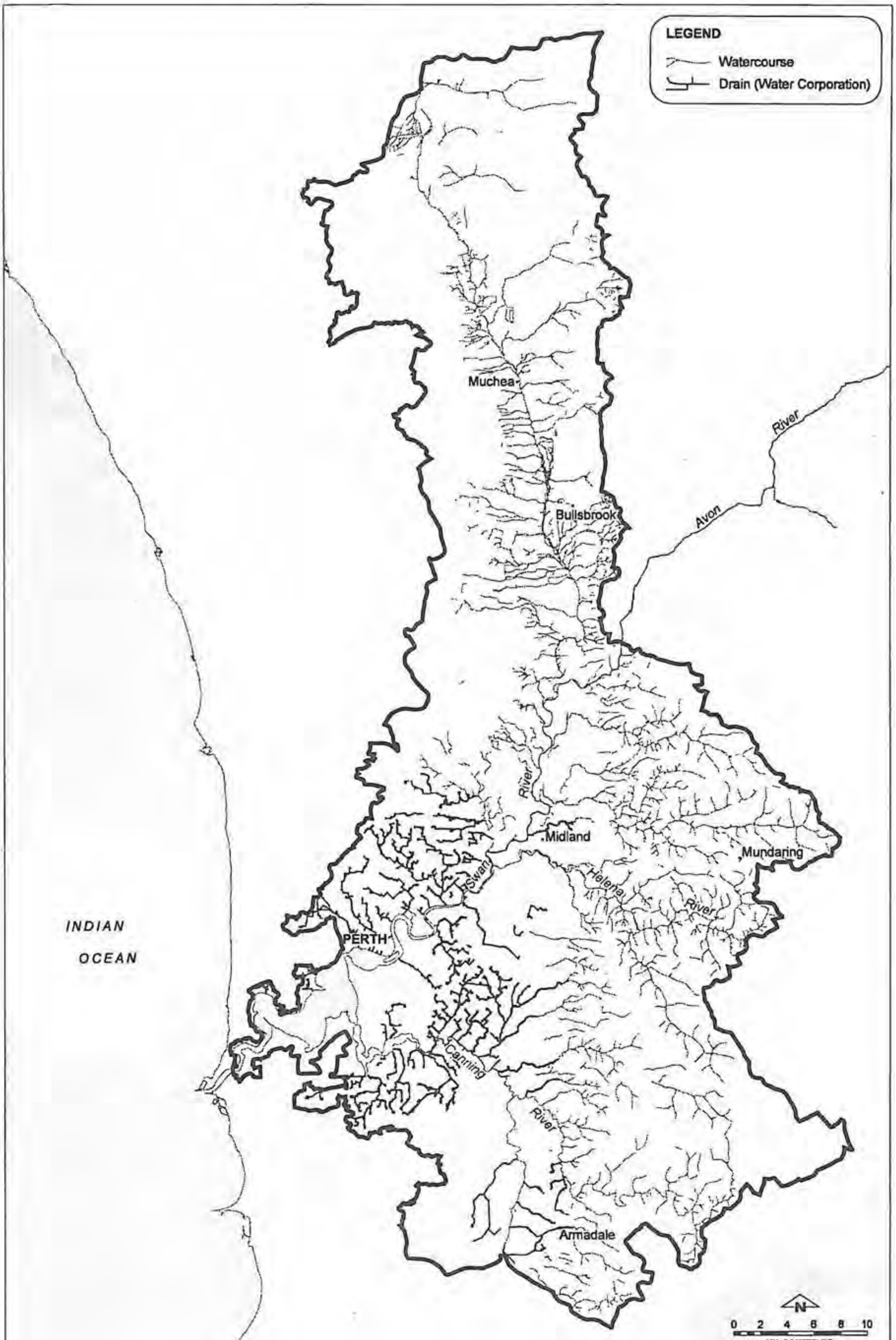

Figure 5: Drainage network of the study area

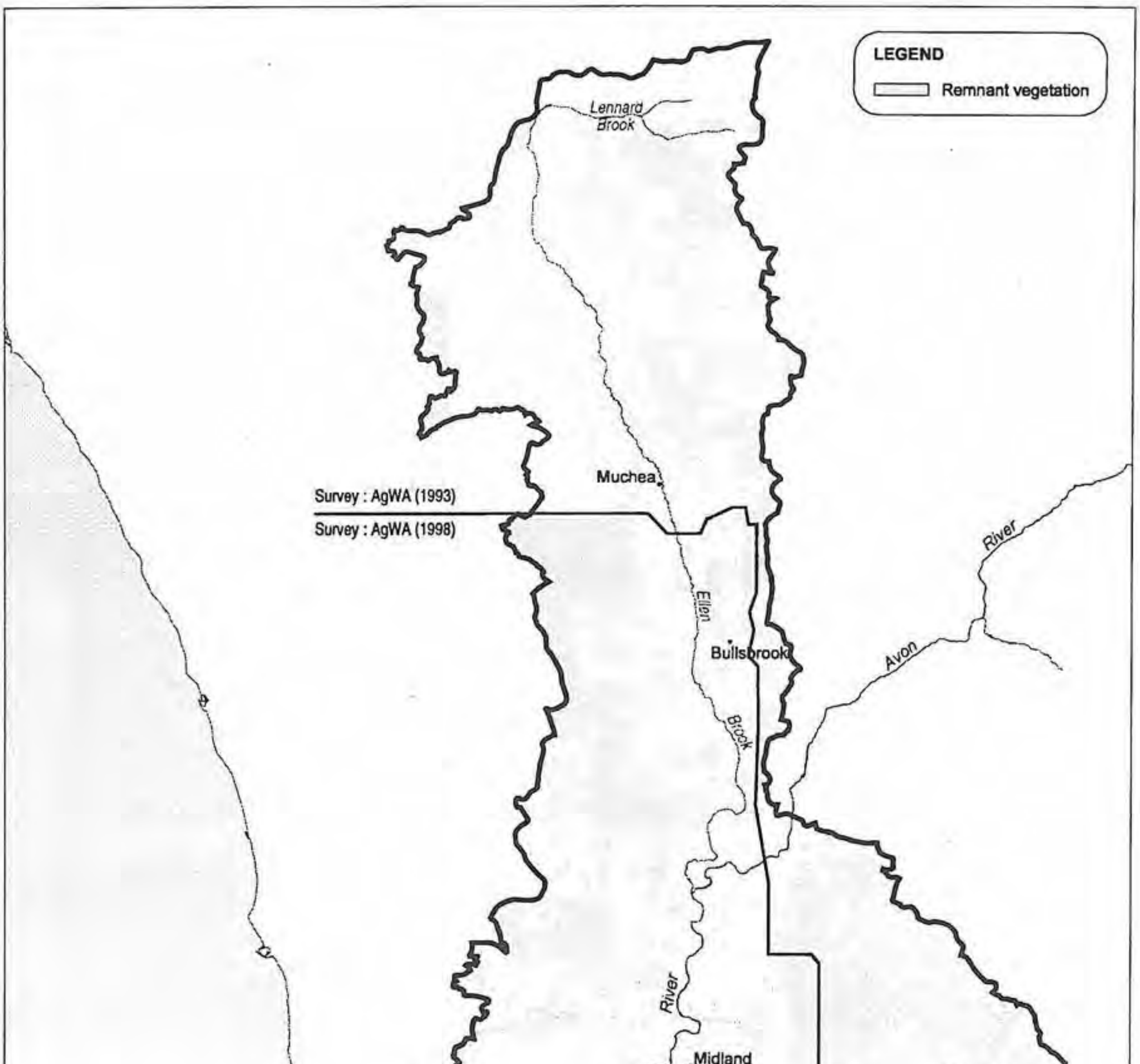

Figure 6: Distribution of remnant vegetation in the study area

1.2 Landuse

As the catchment of the SCRS forms the hinterland of the Perth Metropolitan Region, the whole area is intensively used (**Figure 7**).

Across the catchment as a whole the present proportions of landuse are, on average, 18.5% urban, 1.5% urban deferred, 43% agricultural, 4.2% industrial, 3.4% Crown Land, 12.4% State Forest and 17% open space (**Table 1**). Although used mainly for grazing, with some developing horticulture, floriculture and poultry, Ellen Brook is the most extensively developed for agriculture (73% agriculture). The Hills catchments are the least developed and have 24% open space and 10% forest.

Table 1: Differences in landuse in the catchment of the SCRS (%)

	Ellen Brook	Hills	Southern / Canning	Urban	Average
Crown Land	14.0	-	-	-	3.4
Industrial, railways and roads	0.2	2.9	3.5	10.3	4.2
Public purposes, parks and recreation	3.8	23.9	20.0	20.1	17.0
Rural	73.0	52.0	32.3	14.3	43.0
State Forest	7.0	10.0	22.8	10.2	12.4
Urban	2.0	11.2	16.4	44.3	18.5
Urban deferred	-	-	5.0	0.8	1.5

Several major transport routes (such as the Great Eastern Highway, the Great Northern Highway, the Tonkin Highway, the Albany Highway and the Kwinana Freeway) cut through the catchment. In addition, regionally significant facilities such as Perth Airport, the Pearce Airforce base (at Bullsbrook) and several solid and liquid waste disposal sites are located in the area. The construction of a new Darwin Highway is also proposed.

Although some horticultural activities do take place on the margins of the Gnangara Mound (a groundwater resource which is a major supply of Perth's drinking water), land usage has purposefully been restricted to State Forests. Management plans have also been developed for both the Gnangara and the Jandakot Mounds (Davidson, 1995).

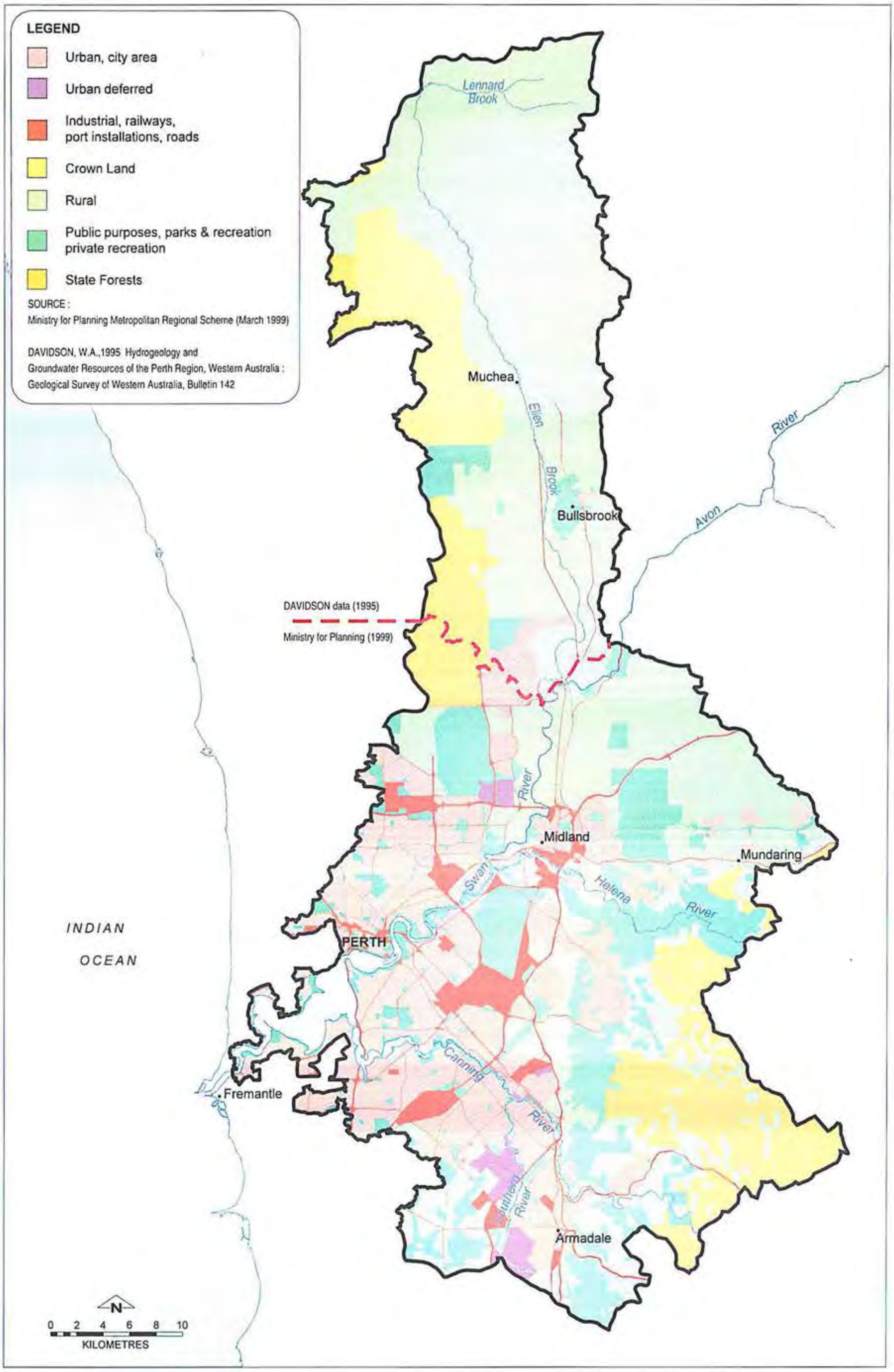

Figure 7: Generalised landuse in the study area

1.3 Water balance

The regional water balance in the catchment of the SCRS is based on extremely complicated relationships. This is because in the development of the City and its environs, the normal hydrological processes which operate in the catchment have become radically and constantly altered in response to continuous landuse changes in the catchment (Cargeeg *et al.*, 1987a, b and c). In simple terms, as water moves through the system of stores and pathways illustrated in **Figure 8**, its quality and quantity is modified by the ever changing demands that are placed on surface and subsurface resources in the metropolitan environment; by water supplies imported from outside the catchment; by varying inputs of precipitation and outputs such as channel flow, evaporation and deep leakages to adjoining groundwater bodies. In most cases, even a slight modification to land use in a catchment has the potential to generate significant changes in the various processes controlling streamflow and water quality.

The construction of drainage systems and sewerage systems in the Perth metropolitan area serves as a good example. As the drainage network of the catchment is expanded and the flow paths of natural drainage lines are altered by sewerage and road development, so surface and subsurface run-off becomes altered. Decreases in permeability tend to increase flood peaks; the deep drains that have been installed to facilitate the usage of septic tanks in residential areas increase base flow during summer months; and, through the construction of drains, the pollutant loads are increased by decreasing infiltration and the bypassing of soil disposition areas.

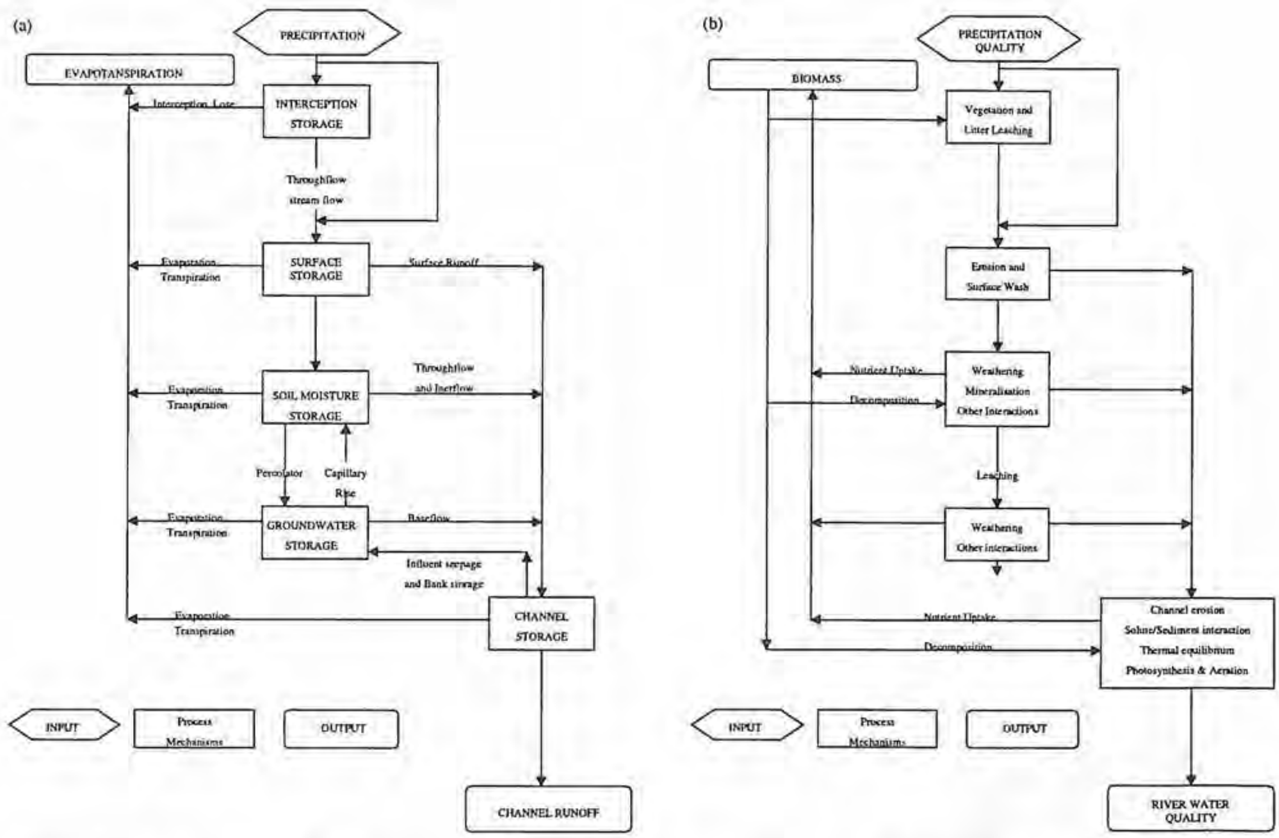

Figure 8: A simplified representation (a) of the hydrological processes operating in a catchment and (b) of the major mechanisms influencing the quality of the water involved

1.4 Water quality

Water quality in the Swan–Canning Coastal Plain Catchment is an effective barometer of environmental quality in the Perth Metropolitan Region as a whole, and fluctuates because of the seasonal variation in rainfall and the variety of landuses described in Section 1.2 (Deeley *et al.*, 1993a).

A large number of water quality studies have been undertaken to assess the health of the river system. Very broadly, these studies show that:

- The use of fertilisers in rural catchments, which have been extensively cleared for agriculture, is the major source of the nutrients that degrade the upper reaches of the Swan Estuary and the lower reaches of the Canning River (Atkins, 1993). Nutrient export can be leaching of excess fertiliser nutrients or redistribution of nutrients from fertilisers and imported feed via animal wastes.
- The widespread occurrence of soils with low phosphorus retention ability, the artificial drainage of wetlands and the excessive clearing of native vegetation have greatly increased nutrient and sediment export from rural areas (Gerritse, 1990; Sharma *et al.*, 1996).
- A total of about 72 tonnes of phosphorus (P) and 744 tonnes of nitrogen (N) is estimated to enter the SCRS each year (Donohue *et al.*, 1994; Eade, 1996). Not surprisingly, approximately 76% is derived from the four catchments that generate the bulk of the inflow, Ellen Brook (contributing 35% of the P), Avon (contributing 30% of the P), and Canning and Southern Rivers (contributing approximately 10% of the P).
- Unlike the Avon River, where the P is chemically bound to fine mineral particles, i.e. is in a particulate form, most of the phosphorus load from Ellen Brook is in a water-soluble (reactive) form (Deeley *et al.*, 1993a).
- Nitrogen (N) is being exported from the catchment in the form of nitrate, ammonia and organic N (in the latter case due to the naturally high organic carbon load). Concentrations remain low during summer but increase dramatically with the onset of winter run-off (Gerritse *et al.*, 1992).
- The most significant process of nutrient export from the catchment is the first flush of a rainstorm and the run-off that occurs after a long, dry period. How much of this nutrient is finally exported out to sea and the role of the nutrients which remain in the system is unclear. However, recent surveys indicate that during winter inflowing nutrients are generally flushed out to sea (Fredericks *et al.*, 1998).
- A large amount of nutrients and contaminants such as heavy metals are entering waterways from urban areas, particularly industrial sites, recreational parks and gardens (Sharma *et al.*, 1992).
- In certain areas, septic tank overflows contribute significant amounts of pollutants (faecal bacteria, organic matter and sulphates) into the waterways (Klemm & Switzer 1994; Wong & Morrison, 1994).
- Contaminated groundwater has the potential to be a serious long-term problem for the SCRS (Appleyard, 1992). For example, in the Ellen Brook catchment where over 75% of the soils have very low P retention capacities, the front of leached P has already reached the groundwater (Kin *et al.*, 1997b).
- Groundwater abstraction is causing saline intrusion in a number of areas along the SCRS (Gerritse *et al.*, 1990). The ecological consequences are unknown.

Classifications of total N and P concentrations in tributary inflows of the SCRS, performed by the Water and Rivers Commission between 1987 and 1997, have shown that in the last decade the amount of P being exported from sub-catchments such as Bennett Brook, Blackadder Creek, Bayswater and Bannister Creek (**Figure 2**) has noticeably declined. Although still excessive in terms of the targets set, improvements have been detectable in the case of Ellen Brook and the Southern River catchments. In contrast, there has been no improvement in P export from the Mills Street Main Drain, and the total amount of N being exported from sub-catchments such as Bannister Creek and the Mills Street Main Drain has increased over the last ten years.

1.5 Pollution sources

The majority (approximately 70%) of the phosphorus load is contributed in the winter months from rural catchments on the coastal plain, when low-lying fertilised pastures become waterlogged (Gerritse, 1994). 24% (17.5 tonnes) of the total P load and 21% (155 tonnes) of the total N load enters the SCRS via urban drains (Henderson & Jarvis, 1995).

Within the rural catchments, the Ellen Brook and the Avon River are the major contributors of nutrients, between them carrying, on average, approximately 37 tonnes of phosphorus and 324 tonnes of nitrogen per year (Deeley *et al.*, 1993a; Kin *et al.*, 1997a). The Bayswater Main Drain, on the other hand, historically contributed the highest nutrient load from the urban sub-catchments (i.e. approximately 24 tonnes of N and 4.9 tonnes P per year). The nutrient contribution of the Bayswater Main Drain is now considered to be much less and has been replaced by other urban drains such as Mills Street Main Drain (Swan River Trust, 1998). In these urban cases, as a result of the increased impervious surface areas and reduced amount of infiltration, water quality is influenced by factors such as population density, landuse and waste disposal practices.

Urban pollution loads of nutrients and toxic substances such as copper, cadmium, lead, chromium (4.3 tonnes / yr) and zinc (29 tonnes / yr) are a growing concern (Hosja *et al.*, 1993; Henderson & Jarvis, 1995) but, generally speaking, industrial point sources of pollution appear to be under control through current licensing procedures. The main problem is still nutrient enrichment from diffuse sources, such as urban septic systems, urban gardening, light industrial and commercial activities, and the legacy of decades of farming activities based on the use of phosphatic fertilisers (Atkins, 1993) in what are now largely high-density urban areas.

Whilst legislation and guidelines may be in place to control and manage industrial activities in the catchments, historical contamination (such as a number of old landfill sites along the river and other known contaminated sites) have yet to be fully addressed. Little is known about the extent of historical contamination of groundwater, although previous studies have found that long-term and effective management strategies are needed to minimise off site impact.

The Hills catchments, Canning catchment and Avon catchment are also important pollution sources mainly because of the amount of silt generated by soil erosion. The influence of pollutants bound to soil particles on the export of nutrients such as phosphorus (which becomes physically bound to fine mineral particles) and nitrogen (which enters waterways in particulate organic matter is highly significant.

2. Committee structures, membership and major achievements

2.1 Catchment Advisory Committee

The Catchment Management Technical Advisory Committee (also referred to as the Catchment Advisory Committee or CAC) was formed, under the auspices of the SCCP Task Force in 1996, to develop catchment action recommendations for the SCCP Action Plan. The Committee was convened by Mr G.J. Parlevliet, a Senior Development Officer in *Agriculture Western Australia* (AGWEST) and member of the SCCP Task Force. The Committee relied on representatives from a number of different organisations, including:

- *SRT*- Dr Tom Rose.
- Water and Rivers Commission (WRC)- Ms B Thurlow and Mr P. George, with contributions from Ms C. Seal; Mr S. Wong and Mr W. Horwood.
- Department of Environmental Protection (DEP) (Catchment Management Section)- Mr C. Nicholson.
- Ministry for Planning (MfP)- Mr. Max Poole.
- Swan–Avon ICM/Swan Working Group- Ms P. Hart.
- Swan Catchment Centre- Mr P. Nash.
- CSIRO- Dr R. Gerritse, with contributions from Mr P Kin.
- Agriculture WA- contributions from Mr N. Lantzke.
- Bayswater ICM *Group*- Ms R. Glass.

2.2 Rivercare and integrated catchment groups

The increasing interest and involvement of local communities in river and catchment restoration activities, is a process typified by the Swan-Avon Integrated Catchment Management (ICM) Program. The latter is funded through a variety of sources including the Federal Government's former National Landcare Program, the Swan Catchment Urban Landcare Program (SCULP) and the Natural Heritage Trust (NHT) which replaced the National Landcare Program (Swan-Avon ICM Coordinating Group, 1997).

One of the most important developments in the catchment of the SCRS has been the emergence of 52 semi-independent Catchment Management and/or Rivercare Groups (Larcombe *et al.*, 1996). Collectively, their influence currently extends over five major sub-catchments in the area (**Figure 9**).

2.3 Support to catchment groups

The Rivercare and Integrated Catchment Groups are, in turn, supported by 12 different government agencies, 22 Local Councils and 29 non-government organisations (Larcombe *et al.*, 1996) (**Figure 10**).

2.4 Overall goal

The SCCP objectives have been deliberately directed at the management of algal blooms in the estuary. It is the firm belief of the CAC that nutrient ingress from the catchment can only be addressed by gradually introducing landuse practices which reduce nutrient and sediment transport by increasing precipitation and biological uptake. Thus, the strategic aim of the CAC is to foster the coordinated and sustainable use of the catchments in the Swan–Canning River System.

In recognition of the catchment's direct effect on water quality in the upper reaches of the Swan Estuary and the lower reaches of the Canning River, the CAC adopted the following management objectives:

- to help change landuse practices that lead to poor water quality in the SCRS;
- to identify the range of environmental problems and associated activities which affect the catchment and the resources to be managed;
- to seek solutions to the issues identified;
- to assist with the implementation of the proposed solutions by pro-active landuse planning; and to raise, to the maximum extent possible, the level of community awareness and understanding of the issues at stake.

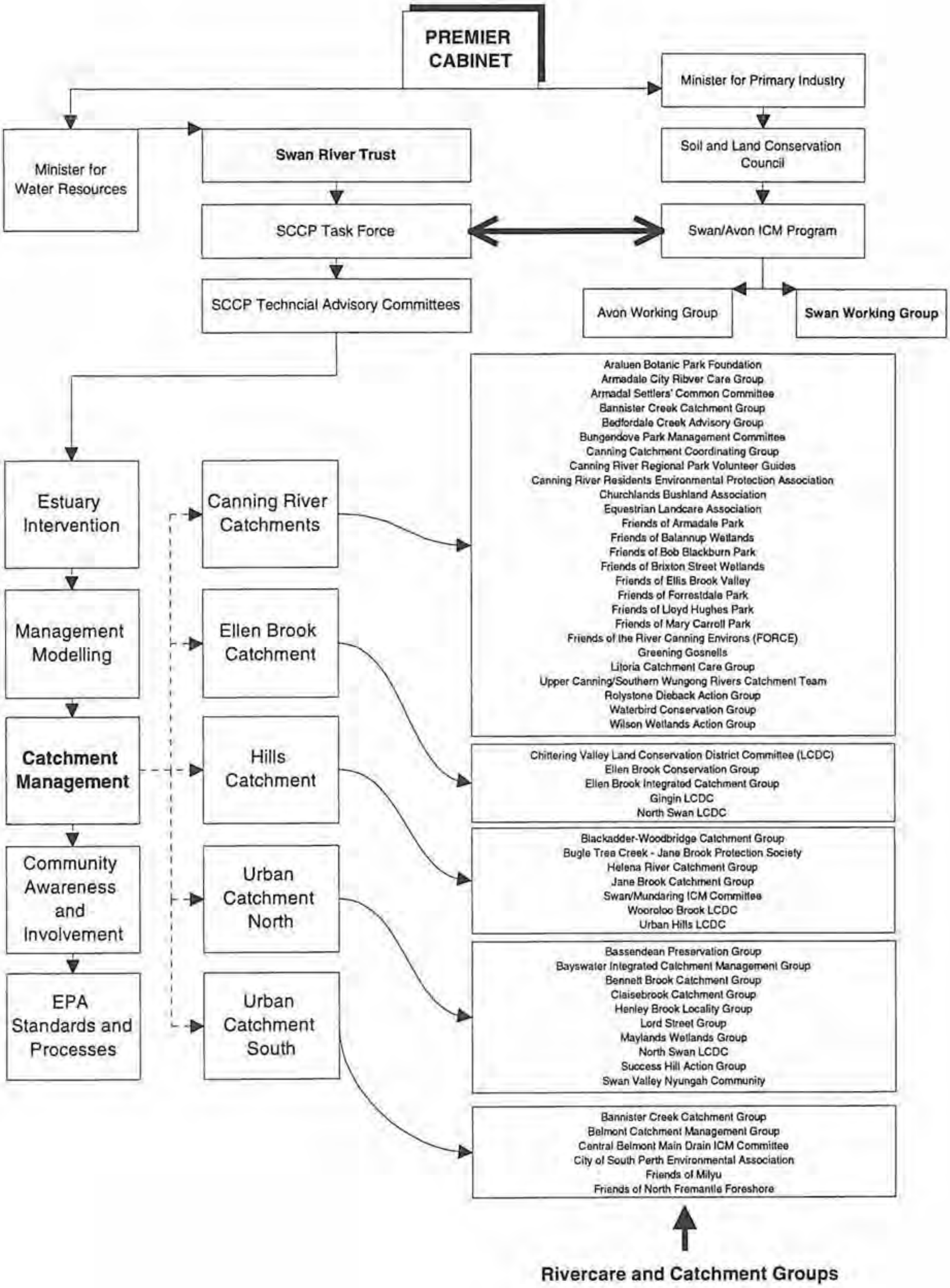

Figure 9: Operational linkages between the Rivercare and Integrated Catchment Groups operating in the Swan–Canning catchments between 1994 and 1998

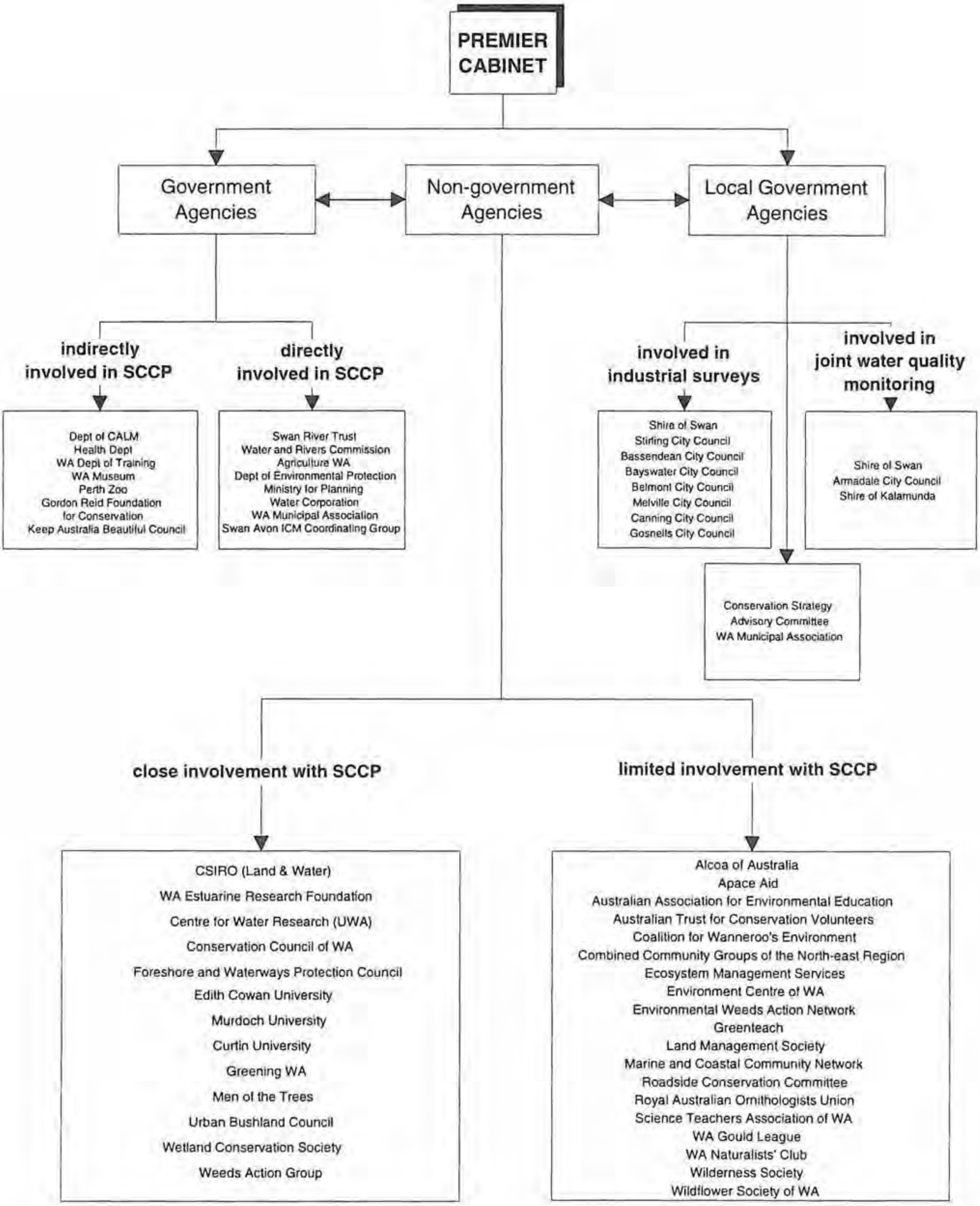

Figure 10: Operational linkages between the support groups involved in the Swan–Canning Cleanup Program between 1994 and 1998

NB: Alcoa now sponsor the Swan-Canning Urban Landcare Program (SCULP) and are thus closely involved with the Swan-Canning Cleanup Program (SCCP). SCCP also contributes significant funding to this excellent program.

2.5 Environmental outcomes

If implemented successfully, the expected outcomes of the strategic aims outlined above are:

- a diminution in the frequency and duration of blooms of nuisance algae in the upper reaches of the Swan Estuary and the lower reaches of the Canning River;
- an improvement in the amenity value of the abovementioned waterbodies; and
- balanced resource utilisation and conservation throughout the catchment of the SCRS.

2.6 List of investigations

A large number of catchment investigations, aimed mainly at obtaining an understanding of water quality related management issues, have been initiated by agencies such as the SRT, WRC, Agriculture WA, the Swan Working Group, Western Australian Estuarine Research Foundation (WAERF) and the CSIRO. These include:

- Water quality monitoring programs;
- Point source pollution studies;
- Groundwater contamination surveys;
- Land degradation and land suitability assessments;
- Surveys of remnant vegetation;
- Resource inventories and geographical information system (GIS) mapping;
- Industrial audit surveys;
- Movement of nutrients under horticulture;
- Fertiliser management trials on pasture;
- Improved fertiliser management in potato and carrot crops;
- Nutrient distribution in soils on farms;
- Industrial survey on non-licensed industrial premises;
- Contaminated sites inventory; and
- Catchment modelling.

A list of the catchment-related investigations currently associated with the SCCP, the stage of completion and the management agencies and organisations responsible for project implementation is given in **Table 2** below.

Table 2: Status of the recent/ongoing catchment related investigations associated with the SCCP (unpublished internal reports)

PROJECT	ORGANISATION RESPONSIBLE		STATUS	
	MANAGEMENT	AUTHORS	INITIATED	COMPLETION DATE
Groundwater contamination in Ashfield/Bayswater area (Pilot study)	WRC	S. Appleyard/ S. Wong	January 1997	November 1997
Slipping operations along the Swan River	SRT/WRC/ DEP	S. Wong	March 1997	August 1997
GIS mapping of landuse and catchment resources	SRT	Brett Harrison	1996	on-going
Techniques for water quality management manual	WRC	Evangelisti & Associates	1996	July 1997
Fixed interval water sampling of selected streams and storm event sampling	WRC	Rob Donohue	1996	on-going

PROJECT	ORGANISATION RESPONSIBLE		STATUS	
	MANAGEMENT	AUTHORS	INITIATED	COMPLETION DATE
Catchment Management Planning				
Ellen Brook	MfP/SRT/ AGWEST	Evangelisti & Associates	Feb 1998	May 1999
Upper Canning Southern Wungong	SRT/ AGWEST	Everall Consulting Biologist	Nov 1997	Jan 1999
Industrial audit survey (pilot study)	SRT	L. Barnacle/ S. Wong	April 1997	November 1997
Catchment modelling (LASCAM)	WRC	Viney and Sivapalan	1996	1998
Groundwater modelling (FEFLOW)	WRC	Linderfelt *et al.*	1995	1997
Run-off modelling in Ellen Brook (AGNPS)	WRC	Kin *et al.* Sharma *et al.*	1996	1998
GIS modelling for Ellen Brook	SRT	D Deeley	1994	1995

2.7 Major achievements

Nothing would have been accomplished without the cooperation and hard work of the government agencies, Rivercare and ICM groups mentioned earlier, or without access to the information derived from the catchment investigations listed in Section 2.6 above. However, some of the most important achievements of the organisations concerned have been the preparation and progressive implementation of a number of widely supported catchment management strategies and/or plans.

Excluding those in the Avon catchment, the initiatives referred to include development of:

- The Upper Canning Southern Wungong Catchment Management Plan;
- The Ellen Brook Catchment Plan (partially complete);
- The Bayswater Main Drain Catchment Management Strategy;
- River restoration plans and tree planting programs for the Upper Canning and Southernwood Creek;
- Management plans for the Gnangara and Jandakot Mounds;
- Mundaring Environmental Strategy;
- Kalamunda Environmental Strategy; and
- Various local area and sub-catchment plans.

Community and catchment groups have contributed to a wide range of activities that include revegetating and weeding substantial areas of foreshores, wetlands, drains, parks and reserves over the last 5-7 years. These groups have also undertaken activities to improve best practices of industries and local government, and have contributed to improved education, training initiatives and decision-making over new developments.

In addition, various forms of corrective action in respect of pollution arising from industrial areas and old landfill sites has been exercised through:

- Encapsulation of the CSBP sites (in North Fremantle and Bayswater);
- Bioremediation of an old landfill site (East Perth);
- Cleanup of Susannah Brook embankment;
- Various industrial park cleanups;

- Contaminated site cleanup at East Perth Gasworks, former State Engineering and CSBP sites in North Fremantle, upper reaches of Susannah Brook and river foreshore at Rivervale;
- A 27% reduction in the number of licensed industrial discharges to the river;
- Contaminated stormwater diversion from unsewered stable properties in Ascot and Western Australian Turf Club; and
- Reduction of pollutant load from stockholding yards.

The construction of artificial wetlands has also commenced in the Bayswater catchment in order to gauge their effectiveness as a management tool for nutrient assimilation.

Finally, in order to provide a clearer vision of where ICM should be heading, as well as to promote the development of techniques designed to improve predictions of nutrient loss and pollution loads from rural and urbanised catchments, the WRC, the Water Corporation and AGWEST have provided considerable support to modelling to improve or develop decision support systems.

The models are aimed at assisting managers to evaluate different (and often conflicting) policy options relating to the equitable and rational management of the catchment's resources. To date, the catchment process and groundwater models being developed and/or applied include the:

- Agricultural Non-Point Source Model (AGNPS) – being developed by the CSIRO (Land and Water Division);
- Large Scale Catchment Model (LASCAM) – being developed for the Avon and Ellen Brook catchments by the Centre for Water Research (UWA) ;
- Aquifer Finite Element Model (AQUIFEM) and FEFLOW – both groundwater models being developed by the CSIRO; and
- Perth Urban Water Balance Model (PUWBM) – being maintained by Water and Rivers Commission.

Further details, outlining the outputs, strengths and weaknesses of each model, are contained in a separate technical report entitled *Management Modelling: A supporting document to the Swan-Canning Cleanup Program Action Plan.*

3. Catchment management issues

The following chapter sets out to briefly summarise the management issues that are prevalent in the catchment of the SCRS.

3.1 Rural catchments

3.1.1 Agricultural activities

One of the inescapable impacts of man is that modern agriculture affects water quality in catchment ecosystems (Gasser, 1980). The situation in the catchment of the SCRS is no different, except that the impact of agriculture is exacerbated by the sandy soils in areas lacking the ability to retain nutrients (such as phosphorus and nitrogen). In addition, there are a number of intensive agricultural enterprises, some of which do not use best management practices (BMPs). Both factors account for the significant impact of agricultural activities on the SCRS and the future potential for pollution. Furthermore, as the run-off from agricultural activities is intermittent and diffuse, the resultant pollution is extremely difficult to control due to the manner by which it reaches the river through surface and subsurface flow (Sharma *et al.*, 1994). In catchments such as Ellen Brook, cadmium from fertilisers is also starting to leach from the soils (Gerritse, 1996).

The types of agricultural activities that have been shown to impact on the quality of drainage water and surface run-off in the catchment of the SCRS include grazing enterprises, intensive horticulture, turf farming and intensive livestock operations. These are briefly described:

Grazing enterprises

Pastures are found mainly in the Ellen Brook and Southern River catchments on low-lying areas that were formerly wetland (**Plate 1**). As most of the pastures are clover-based, little nitrogen is applied as a fertiliser. However, most clover-based paddocks are responsive to potassium and sulphur. In the past, superphosphate was applied which contained a significant amount of sulphur. These superphosphate fertilisers, because of their sulphur content, gave good crop growth responses and, thus, led to the overuse of superphosphates. Lime is also applied to these pastures to reduce soil acidity (Parlevliet, *pers. comm.*). Pastures are considered to be a major source of the current phosphorus outflow from the area because of the low P holding capacity of the soils and the high water table conditions in the area. The mean annual input of fertiliser P to grazing land in the Ellen Brook catchment is 7kg/ha (Sharma *et al.*, 1994), although slightly higher rates of 12-15kg/ha are recommended by Agriculture Western Australia (Angell, 1998). Fertiliser N is rarely applied to pastures, and the N necessary (100kg/ha) for pasture dry matter production at a level of 5t/ha comes equally from organic residues and from N fixed by clover (Kinhill Engineers, 1995).

Cattle exhibit a strong preference for riparian zones due to the availability of water, shade and the quality and variety of forage. Consequently, they are one of the most destructive forces in riparian ecosystems due to soil compaction and herbage removal (Kauffman & Krueger, 1984; Halse *et al.*, 1993).

Animals grazing pasture excrete an average of 30-40kgN/ha/year (Kinhill Engineers, 1995) and 3-4kgP/ha/year. These data are based on a stocking rate of 5 DSE/ha (0.5 cattle, 0.5 horse). Most of the N is in urine and most of the P is in manure. For example, a typical mature horse on agistment will excrete 49kgN and 1kg P in urine and 13kgN and 5kg P in manure per year (Coster, *pers. comm.*). The excreta of thoroughbred horses in racing condition have much higher nutrient levels than those quoted.

Animals grazing riparian zones deposit nutrients directly into watercourses. Manure not collected from paddocks over summer can be transported off site during intense rainfall events in autumn and early winter, especially on grey sands that become hydrophobic (Sharma *et al.*, 1994). In dryland pastures the concentrations of soluble nutrients, either from fertilisers or mineralised from animal wastes, can accumulate to a level that is greater than plant growth demand. In the Ellen Brook catchment, the primary mechanisms of nutrient discharge to streams are via vertical leaching to shallow groundwater and lateral leaching in waterlogged sandy soils (Sharma *et al.*, 1994).

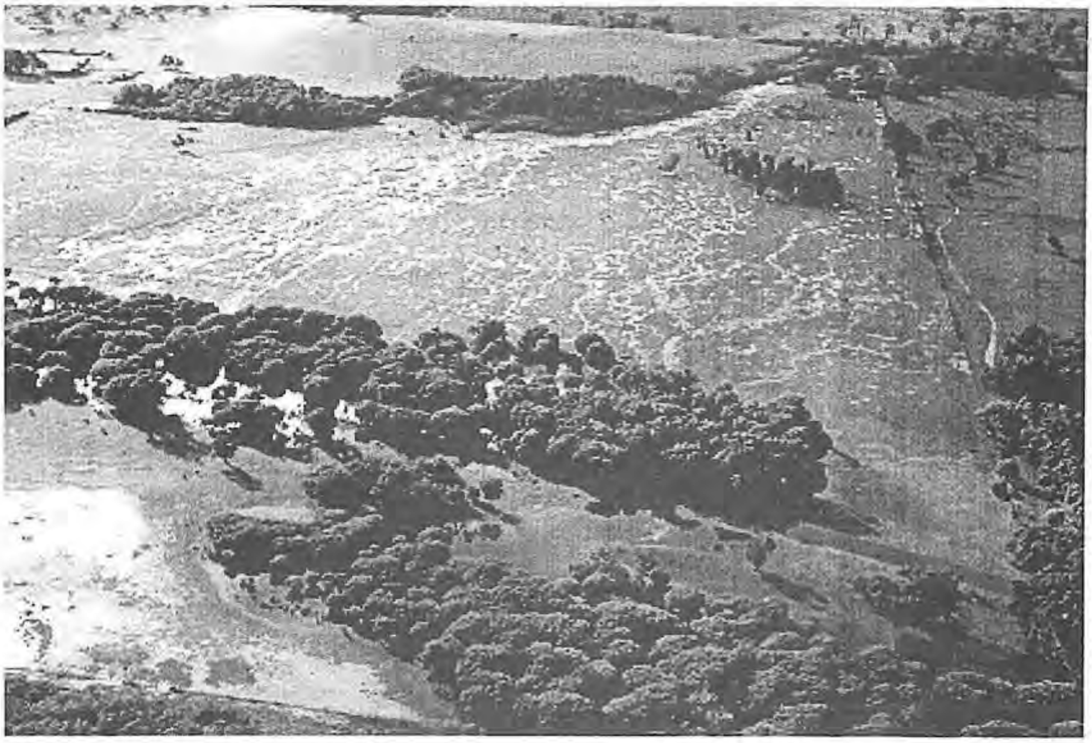

Plate 1: Section of Ellen Brook showing typical pastures (which are often fertilised) on either side of the channel in an environment that is characterised by soils with a naturally low phosphorus retention capacity and is highly prone to overland flow (Date: 3 July 1997)

Intensive horticulture

Fruit growing is a well-established industry in the Lennard Brook area and in the Hills catchment near Kalamunda and Armadale, as is grape growing in the Shire of Swan. Nutrient losses from orchards and vineyards can be high (Kin *et al.*, 1997b), and the dependence of these industries on biocides to improve yields could increase the potential for pollution of the river system in the future.

In addition to fruit growing, there are numerous vegetable producing properties, cut flower operations and nurseries within the rural catchments of the SCRS. The tendency to over-fertilise or use high nutrient applications on these properties ensures that nutrient deficiency does not limit yields, but greatly increases the potential for the pollution of nearby streams and waterways (Gerritse, 1990). Where producers use poultry manure for fertilisation of the gardens, and application rates of up to 50 m^3/ha are used, the levels of phosphorus in the resulting run-off are particularly high.

Results of a survey of 35 market gardens on the Swan Coastal Plain carried out in 1990 (McPharlin & Jeffery, unpublished) highlighted the wide variability in fertiliser use on vegetable crops. The range and mean of annual N and P application rates as given by the growers for two vegetable crops per year were 180-5620, mean 1260 kg/ha/year and 75-990, mean 310 kg/ha/year, respectively. The mean values are very similar to those recommended by AGWEST as maximum rates for new land (Lantzke & Galati, 1997). Based on a recent survey, rates of nutrient application by vegetable growers in the Ellen Brook catchment appear to be similar to those from an earlier survey (Lantzke, 1997).

One reason for the wide range of nutrient applications would be variation in the rate of application of poultry manure. In the 1980's much higher rates of poultry manure were recommended, up to 100m^3/ha/crop (Luke, 1990), compared with current recommendations of $30m^3$/ha/crop. Annual applications of poultry manure could vary from 20-200m^3/ha, which would add the equivalent of 200-2000 kgN/ha and 70-700 kgP/ha (Paulin, 1997).

One reason for high application rates of inorganic fertiliser N during crop growth is to minimise the effects of irrigation systems that do not apply water evenly (Milani, 1990). Where localised over-watering and extra leaching occurs, higher rates of N are applied to compensate in order to achieve maximum yield over the whole crop.

Residual nutrients in the topsoil after harvest are generally not taken into account when planning the fertiliser program for the following crop. In the past, some vegetable growers have relied on heavy rates of irrigation after harvest to flush accumulated nutrients from the root zone. In some cases, this practice has increased nitrate-N concentrations in shallow groundwater to levels that are toxic to sensitive crops (Luke, 1990).

If the 'grower average' rates of nutrients are applied each year, these are far in excess of nutrients removed in (two) crops, which are about 260kg/ha and 50kg/ha per year respectively for N and P. The residual nutrients available for leaching would, therefore, be about 1000kg/ha and 260kg/ha per year of N and P.

Soils from the survey of market gardens (McPharlin & Jeffery, unpublished) had accumulated high to very high concentrations of available P in the cultivated layer. Three-quarters of the sites had >50mg/kg of available P and just over half had >100mg/kg. At 8 of the sites there was less than 50mg/kg of available P, although these were grey sandy soils which would have had PRIs <2 prior to development and, therefore, had very little capacity to accumulate P.

The samples of topsoil from all sites had PRIs that were much less than 0 and, in most cases, less than -2. Such results indicate that the concentrations of P in soil solution (leachate) in the cultivated layer were generally in excess of 20mg/L. Of the subsoil samples from a depth of 80cm, more than 75% had PRIs less than 0 and, hence, leachate P at this depth would generally have been in excess of 10mg/L. Similar levels of P were measured in shallow groundwater under production areas of intensive horticulture (Lantzke, 1997).

Subsoils from each survey site were also examined to assess their capacity to retain leached P, and the results were used to calculate the amount of leachable P retained in the top 100cm of soil profile. When combined with the annual rate of P exported in crops (50kg/ha) and the fraction of non-leachable P in fertilisers, the proportion of P retained was estimated for periods of 5 or 20 years of vegetable production. This was undertaken for the three PRI categories of soil and assumed an average P application rate of 310kg/ha/year. The total rates of P (kg/ha) leached beyond a soil depth of 100cm during the same period were also estimated. The small proportion of fertiliser P retained by the very low PRI soils (**Table 3**) is consistent with evidence from the Ellen Brook catchment that the leaching front of P has already reached the groundwater (Kin *et al.*, 1997a).

Table 3: Estimates of the proportion of P retained and the rates per hectare of fertiliser P leached beyond a depth of 100cm after 5 and 20 years of vegetable production on Swan Coastal Plain sandy soils

PRI CATEGORY	PROPORTION OF P RETAINED IN 100CM OF SOIL PROFILE OR REMOVED IN CROPS (%)		P LEACHED BEYOND 100CM (kg/ha)	
	5 years	20 years	5 years	20 years
<=1	30	27	1085	4526
1-3	56	34	682	4092
3-7	98	53	negligible	2914

Nitrogen applied pre-planting with poultry manure is generally leached beyond the root zone within 4 weeks and, therefore, a small proportion would be utilised by the crop. Inorganic N applied during crop growth can be leached even more rapidly. A rainfall event of just 9mm leached 75% of nitrate-N from the top 15cm of a Spearwood sand under lettuce, reducing the concentration from 75 to 15mg/kg of nitrate-N (McPharlin *et al.*, 1995b).

Nitrate-N concentrations in excess of 10mg/L are commonly found in groundwater beneath horticultural properties (Paulin *et al.*, 1995). A survey of 28 market gardens on the Swan Coastal Plain identified 8 properties with irrigation water containing between 10 and 50mg/L of nitrate-N. Most of these were older market gardens with bores extracting the shallow groundwater. High concentrations of nitrate-N are more likely under properties on Spearwood and Karrakatta sands. A significant degree of denitrification occurs in the water table under Bassendean sands, and this greatly reduces the extent of nitrate-N enrichment of groundwater.

Turf farms

There are also several irrigated turf farms in the catchment area, from which the leaching of surplus nutrients into waterways is of general concern (del Marco, 1990). Through infiltration and percolation, the fertilisers that have been applied quickly enter the groundwater and move down-gradient towards the nearest stream.

The maximum rates of application recommended by Agriculture WA (Lantzke, 1997) are 513 and 80 kg/ha per year, respectively for N and P, but it is not clear whether this includes nutrients from recommended annual applications of 30-50m^3/ha of poultry manure. There is a very small amount of information from the turf industry on the fertiliser programs used on turf farms (Chemistry Centre-AGWEST, informal report) which indicates that monthly maintenance applications of N and P are 20-80kg/ha and 3-10kg/ha, respectively. When combined with the inputs from poultry manure, the total annual rates of application could be 500-1000kg/ha of N and 130-190kg/ha of P.

In a recent study (Lantzke, 1997), high concentrations of nitrate-N (29mg/L) and P (16mg/L) were measured in shallow groundwater beneath the production area of a turf farm in the Ellen Brook catchment. The annual rates of nutrient application at this property for the first two years of production were estimated to be 900kg/ha of N and 430kg/ha of P.

Intensive livestock operations

Feedlots, stockyards, sheep holding pens and other concentrated livestock operations such as dairies, stables, poultry farms, and piggeries have in the past or currently introduced animal wastes, principally urine and manure, into the SCRS. Animal wastes gain entry either directly via surface flow (as stormwater run-off) or indirectly via subsurface groundwater movement (Deeley *et al.*, 1993b).

Pollution from livestock operations causes eutrophication, oxygen reduction and bacterial contamination of surface waters (see Section 3.2.3). Although livestock operations are fairly obvious, easily isolated, 'point sources' of water pollution, it is felt that they have not yet been brought under adequate control or incorporated enough nutrient reduction features to reduce their impact on nearby waterways (Rose, *pers. comm.*).

3.1.2 Soil loss/erosion

Land used for agriculture generally yields about four times more sediment to public waters than any other erosion source (Clark, 1983). It is estimated that, in the case of the SCRS catchment, agriculture contributes about 80% of the estimated 2,800 tonnes of sediment that is generated each year (Water and Rivers Commission, data). These eroded materials carry excess nutrients and toxic substances (e.g. pesticides) into the waterways, and cause water turbidity and the accelerated sedimentation of the estuary, the river and its tributaries. Silting also results in the shallowing of river systems, the infilling of deep pools (Waterways Commission, 1993) and weed growth in response to these changes. In summer, the infilling of deep pools can be expected to severely impact on aquatic fauna.

The land degradation assessments carried out to date indicate that the erosion hazard is worst in the 119,000 km^2 catchment of the Avon River, from which the annual soil loss is estimated to be in the order of 9,500 tonnes/year (Water and Rivers Commission, data). Due to the alteration and removal of riparian vegetation and the impact of livestock grazing on unfenced creeks and waterways, bank erosion is a major contributor to the sediment yield.

3.1.3 Nutrient shedding

'Nutrient shedding' is a major problem in catchments such as Ellen Brook where, after heavy rainfall, the export rate of phosphorus is massively increased when run-off assumes the form of sheet-flow across the low-lying, fertiliser-applied, sandy soils of the catchment (**Plate 1**). Under these circumstances, the area literally 'sheds' nutrient over land into the nearest waterway, and any management measures designed to control nutrient export are usually overpowered.

3.1.4 Rural housing

When located in low-lying areas with a naturally high water table, rural housing can become potential sources of pollution due to use of septic tanks. Once the adjacent soils become saturated after periods of heavy rainfall, the liquid wastes from septic tanks tend to rise to the surface and overflow into public waterways. The actual contribution from septic tanks in rural areas to the overall nutrient load currently being exported from the catchment is unknown, and is probably of minor importance, but in certain areas such as the Upper Canning it is considered to be a significant input (Wong & Morrison, 1994).

3.1.5 Loss of habitat and riparian zones

The ongoing clearance of indigenous vegetation is a serious conservation issue in the catchment of the SCRS. Apart from preventing the uptake of nutrients and altering the water balance by increasing or decreasing run-off and/or evapotranspiration, bush clearing and the elimination of riparian zones has caused a steady diminution of biodiversity and habitat availability (Halse *et al.*, 1993).

From a hydrological point of view, bush (or 'broadacre') clearing creates a significant change to the water balance in the catchment, the nett effect of which is detrimental to aquatic resources, particularly wetlands. In the Avon catchment, for example, where over 65% of the area has been cleared of native vegetation, a substantial rise in groundwater levels has resulted (Viney & Sivapalan, 1996) and salinity problems are widespread and increasing. Up to 20% of the greater Swan Coastal Plain is estimated to be affected by salinity, with up to 36% of irrigated land in some areas experiencing extreme salt levels (State Salinity Council, 1999).However, the figure is much reduced in the SCRS.

The disturbance of riparian zones (i.e. phreatic, bank and floodplain areas), by the removal of vegetation to increase farmland or by the trampling and erosion of riverbanks through the activities of livestock, has similar effects to those described above. Riparian zones are of utmost importance in river conservation because they form a part of the catchment that directly affects aquatic ecosystems and streamflow quantity and quality. The vegetation of these zones plays an important role in the river ecosystem by supplying food (particulate organic matter) to the aquatic fauna, controlling the drainage of water, nutrients and other minerals to the streams, by providing shade, and by stabilising the banks (Ward & Stanford, 1979; Walling, 1980).

With the large amount of functional riparian habitat that has been altered or destroyed in the catchment of the SCRS (Bridgewater, 1980), it is widely accepted that the capacity of the SCRS for self-purification has been overwhelmed. In other words, the now much smaller SCRS is unable to assimilate and process the now much greater quantity of nutrients being exported from its catchment (Pen, *pers. comm.*).

3.1.6 Loss of biodiversity

From a catchment management perspective, the importance of biotic diversity lies in its value as an indicator of change in ecosystem status.

There is evidence to show that naturally adapted indigenous and endemic communities are starting to be replaced in the SCRS by alien species (Brock and Pen, 1984). Supporting evidence for the loss of fringing plant communities along the shoreline of the SCRS is provided by Pen (1987, 1993), and the number and abundance of waterbird species associated with the SCRS is considered to be declining by Jaensch (1987). Similar changes have been observed in the invertebrate fauna (Davis *et al.*, 1993) and freshwater fishes of the system (Morgan *et al.*, 1998).

The nett effect has been a loss in biodiversity, particularly in upland areas and every indication of a system undergoing unwanted change as a result of pollution and habitat loss.

3.1.7 River regulation

Flow regulation is a catchment management issue because of the dams that have been constructed on many of the major tributaries of the SCRS (see Section 3.2.5). Flow regulation has repercussions downstream on river functioning and self-cleansing processes (Ward & Stanford, 1979). It is strongly suspected that, together with the large number of abstraction weirs on the rivers and streams of the SCRS, the existing dams have caused a reduction in the annual variations in flow. In the process, the temporal and spatial heterogeneity of the environment in which the biota have evolved are likely to have altered (Walker, 1980).

By altering the flow regime / hydrological variability of rivers through dam construction, flood events are rarely storm driven. Downstream flushing is reduced, sediment and nutrients accumulate as the river channel contracts under the lower flow regime, and the seasonality of the flow peaks and troughs are evened out, often with adverse physical and biological consequences for riverine and estuarine areas further downstream.

To complicate matters further, the Kent Street Weir was built across the upper reaches of the Canning Estuary in 1927 to prevent the intrusion of saline water and, thereby, facilitate the upstream development of irrigated market gardens, orchards and dairy farms (Water and Rivers Commission, 1996a). Blooms of blue-green algae and the prolific growth of introduced aquatic macrophytes (*Hydrocotyle*), that periodically occur upstream of the weir, are due to the impoundment of nutrient rich freshwater in the area (Hamilton, 1996). It is hypothesised that the resultant change in the ecology of the river was likely to have been a significant factor in the prolific blue-green algal blooms that occurred in the Canning River over the 1993–1994 and 1997-1998 summers (Donohue, *pers. comm.*).

3.1.8 Interbasin water transfers

Interbasin transfers (or diversions) of water from streams and rivers that rise in the Darling range outside the catchment of the SCRS form an important part of the overall strategy for the supply of water to the Perth metropolitan area (Water Authority of Western Australia, 1995). The source of this water currently includes the Serpentine River, the North Dandalup River and the South Dandalup River. However, as Perth continues to grow, so will the need to import more and more water into the catchment of the SCRS. For example, serious consideration is presently being given to the transfer of water from the Harvey River (via the Stirling Dam) that lies in an area with higher and more reliable rainfall than the Perth region (Water and Rivers Commission, 1998a).

Although of no direct consequence to consumers of water in the Perth metropolitan region, the general effects of interbasin transfers are to break down the natural divides between catchments so that physical and biotic components are translocated and aquatic gene pools are mixed or destroyed (Petitjean & Davies, 1988).

3.1.9 Fire management

The effects of bushfires on streamflow and water quality in the SCRS are largely unknown. However, from research conducted in other parts of the world, catastrophic fires (i.e large scale wild fires) in forested catchments are known to have caused major changes in water quality (van Wyk, 1986). These changes include extremely high increases in levels of nitrogen and severe sedimentation.

Although it can be argued that fire is necessary for the regeneration of certain natural flora, the frequent summer fires that occur within riparian vegetation negatively affects its functional value as a buffer zone along streamlines and creeks (Cooperative Research Centre for Catchment Hydrology, 1997). Fire does so by eliminating the additional take up of nutrients that would have resulted from the understorey of shrubs, tree seedlings, low trees, grasses and other herbs. Too frequent fires also encourage those plant species adapted to fire and increase the potential for weeds to dominate.

From a riparian management viewpoint, the lack of adequate environmental consideration given to burning as a means of fuel load reduction in riparian areas is, therefore, an issue that needs a thorough review (see Section 5.5).

3.1.10 Aquaculture

Aquaculture can potentially affect the environment like any other intensive agricultural enterprise. The run-off of nutrient laden water from the dams and pond systems, that are being developed to support marron and yabby aquaculture ventures in the catchment of the SCRS, has the potential to cause the pollution of nearby streams and rivers (Hosja, *pers. comm.*). Apart from nutrient enrichment stimulating algal growth, other potential effects include increased bacterial densities, the presence of toxins (nitrate and ammonia) and reduced dissolved oxygen concentrations. The issue of accidental introduction of non-indigenous species could also have disastrous results for our local waterways (L Pen, *pers. comm.*).

The increasing interest that is being shown in such enterprises by rural and peri-urban communities is, therefore, a water quality management issue that requires monitoring and direction towards BMPs.

3.1.11 Soil testing for phosphorus

Soil testing is the measurement of the mineral and organic nutrient concentrations in soil by chemical analysis. In WA, soil testing is most useful for measuring salinity, pH, organic matter, lime requirement, available P, phosphorus retention (PRI), available K, exchangeable cations (Ca, Mg and K) and sulphur. Occasionally, copper and zinc are measured. Soil testing is of little value for N because nitrate in soil is rapidly leached.

Soil testing is used to diagnose crop growth problems, to monitor the fate of fertiliser nutrients, to compare the chemical properties of different soil types and, most commonly, to assist with planning a fertiliser program. Most commercial and Government laboratories are accredited with organisations such as ASPAC (Australian Soil and Plant Analysis Council) or the National Association of Testing Authorities (NATA) and use standard methods of soil analysis.

The most research into calibration of soil tests, and the greatest confusion with interpretation of results, is associated with soil testing for P. One major reason for this is that there are a large number of tests used worldwide to assess available P and P retention capacity. Laboratories within Western Australia utilise three possible soil tests to determine P availability and retention. Further confusion arises when a laboratory varies the test conditions so that results differ from those using the standard procedure. Not all laboratories offer the PRI test that must be carried out to enable correct interpretation of results for available P.

This is not a trivial problem because, while the primary producer need not be conversant with the techniques, it must be realised that soil tests from different laboratories cannot be compared if different methods are used. This has been a contributing reason as to why soil testing has not been greater utilised in the planning of fertiliser programs.

3.2 Urban catchments

3.2.1 Non-point source (diffuse) pollution

It is well known that in developed, or developing areas, the amount of run-off increases proportionally with the extent of impervious surfaces and roof tops (Clark, 1983). However, a pilot study conducted by the Water Authority of Western Australia (Water Corporation) concluded that there was a profound difference in nutrient loading and seasonal trends between sandy and clay catchments. Clay catchments were found to export more nutrients over the years, particularly when the clay had become saturated with nutrients (and was unable to adsorb further nutrients) and prevented percolation (Water Authority of Western Australia, 1991). However, this is highly dependent upon the landuses affecting the catchment. Historically, the standard practice has been to conduct run-off directly into surface waters, with little or no treatment, via open or closed drains. In the process, natural sub-surface purification is bypassed and the potential for serious, adverse effects on water quality arises, involving a wide variety of oxygen demanding substances, nutrients, bacteria, suspended solids (particulates) and toxic compounds.

Being unable to pinpoint the sources of the pollutants concerned (e.g. road surfaces, motor vehicles, atmospheric fallout, accidental spillages of chemicals, street litter, unauthorised dumping, construction sites and the excrement of domestic pets), urban run-off is extremely difficult to control (Gerritse, 1993; Wong & Morrison, 1994). Moreover, the urban environment produces a mixture of various pollutants because of its multiplicity of outflows.

The significance of domestic animals, particularly dogs, as sources of pollution has not yet received sufficient recognition in the Perth metropolitan area (Gerritse *et al.*, 1992). In both medium-density residential and rural residential areas, pets contribute between 10–15% to inputs of nitrogen and phosphorus. This is not only because packaged dog food is high in phosphorus but also because dogs are walked alongside rivers and streams, often in foreshore settings. This results in the rapid transfer of faeces into public waterways after rainfall occurs in the area.

3.2.2 Point source pollution

Point source pollution in the Swan–Canning catchment has been targeted for investigation by officers from the SRT, WRC and the DEP (Wong, 1997). Some of these include:

- The potential for nutrient contamination through modification of hydrological patterns, as a result of development around the extant landfill area (the old Belmont tip site) at Ascot Waters;
- Site remediation and redevelopment of the Swan Portland Cement site at Burswood;
- Development of control measures to reduce wastewater overflows into the Swan Estuary;
- Industrial survey of non-licensed industrial premises;
- Groundwater contamination in the Ashfield and Bayswater industrial areas;
- Pollution issues from stockholding yard in Susannah Brook and Helena River;
- The status of slipping or boat repair operations along the Swan River;
- Cleanup of the CSBP sites in Mosman Park - North Fremantle and Bayswater;
- Previous landfill sites along the Swan Estuary;
- The fate of the disused wastewater treatment ponds at Warbrook Piggery; and
- Development of a contaminated sites database.

Generally speaking, each of the above point sources is currently being managed through the *Environmental Protection Act 1986*, and discussions about their pollution significance are in progress.

3.2.3 Organic enrichment

Organic discharges (often referred to as oxygen-demanding wastes) are a common type of pollution in the SCRS (Deeley *et al.*, 1993b; D.A. Lord & Associates, 1997). The main sources are effluents from domestic wastewater, food processing plants, animal feedlots and other concentrated livestock operations.

Organic enrichment generally depletes or reduces the concentration of dissolved oxygen in the receiving waters as a result of aerobic decomposition of the waste by microorganisms. Increases in turbidity (and, hence, reduced light penetration), suspended solids (and, hence, substrate modification) and nutrients (and, hence, increased potential for algal growth) often accompany oxygen depletion. When combined, these factors significantly affect riverine biota and result in a decrease in richness and diversity of biotic communities (Dallas & Day, 1993).

3.2.4 High-density housing

Research by Gerritse *et al.* (1990) suggests that where housing in the Perth metropolitan area reaches a density of 10 houses/ha, fertiliser use can be as high as 40 kg of phosphorus per hectare per year. This rate of application is more than double that used for agricultural activities in the catchment.

Housing densities approach 20 to 30 houses/ha in several parts of the city (Poole, *pers. comm.*). Consequently, the effects of fertiliser use on groundwater quality in such areas could be significant and is a matter that requires further investigation (see Section 5.5).

3.2.5 Water use

Perth's total water consumption is presently in the order of 550 GL/yr (Water Corporation, 1998). Private water supplies (i.e. bores) provided 55% (300 GL/yr) of the water used, whereas the remainder (255 GL/yr) came from public water supplies made available by the Water Corporation (Water Corporation, 1998). Potable groundwater resources are utilised through bore-fields, established in Underground Water Pollution Control Areas at Gnangara and Jandakot, to supplement surface water supplies. However, a wide variety of licensed and riparian users draw water directly from the surface and subsurface water resources of the catchment for agricultural irrigation, the watering of gardens and domestic needs. Of the 255GL of potable scheme water supplied annually, 64% is derived from surface water supplies (see **Table 3**) and 36% is drawn from subsurface supplies (Davidson, 1995).

The allocation of water drawn directly from the river system is a difficult management issue, not only because of the water rights of users, but also because the freshwater requirements of the river and the estuary are seldom taken into account (see Section 3.1.7 for further details). Much of the downstream usage of water is dictated by licence requirements negotiated through the *Rights in Water and Irrigation Act 1914*. Current Council of Australian Governments (COAG) reforms are also being undertaken to redefine water releases and trading in riparian rights (Water and Rivers Commission, 1999).

Most of the Darling Range is a declared Water Control Area, the water from which is stored in five major reservoirs in the catchment (**Table 4**):

Table 4: Perth Metropolitan surface water supply (transfers of water from outside the catchment of the SCRS excluded)

DAM	DATE COMPLETED	STORAGE CAPACITY (GL/yr)
Canning	1940	90.4
New Victoria*	1991	9.5
Bickley	1921	.006
Mundaring	1903**	63.6
Churchman Brook	1928	2.2
Wungong	1979	59.8

(Source: A. Moulds pers. comm, Water Corporation)

*Note: * Receives water from the Bickley Dam*

** * The wall was raised in 1951*

The total winter flow into the three largest reservoirs averages 40.5 GL/yr (WRC, *pers. comm.*). In summer, when the natural flow of the rivers is inadequate to satisfy riverside landowner requirements, water is released from the public water supply pipelines to supplement the natural flow. The volume of water released generally equates to average dry season flows (Swan River Trust, 1994).

3.2.6 Recreation and parkland areas

The current management practices used for the maintenance of domestic lawns and public parks in the urban catchments of the SCRS are known to result in the substantial transport of nitrogen and phosphorus below the root zone (Sharma *et al.*, 1992). During the irrigation-dominated summer period, when 25% of all domestic lawns and the majority of public parks, golf courses and ovals are watered from bores, irrigation accounts for 55–75% of the total water input. Of this, as much as 70% passes below the root zone (Sharma *et al.*, 1992).

The data collected show that overall there is excessive irrigation in urban areas and that this is likely to cause leaching of nutrients, particularly where Bassendean sands are present. In the past, the fertilisers commonly used for maintenance of turf had nutrient ratios of N:P:K such as 12:2:6 or 12:4:10. In grass clippings, the nutrient ratios are typically 10:1:5 (3%N, 0.3%P and 1.5%K). Consequently, for residential lawns where clippings are removed, these fertilisers provide nutrients in the correct balance when applied at sensible rates to the coloured (P retentive) soils near the coast.

On public parks, sports ovals and golf course fairways, where grass clippings are usually returned to the surface, the concentrations of soil P gradually increase over time. Recent surveys (Jeffery, 1998) have shown that virtually all sandy topsoils (the 0-10cm layer), apart from those under new turf, currently have concentrations of available P that are in excess of that required for grass growth. It was only at 3% of the sites investigated that grass may have responded to fertiliser P application. More than 80% of sites had concentrations of available P that were at least 3 times the level required, and nearly 50% had at least 5 times this level.

At more than half of the sites, the current PRI of topsoils was less than 1 and, therefore, there was almost zero capacity to retain fertiliser P against leaching. Evidence of P leaching under recreational and sports turf was collected at 56 sites where subsoils had low P retention capacities (PRI 0.5-3). At nearly half of these sites, the concentration of P in soil solution at depths of 50-100cm was estimated to be greater than 1mg/L (Soil Management Consultants, unpublished data).

Nitrogen is invariably the limiting nutrient for grass growth on sandy soils of the Swan Coastal Plain. Annual rates of application depend on the quality of turf required. Rates of N application for couch grass on public parks, ovals and golf course fairways are 150-300kg/ha per year (Kinhill Engineers, 1995). Rates of application for kikuyu grass are somewhat lower. Golf and bowling greens receive 300-400kg/ha per year. These figures do not take into account the pre-planting applications of poultry manure that are common for the establishment of turf (A. Conroy, *pers. comm.*). Poultry manure applied at $30m^3$/ha would provide an initial application of about 300kg/ha of N (Paulin, 1997).

Ammonium sulphate, ammonium nitrate and urea are the most common forms of soluble N fertilisers for turf grass maintenance. For the first two mentioned, the ammonium-N is converted rapidly to nitrate-N in sandy soils. The conversion of urea to nitrate-N in a two-stage reaction is somewhat slower. Nitrate-N is the end product of all three fertilisers and, therefore, there is potential for leaching of N if excessive rates are applied.

3.2.7 Unsewered areas

Septic tanks are widely used in the Perth metropolitan area for the underground treatment and disposal of wastewater in residential areas (Whelan & Barrow, 1984) and soak wells are commonly used for the disposal of wastes in industrial areas. For example, in the catchment of the Bayswater Main Drain there are approximately 8,870 septic tanks (Klemm & Switzer, 1994). The septic tanks are functional because of the extensive network of regional drains in the area, but when located in low-lying, flood prone areas with naturally high water tables, they become potential sources of pollution, particularly for nitrate (Gerritse *et al.*, 1992; Wong & Morrison, 1994). The proportion of sulphate also increases strongly in groundwater from unsewered urban areas (Gerritse *et al.*, 1990).

The contents of malfunctioning septic tanks are normally evacuated by contractors and are taken to the Cleanaway Septage Treatment Plan at Forrestdale where, following treatment, the effluent is discharged to the Water Corporation's sewerage system. It is suspected that pollution of the estuary occurs as a result of some septic tank effluent being discharged directly to municipal stormwater drains and by the leaching of septic tanks effluent into the groundwater. However, the current *Liquid Waste Regulations* of 1996 require all liquid waste contractors to be licensed with the DEP. The control mechanism is a permitting system that requires formal approval and payment of a levy to the DEP before wastes can be emptied on site.

3.2.8 Sewered areas and wastewater overflows

The 'MUST' program (Minimise the Use of Septic Tanks) confirms that it is Government policy to make deep sewerage of residential properties in the Perth metropolitan area a priority because of the problems identified in Section 3.2.7. However, even when carried by deep sewers, wastewater can still present a threat to the SCRS if not properly collected, treated and disposed of, and if pumps are not maintained to operate at their capacity.

Because wastewater collection systems operate by gravity flow, pumping stations and sewers are generally located in low-lying, and hence environmentally sensitive, areas. The extent to which untreated wastewater overflow impacts on the SCRS depends on many factors, including the volume of the spills, their duration, their location, the degree of mixing and dilution in the receiving waters and the frequency of occurrence of the spills. In the event of a power failure, blockage or similar malfunction, including leaking pipes, the resultant overflows of raw wastewater create a potential hazard to human health, aesthetic degradation, oxygen reduction, and contribute to eutrophication (mainly by nitrogen pollution) and heavy metal contamination (D. A. Lord & Associates, 1997).

The effluent from wastewater treatment plants, if discharged to streams, can have detrimental downstream effects, the severity of which are dependent on the amount of treatment the effluent received prior to its release. Similarly, even when used for soil blending, appropriately used and applied biosolids can cause the enrichment of nearby waterways through leaching and run-off. The majority of treated wastewater is discharged to the ocean via submarine pipelines.

In 1996 a working group was established (comprising representatives from the Water Corporation, SRT, WRC and DEP) to report on short and long-term actions to prevent, or significantly reduce, the risk of wastewater overflow to the SCRS. It was found that over the period 1992–1996 a total of 19 spills of untreated wastewater, totalling a little over 1 million litres and contributing a total of 12kg of P and 51kg of N, are known to have entered the SCRS as a result of overflows (D.A. Lord & Associates, 1997). In comparison to nutrient loads entering the system from other sources (see Section 1.4), it was concluded that the contribution by spills of untreated wastewater was insignificant. Furthermore, monitoring of the worst of these events (a spill of 500,000 L from the Armagh Street pump station in March 1994) indicated that background conditions along the 4km stretch of river affected were restored within 48 hours.

3.2.9 Dewatering operations

In the past, the SRT has received complaints that short-term dewatering operations alongside the rivers and creeks in the catchment have resulted in discolouration and increased turbidity of the waterways (Swan River Trust, 1994). However, the effects of dewatering activities become particularly severe when the discharge of contaminated groundwater enters the existing drainage network. Albeit a requirement of the Water Corporation, the current practice of pumping contaminated groundwater and emergency spills into the nearest drain is contrary to the environmental management objectives of the SRT. The agencies involved need to revise their management procedures to ensure that such operations are non-polluting. The effects of dewatering activities can include a reduction in dissolved oxygen levels, high concentrations of suspended solids, discolouration (especially in the case of high clay content materials), odours and, depending on the history of the site, the contamination of the river water with nutrients, heavy metals and other toxic substances.

Dewatering operations in the Swan–Canning catchment have not been adequately addressed, particularly when development occurs outside the SRT management area. There is a need for such operations to be addressed during the initial planning stage, so that appropriate management and/or remedial strategies can be considered.

3.2.10 Solid waste disposal

It is predicted that by the year 2020, 2.7 million tonnes of solid waste (i.e. garbage, refuse and other discarded materials from industrial, commercial and agricultural operations and community activities) will be generated in the Perth metropolitan area (Department of Commerce and Trade, 1993). The sandy soils that surround Perth allow the rapid penetration of pollutants and afford little retention or attenuation of pollution. Consequently, the disposal of solid waste at sites that are situated close to rivers, particularly in the case of contaminated materials, is a serious issue that can be expected to undermine the goals of the SCCP for a long time (**Figure 11**). The ammonia-rich pollution plumes detected from the Bayswater and Ascot landfill sites serve as examples (Health Department of Western Australia, 1991).

Of the 47 sites assessed for possible use for waste disposal, 34 were located in Water Corporation Underground Water Pollution Control Areas, in wetlands, or adjacent to river foreshores (Department of Conservation and Environment, 1981). These sites comprised 73% of the land area assessed as available for waste disposal. An intractable (Class 2) waste storage/disposal site has been identified east of Mt. Walton for the disposal of hazardous waste. However, the identification of a readily accessible and secure site for low hazard waste in the Perth area remains an urgent requirement, particularly for the disposal of soil contaminated with low levels of heavy metals and oils (Health Department of Western Australia, 1991).

3.2.11 Drain maintenance

In the Perth metropolitan area, drain maintenance is necessary to effect the most rapid removal of run-off from urban and industrial areas and to protect life and property from the flood damage caused by the run-off from periodic storms (Miles, 1979). The current drain maintenance works include the removal of sediment and vegetation build-up in the compensating basins that may impede flow. However, from the point of view of the SCCP, it would be preferable if the sediment removed was carted away. Furthermore, drain maintenance can inadvertently remobilise contaminants that have become isolated within the sediments on the floor of drains (particularly when a back-hoe is used for regrading purposes) or trapped within the basin floor; can accelerate erosion by increasing flow velocities within the drain; and exacerbate sedimentation and turbidity downstream. Through the inappropriate use of herbicides for the control of vegetation and the random removal of vegetation, the capability of nutrient removal through vegetation uptake can be adversely affected and, thus, nutrient throughflow increased.

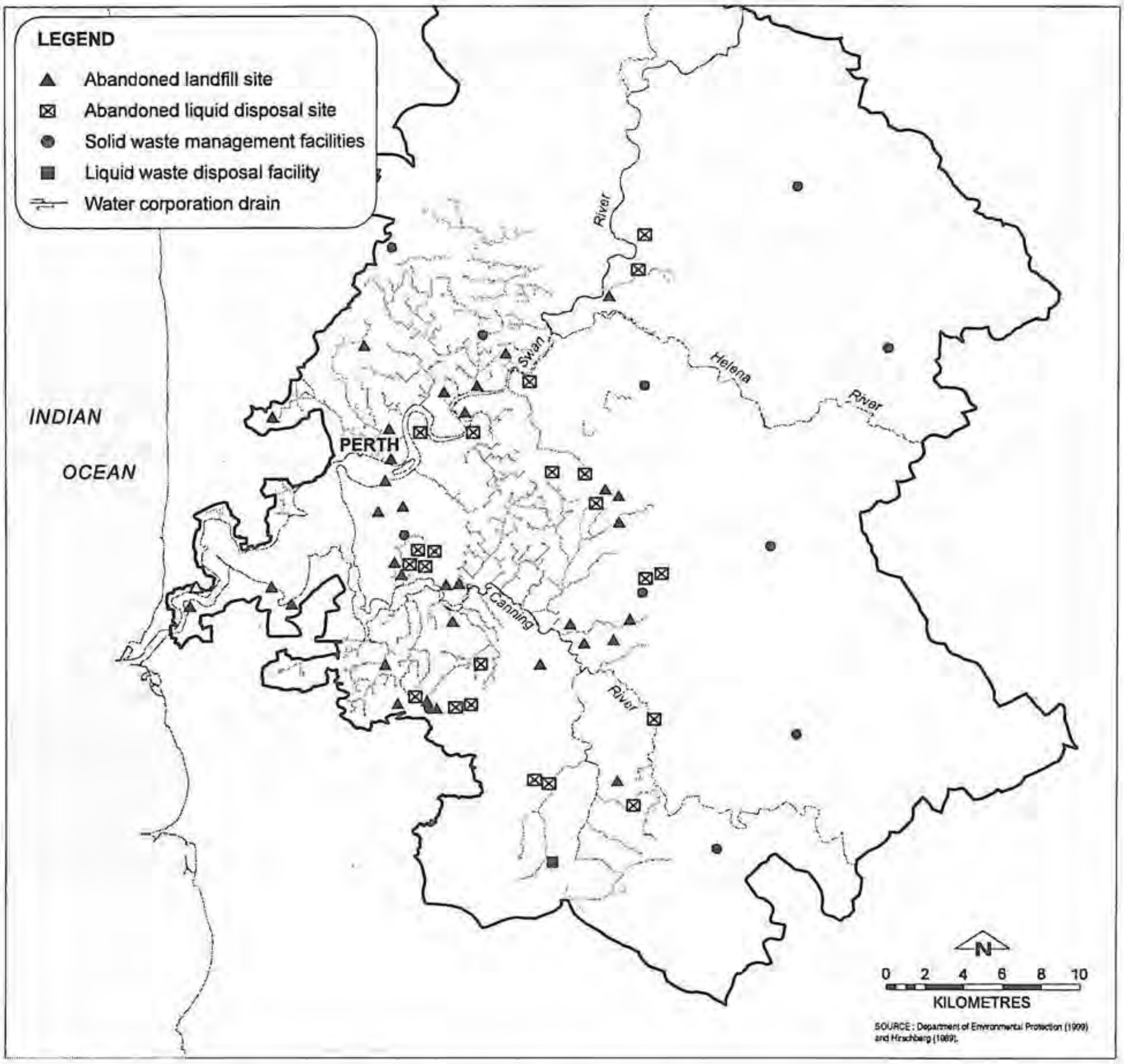

Figure 11: Present location of existing and relict waste disposal sites. Data courtesy Department of Environmental Protection and Hirschberg (1988)

3.2.12 Introduced weeds

The degradation of aquatic and terrestrial habitats in the catchment of the SCRS by introduced plants (i.e. weeds) is considered by many catchment management groups to be a serious conservation problem. There is a tendency for weeds to out-compete indigenous plants and, in the process, to reduce species diversity and diminish the ecological value of what few undisturbed habitats remain in the area. In many cases, weed dominated riparian zones have reduced functionality in terms of nutrient uptake and energy flows.

Although aggravated by the presence of the Kent Street Weir, and subsequently eradicated with the aid of herbicides, the spread of the introduced aquatic weed *Hydrocotyle ranunculoides* in sections of the Canning River serves as a good example. By 1992 these infestations covered approximately 30% of the water area within the Canning River Regional Park and, by that stage, were considered to be negatively affecting the amenity value of the river and oxygen levels in the water column (Klemm *et al.*, 1993). At the same time it is noteworthy that, despite such disadvantages, the plant was providing a valuable habitat for numerous species of wildlife including crustacea, amphibians, fish and birds.

3.2.13 Loss of habitat

As in the case of rural areas (Section 3.1.5), the ongoing clearance and degradation of indigenous vegetation in urban areas (or ecosystem fragmentation) is a conservation issue that warrants far more attention than it is currently being given (Saunders *et al.*, 1991). In the last two years, for example, 6,400 ha of bushland have been cleared in the metropolitan region, 23% of which was regarded as a regionally significant asset (Ministry for Planning, 1995).

While implementation of the recently released Bushplan (Ministry for Planning, 1998; Alan Tingay & Associates, 1998) will help retain some habitat, the overall diversity of habitat will decline if Perth's population and housing expansion continue at present levels.

3.2.14 Soil erosion and sedimentation

The lack of an erosion control policy in urban catchments that are characterised by steeply sloping terrain, is also a serious issue. The significant amount of soil loss associated with urban drainage in the Shire of Mundaring (Jim Davies & Associates, 1998) and with the development of the Araluen Country Club Estate, a golf course development in the Armadale area (Lloyd, 1997), serve as examples.

Much of the erosion in the catchment generally results from the installation and maintenance of infrastructure and developments, e.g. roads, subdivisions and stormwater drains (Lloyd, 1997 and 1998). These provide sediment inputs into the SCRS on a regular basis and contribute to infilling of the estuary and waterways with silt (Waterways Commission, 1993). From a nutrient management viewpoint, one of the benefits of minimising erosion is that nutrients already bound up in the soil would be prevented from reaching receiving waters downstream. Solutions to this issue include requiring developers to implement adequate development controls and conditions so that erosion is minimised. This can be done through local government Town Planning Schemes.

3.2.15 Urban growth

Due to drainage, clearing of deep rooted vegetation, reduced transpiration and imported water from septic tanks and irrigation, urbanisation in the Perth region is thought to have resulted not only in a net increase in the local quantity of water recharged to the unconfined aquifer, but also to changes in groundwater quality (Gerritse *et al.*, 1990). However, through the uptake of phosphorus by soil materials such as aluminium and iron oxides, the water quality of groundwater does not always reflect the different types of landuse in urban areas (Gerritse *et al*, 1998). Generally speaking, groundwater quality in most urban residential areas is detrimentally affected by the input of fertilisers and leachates from septic tanks.

The Water Corporation (formerly Water Authority of Western Australia) has identified differences in run-off and nutrient yield depending on soil, landuse and hydrology of groundwater (Water Authority of Western Australia, 1991). The previous belief that clay and Spearwood sands have a similar nutrient binding capacity does not appear to apply to surface run-off. The study concluded that the erosion of clay and the presence of clay dust on road surfaces are largely responsible for the high phosphorus concentrations found in surface run-off. The impact of urban run-off on water quality has also been exacerbated due to the large increases in impervious areas associated with urban growth.

3.3 Organisational issues

3.3.1 EPP water quality targets

After extensive deliberation by the Targets Working Group (convened by the DEP), provisional targets for total phosphorus loads from the major sub-catchments discharging into the SCRS were initially set by the Environmental Protection Authority (EPA) in 1997. Despite the well-known inaccuracies that are inherent in pollutant load estimates, both 10 and 20 year targets were set because of the inevitable time lag between implementation of improved management and observable improvements in water quality. The set targets applied to all point and non-point sources throughout the catchment and implied that there should be no nett increase in total phosphorus concentrations where sub-catchments were currently below target concentrations (**Table 5**).

Table 5: Provisional target phosphorus and dissolved oxygen concentrations for the Swan–Canning waterways under average flow conditions

	10 YEAR TARGET	20 YEAR TARGET
Dissolved oxygen (mg/L)	>6	>7
Filterable reactive phosphorus (μg/L)	<15	<10
Total phosphorus (μg/L)	<50	<25

The EPA's overall requirement was for the current average mass load of phosphorus entering the Swan–Canning river system (72 tonnes/yr) to be reduced to 40 tonnes/yr by the year 2007 and to 20 tonnes/yr within ten years thereafter. However, with current landuse practices well established in catchments such as Ellen Brook and most of the soils in the area already enhanced by applied nutrients, the CAC maintains that a target that initially aims at preventing the current situation from getting any worse would seem to be, not only more realistic, but also more achievable. Furthermore, the CAC initially advocated that management should first concentrate on water-soluble phosphorus and secondly on total phosphorus, which is mainly particulate. The CAC now advocates coupled management and reduction of both nutrients.

Although nitrogen is known to be a key nutrient responsible for phytoplankton blooms in the upper reaches of the Swan estuary (Thompson & Hosja, 1996; Eade, 1996), it is noteworthy that, even in 1997, no targets had been set for nitrogen. The CAC acknowledged that nitrogen targets were difficult to set because of the naturally high background level of organic nitrogen. Nevertheless, the Committee saw merit in the setting of targets directed at major sources of inorganic nitrogen in the rural and metropolitan areas, including septic tanks, domestic garden fertilisers, paddocks, and horticultural and intensive agricultural operations.

The Swan–Canning EPP (SCEPP) was gazetted in July 1998 (Environmental Protection Authority, 1998). Although no explicit water quality targets were outlined in the policy, the environmental objectives of the SCCP were endorsed by the statutory requirement for a Comprehensive Management Plan (CMP) in the EPP. This will enable the future establishment of statutory water quality targets and objectives, and will provide the framework and influence needed to improve the health of the catchment of the SCRS. Emphasis was also given in the SCEPP to nutrient concentrations and exceedence values as targets (rather than nutrient loads), and both N and P were targeted equally.

3.3.2 Accountability

With numerous different controls being exercised by a wide variety of government agencies existing in the Perth metropolitan region, environmental management of the SCRS catchment is a complicated affair (Helen Grzyb & Associates, 1998). This is primarily due to the lack of clearly defined administrative responsibilities for the many laws, by-laws, international treaties and conventions that apply (Mouritz Environmental Services, 1995).

The above situation means that without one single agency being responsible for all aspects of catchment management, very few issues can be properly addressed and resolved (Everall Consulting Biologist, 1998). For example, the WRC cannot reject a development on environmental grounds unless water is involved;

AGWEST can only pass comment on the application if requested to do so by the local Council; the Council cannot reject the application if the area is rural; and the MfP cannot do anything by regulation until an application for development (i.e. subdivision) or change of landuse is submitted. Finally, local governments can only affect catchment management if they have policies and Town Planning Schemes which direct and legitimise their decision making.

3.3.3 Interagency cooperation

The agencies responsible for management of the catchment of the SCRS often act independently and without reference to each other and, on occasions, have conflicting approaches to environmental management (see Section 3.3.2). The result is overlapping responsibility, duality of functions, conflicts of interest and the inhibition of onground progress with catchment management.

There is a noticeable lack of vertical integration between the administrative and operational division of the agencies involved. Many people also feel that the DEP, CALM, AGWEST, WRC and local governments should be playing a far greater role in management of the catchment of the SCRS. Utilising formally endorsed Memoranda of Understanding (MoUs) is an avenue that warrants scrutiny, because MoUs strengthen ICM and provide a collective management capacity to contribute to broadly supported catchment solutions. The CAC recognises that it is essential to have cooperation at many levels.

The SCEPP CMP needs to recognise the major mechanisms that can support ICM and can help to establish a framework for the coordinated management of protected waterways and catchments. The CMP will also need to specify the people, agencies or organisation responsible for that management. In this respect, the CMP can be used to give effect to non-statutory catchment management plans and formally recognise the MoUs that need to be developed to ensure effective ICM (Bott, *pers. comm.*).

3.3.4 Lack of legislative powers

The controls exercised by government agencies such as the WRC, Agriculture Western Australia and the MfP over landuse in the catchment of the SCRS, potentially give these agencies the most extensive and direct authority over issues such as wetland alteration and the usage of privately owned land. However, no single agency, other than the EPA, has the legislative powers needed to regulate matters such as fertiliser use on areas dominated by high leaching sands in catchments such as Ellen Brook. Without such powers being available to show that the government is serious about achieving the environmental goals of the SCCP, and without a mechanism in place to 'persuade' farmers to adopt a non-regulatory approach to catchment management, the risk of the SCCP and its objectives failing is high.

3.3.5 Sharing the burden of ICM

Despite all its advantages in terms of ensuring the long-term environmental sustainability of landuses and catchment health, ICM is not currently State funded. Instead, the responsibility for tasks associated with ICM is presently being born largely by Local Councils, all of which are under-resourced and under-funded.

As the resources of the SCRS are shared, additional funds to those provided by Local Councils and the Natural Heritage Trust (NHT) are required to finance the necessary planning, equipment and people needed to implement ICM strategies. The State must also be seen to contribute financially because ICM is a dynamic process that must set and achieve realistic milestones, or its participants will lose interest in the result.

3.3.6 Improving support needed by rural and urban community volunteers

In spite of the establishment of 52 semi-independent ICM and/or River Care Groups in the catchment of the SCRS (Fig. 9), the lack of adequate support required by each group effectively means that little work gets done on the ground (Nancarrow *et al.*, 1998). Many groups are reported to be frustrated and disillusioned by the proliferation of committees and the perception that large sums of money are spent on committee support and endless research programmes, most of which do not provide them with the answers being sought.

The small number of active members, totalling approximately 400 individuals in the catchment of the SCRS (P. Hart, *pers. comm.*), also means that the willing few run the risk of suffering from "burn out" (Chambers & Galloway and Associates, 1995).

3.3.7 Achieving behavioural change

In spite of the Swan Catchment Centre having been established to provide "locally applicable technical and administrative support, information, advice and training" to the local ICM Groups involved in management of the catchment of the SCRS, overcoming the inertia towards behavioural change in urban and rural society is a lengthy and tedious process (Institute of Water Research, 1995).

Many a well-planned campaign aimed at heightening community awareness has met with very disappointing results (Nancarrow, *pers. comm.*). The reality is that establishing a strong foundation for an effective catchment management plan, especially in an area the size of the catchment of the SCRS, requires long-term commitment, great determination and large sums of money to see the process through to completion.

3.3.8 Networking

Flowing directly from issues 3.3.6 and 3.3.7 above, there appears to be a lack of effective communication and/or interaction between active members belonging to the rural and urban volunteer groups that have formed in the catchment of the SCRS.

The establishment of the Swan Catchment and Avon Catchment Councils in 1998 will help communication between what are essentially urban and rural areas of the Swan Avon catchment. However, the development of a human (and electronic) network among ICM practitioners, rather than between researchers and government agencies, could well be a powerful tool in improving information transfer, promoting greater collaboration, and generating the synergy and cooperation needed to make real progress.

4. Options for land and water management

4.1 Rural catchment management

4.1.1 Fertiliser management

There are many methods available to avoid the overuse of fertilisers and, in the process, reduce water pollution and ecosystem disturbances in the catchment of the SCRS. However, the key to all such measures is seeking the proper advice on all aspects of fertiliser management from the right people.

In brief, the operational practices for reducing fertiliser loss and nutrient control include:

- eliminating excessive fertilisation;
- using the appropriate nutrients;
- timing fertiliser applications to coincide with the period of greatest need;
- using animal and plant wastes for fertiliser, to make the nutrients required for plant growth available over a longer period of time;
- using slow release fertilisers where applicable;
- matching fertiliser requirements to the different soil types in the catchment by reliable soil testing (del Marco, 1990);
- using deep rooted crops and pastures that access nutrients deeper in the soil profile;
- using legumes to supply nitrogen to the soil;
- preventing animals grazing in watercourses;
- minimising transport of particulate matter from paddocks where manure residues have accumulated over summer; and
- maximising the uptake of nutrients whether applied in manures or inorganic fertilisers.

Provided total inputs of nutrients are reduced, all of the above practices can be expected to appreciably reduce the leaching and run-off of phosphorus and nitrogen in the long-term. For example, del Marco (1992) provides evidence to suggest that there is considerable potential for fertiliser savings among irrigated turf and lawn production areas in the catchment. With nitrogen being the limiting nutrient for grass growth, it was demonstrated that only low concentrations of phosphorus are necessary to maintain an adequate level of growth.

The catchments of the Peel-Harvey Estuary and the south coast estuaries have areas of poor sandy soils under pasture similar to those of the SCRS. Soil testing has been an integral part of the development of improved fertiliser management strategies, aimed to reduce nutrient export into those environmentally sensitive river systems. Intensive soil testing programs were carried out in both regions and the information collected has direct relevance to fertiliser management in the catchment of the SCRS.

In the south coast estuary catchments, 43% of surface soils had very low P retention capacities with PRIs less than 2. Many had PRIs which were equal to or less than zero (Weaver, 1992). The majority of these had concentrations of available P that were between 4 and 14mg/kg, and even at these relatively low levels about two-thirds of topsoils would have desorbed a significant proportion of available P under leaching conditions (Allen *et al.*, 1991). Further applications of water-soluble fertiliser P would only increase the pool of easily leachable P.

Soil testing has been shown to be a valuable technique for improving the management of fertiliser P for vegetable crops grown on the sandy soils of the Swan Coastal Plain. For newly cleared land on Karrakatta sand, rates of P between 150kg/ha (cabbage, cauliflowers) and 500kg/ha (onions, lettuce) are necessary to achieve maximum yields. Higher rates are needed on Spearwood sands (Lantzke & Galati, 1997). These soils soon develop a bank of residual (available) P that can be measured by soil testing, and taken into account for following crops.

The results of a survey of 36 market gardens on sandy soils of the Swan Coastal Plain (McPharlin & Jeffery, unpublished) demonstrate the potential of soil testing to assist growers to make more efficient use of fertiliser P, and to increase profit (Dawson *et al.*, undated report). Topsoil samples had high to very high concentrations of available P. Sixteen sites were on Karrakatta or Spearwood sands (virgin PRI between 2 and 7) and 75% of these had greater than 100mg/kg of available P.

The other 25% had between 50 and 100mg/kg of available P. Recent research has shown crops such as potatoes (Hegney *et al.*, 1997), cauliflowers (McPharlin *et al.*, 1995a), carrots (McPharlin *et al.*, 1994) and possibly lettuce (McPharlin *et al.*, 1996) would achieve maximum yields at these levels of available P. Additionally, the fertiliser P application would only need to match crop removal (25-30kg/ha). These rates are much lower than those currently recommended (100-170kg/ha) by AGWEST for vegetable crops on established market gardens.

Twenty of the market gardens were on poorer (PRI <2) sands, and the average concentration of available P in topsoils was somewhat lower because the soils were less able to accumulate a bank of P. There is some evidence (McPharlin, *pers. comm.*) that lower levels of available P (<30mg/kg) are needed for maximum yield of crops such as carrots on the poorer soils (the very low PRI soils are generally not well suited to soil testing for P, unless soil amendment is carried out to increase the P retention capacity). Split applications or fertigation of P are other strategies that will reduce the potential for P leaching on the poorest soils.

Encouraging the farming of vegetable crops away from the poorer soils may also reduce P leaching. Lettuce, onions and tomatoes have much higher P requirements on new and established land compared with many other crops grown on the Swan Coastal Plain sands (Lantzke & Galati, 1997). The concentrations of residual available P for maximum yield of lettuce and onions are also higher. The low PRI soils are unable to build up the required level of available P and, therefore, the maintenance rates of fertiliser P for these crops will always be high. These crops are better suited to the Spearwood and Karrakatta sands.

Applications of poultry manure prior to planting are common and, at a rate of 30m^3/ha, will supply approximately 300kg/ha of N over a four week period. This is in excess of crop requirements during early growth, and much of the nitrate-N can be leached. Recent research has shown that crops such as lettuce, cabbage and potato do not require pre-planting applications of N, provided post-planting applications begin immediately. This can reduce the overall rate of N applied to these crops. For example, lettuce grown on a Spearwood sand without pre-plant poultry manure required 40-70% less fertiliser N for maximum yield compared with the recommended rate which includes large amounts of pre-planting poultry manure (McPharlin *et al.*, 1995b).

Management of fertiliser N during crop growth is closely linked with irrigation management. Where broadcast applications of N are combined with over-watering there is increased potential for nitrate leaching. More fertiliser N is required to achieve maximum crop yields. Significant improvements have been achieved by applying N in small frequent applications, such as by fertigation on a daily basis. Lettuce grown under trickle irrigation with daily application (fertigation) of N was 21-42% more profitable. The plants gave a significantly higher yield, and were as much as 25% more efficient at using fertiliser N compared with lettuce that were sprinkler irrigated and fertilised at equivalent rates on a weekly basis (McPharlin *et al.*, 1995b). Similarly, for potatoes grown on a Spearwood sand, maximum yields could be achieved with fertigation of N at 460kg/ha for winter crops and 350kg/ha for summer planted crops. These rates are much lower than the average rate of 990kg/ha currently used by potato growers on the Swan Coastal Plain (Hegney *et al.*, 1997).

There is also potential to utilise the nitrate-N that has accumulated in shallow groundwater under some market gardens. If irrigation of summer crops is applied at an average of 150% of pan evaporation, then the total water applied to a crop over a period of 5 months would be about 2000 millimetres. If the bore water contained 20mg/L of nitrate-N this would provide the equivalent of 400kg/ha of fertiliser N, which for many vegetable crops is the total fertiliser N required.

At the same time, the significance attributed above to the likely benefit of reducing fertiliser input should be tempered by the recent AGNPS modelling of P leaching via surface flow from high-risk soils alongside streams such as Ellen Brook (Sharma *et al.*, 1996). The model (for two rainfall events) indicated that a 70% decrease in fertiliser application only resulted in a 25–45% decrease in P leaching.

However, paired catchment studies conducted on pure Bassendean sands (Ellen Brook has many areas of duplex soils) demonstrated that 60-70% reductions in phosphorus export can be achieved by improved fertiliser management, based on Best Management Practice approaches to soil and tissue testing (Jeffery, 1997).

4.1.2 Landuse change

The modelling which has been carried out by Sharma *et al.* (1996) indicates that landuse change holds considerable promise as a way of significantly reducing N and P inputs from problematic catchments. For example, the modelling showed that P leaching is reduced by 80% when the amount of horticulture, on lands that are positioned close to the watercourse, is reduced from high to low proportions.

4.1.3 Soil amelioration/amendment

As a catchment management tool, soil amendment holds considerable promise as a means of improving the water holding and nutrient binding properties of the sandy Bassendean soils that dominate many parts of the catchment of the SCRS (George, 1986).

The techniques include amending sand by introducing clay, loam, 'red mud' (a by-product of alumina processing), and even the waste products from mineral sand operations. These soil amendments improve the retention of irrigation water and applied fertiliser at correct rates within the main feeding and water uptake zone of plants (Hill & Nicholson, 1989). Providing sight is not lost of the potential for high sludge dosing rates to cause groundwater contamination, the introduction of organic matter in the form of sewage sludge and mulches is also an effective way of improving infiltration and water conservation.

There are two major types of soil amendments, inorganic amendments where the principal aim is to increase the soil P retention capacity by adding material rich in iron and aluminium oxides, and organic amendments that act as slow release nutrient sources. Both types of amendment also improve soil structure and increase water-holding capacity.

Inorganic amendments

These can be natural soils such as Gingin loam, or industrial by-products from the production of alumina (bauxite residue, red mud, Alkaloam), mineral sands (Neutralised Acid Effluent Waste, NAEW or Iron Oxide Waste, IOW) or electricity (fly ash). These materials are rich in iron and aluminium oxides, which are the major components of soil that determine P retention capacity. They have been thoroughly investigated in WA for improving P fertiliser management and reducing the leaching of P from very low PRI (Bassendean) sands.

Soil amendments must be friable and readily incorporated. The proportion of material that does not crumble into fine earth (less than 2mm) must be taken into account when assessing the rate of application of amendment required to raise the soil PRI to a certain level. An essential part of the soil amendment strategy is the use of soil testing to provide optimum, but not excessive, levels of available P for plant growth. Soil amendment only increases the PRI of the topsoil, so if the amended layer becomes saturated with P due to excessive fertiliser applications, then P will be leached from the surface at the same rate as unamended soils.

Research trials have been conducted for a number of years to assess the value of Alkaloam as a soil amendment in the Peel-Harvey Estuary Catchment. In areas that have been amended, the amount of P exported to waterways is decreased. Other benefits have been observed, such as an increase in soil pH due to the liming effect of the Alkaloam. Assessments to date on the impact of Alkaloam on environmental water quality and flow, dust levels and composition, animal health and leaching of metals have provided results without any adverse findings (Rivers, 1998). However, at the time of this report, the EPA was determining the environmental acceptability of using Alkaloam and red muds. A favourable decision is expected.

For amendment of horticultural soils, Alkaloam is first mixed with gypsum to lower the pH to that of calcium carbonate. Application rates of Alkaloam/Gypsum up to 240t/ha have been investigated with vegetable crops such as carrots, lettuce, cauliflowers, cabbage, onions and potatoes (McPharlin *et al.*, 1998). Addition of Alkaloam/Gypsum significantly increased pH, P retention capacity, water holding capacity and cation exchange capacity.

Soil testing for P, to assist with fertiliser programs, is advisable on soils amended with Alkaloam/Gypsum compared with unamended soils where rapid P leaching occurs. In a pot trial, the leaching of fertiliser P was so high (79% of P applied) on unamended Joel (Bassendean) sand that the yield of carrots did not reach a maximum despite high levels of applied P (up to 400kg/ha). Addition of Alkaloam/Gypsum at 125t/ha reduced P leaching to 6% of P applied, and maximised yield at 314kg/ha of fertiliser P. The improved yield from amended soils was attributed to increases in both nutrient and water retention.

Some negative effects of amending soils with fresh Alkaloam/Gypsum include decreased yields with some vegetable crops due to increased salinity and induced potassium deficiency. No health risks from heavy metals or radiation were identified for vegetable crops grown on amended soils.

Fly ash from the coal fired Kwinana power station, applied at 50t/ha, was used to amend Bassendean sand. Large increases (49-278%) in clover dry matter production were attributed to improvement in both nutrient and water retention (Summers *et al.*, 1998). The fly ash provided a substantial amount of the P needed for clover growth. Some turf farmers on Bassendean sands have commented favourably on increased water holding capacity from applications of fly ash (R. Summers, *pers. comm.*).

Organic amendments

In the virgin state, sandy soils of the Swan Coastal Plain are extremely infertile, have very low concentrations of available nutrients or organic matter, and have very low water holding capacities. Organic amendments have been essential for the development of vegetable production on these sands, by increasing water retention, increasing organic matter content and providing a slow release source of nutrients.

The most commonly used organic soil amendment has been poultry manure. Horticulture uses most of the estimated 200,000 tonnes of poultry manure that is produced around Perth. As well as environmental concerns over the potential for nitrate-N leaching from pre-planting applications of poultry manure, the management of stable fly has become a significant problem associated with the use of manures. Guidelines for the use of poultry manure in horticulture and turf production have been developed to minimise the potential for fly breeding. These guidelines also provide information on the nutrient content of poultry manure, so that this can be taken into account for crop fertiliser programs (Paulin, 1997).

There is now greater emphasis on the use of composted organic materials as soil amendments in place of fresh or untreated manures. This produces potential benefits to horticulture and the environment, including improved soil quality, reduced fertiliser applications and less nutrient leaching to groundwater (Alan Tingay & Associates, 1997).

Trial work to date in Western Australia has investigated 4 composts at varying rates on established vegetable properties on Bassendean and Spearwood sand. The composts utilised were pig manure sludge plus biosolids and straw; chicken manure plus straw and vegetable waste; greenwaste plus biosolids and Alkaloam/Gypsum; and greenwaste plus biosolids. Yield increases of up to 25% were recorded for onions and carrots, with no improvements for cauliflowers and potatoes. Carryover effects of 10-15% yield increases were recorded for potatoes and carrots. Rates as low as 12t/ha of animal manure plus straw compost gave significant yield responses in some crops. Some yield reductions were obtained with greenwaste plus biosolids compost (Paulin *et al.*, 1999).

In summary, soil amendments generally do not significantly reduce nitrogen export. Care must be exercised to ensure that nitrate contamination of groundwater does not arise. In addition, possible soil contamination from soil impurities in the waste streams of industrial processes should also be considered before wide-scale use.

4.1.4 Riparian management

Much can be done, both physically and biologically, to improve riparian zones in the catchment. Riparian zones make up a minor proportion of the overall catchment area, however, they are critical sources of species diversity and are generally more productive in terms of plant and animal biomass than any other habitat in the area (Pen, 1987; Halse *et al.*, 1993). The revegetation of watercourses, drains, riparian areas and wetlands has also proved to be a very effective method of trapping nutrients associated with the movement of particulate matter, and of reducing erosion and sediment export from catchments (Maltby, 1992; Pinay *et al.*, 1992; Cooperative Research Centre for Catchment Hydrology, 1997).

Possible approaches to riparian zone rehabilitation include:

- "soft" engineering river training to reduce erosion;
- controlled burning;
- the selective planting of bank-binding vegetation;
- the exclusion, or careful management, of livestock grazing by fencing;
- the adoption of alternative grazing strategies; and
- the use of in-stream structures (e.g. gabions, small rock dams and wing deflectors) to improve pool quality and streambank stability, and to increase the water table in adjacent backwaters and wetlands.

However, only after diagnosing the specific problems related to each section of the river or stream selected for restoration, can the treatments required for each zone be individually prescribed.

4.1.5 Improving in-stream flow allocations

Attention has already been drawn to the fact that run-off from the catchment of the SCRS is influenced by substantial regulation (see Section 3.1.7).

An interim environmental flow policy has been prepared by the WRC for the Canning, Wungong and Southern Rivers (Water and Rivers Commission, 1996a). However, in terms of the principles adopted in 1996 by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australian and New Zealand Environment and Conservation Council (ANZECC), there is a need for closer attention to be paid to in-stream flow allocations. This is in order to sustain the environmental and ecological water requirements of downstream ecosystems that are situated elsewhere in the SCRS. The interim policy will be revised as part of an environmental flow study being undertaken for the Canning River following adoption of the SCCP Action Plan.

Understandably, the process of achieving "environmental flows" will have to be balanced against the cost of providing the potable water and irrigation supplies currently required for the metropolitan area.

4.1.6 Nutrient uptake by tree cropping

Properly managed plantations can be an effective way to reduce the discharge of nutrient rich wastewater into rivers (Anon, 1994). Furthermore, the economics of irrigating plantations are often more attractive than the costs of alternative treatment methods for nutrient removal, such as chemical or biological technologies. The economic value of plantation products can also be a significant source of income to owners. However, as with other forms of landuse, there are many important soil and environmental factors to consider. For example, the accumulation of nutrients by trees generally decreases once the canopy has closed after 2–5 years. This means that any further nutrients applied after that stage are likely to overload the soil and easily leach into groundwater. However, this factor must be balanced by the fact that trees have high evapotranspiration rates and dry the surrounding topsoils, thus, increasing the potential for soil absorption. The use of tree lots to increase nutrient uptake needs to be managed with these factors in mind.

4.1.7 Nutrient stripping

There is a great deal of current interest in using the biological processes that are operative in wetlands to act on nutrients and other materials, in both stormwater and base flow run-off, by transforming them into other forms. These transformations, referred to here as mechanisms for 'nutrient stripping', include uptake and incorporation of inorganic nutrients into living organisms, the loss of organic nutrients by secretion and decomposition and, in the case of denitrification, by removing them from the system entirely via atmospheric exchange (Athanas, 1987; Horne, 1995).

It is difficult to assess how efficiently a wetland removes a given pollutant (Raisin & Mitchell, 1995). However, the two basic requirements for the above-mentioned biological processes to act on the nutrients in stormwater are: firstly, an area that permits adequate development of populations of aquatic plants, algae, fungi and bacteria; and secondly, an area large enough to retain the incoming stormwater for long enough to allow such transformations to occur. Under normal circumstances, natural wetlands have several attributes that enhance their capacity for improving water quality. These include:

- a high capacity for reducing the velocity of water flow;
- considerable contact between water and sediment;
- a variety of anaerobic and aerobic processes that remove pollutants from water;
- high plant productivity, leading to high rates of mineral uptake;
- high soil organic matter content; and
- well-established natural communities of microbes, and substantial surface area (above-ground and below-ground) to encourage further attachment and growth of microbes.

The idea of creating artificial wetlands by incorporating them in compensation basins (see Section 4.3.1) stems from these attributes.

4.1.8 Wetland creation and restoration

The creation and restoration of wetlands in locales that were historically poorly drained (i.e. creeks, floodplains, fringing forest, marshes and mudflats) is an attractive option for the control of non-point source pollution (Mitsch, 1992). Providing it is performed in an ecologically sound manner, this has the potential to significantly enhance the nutrient processing capacity of the SCRS (i.e the ability of streams and tributaries to cleanse themselves).

"Wetland creation" refers to the construction of wetlands where they did not formerly exist, whereas, "wetland restoration" refers to the enhancement of existing wetlands. Generally speaking, created wetlands require deliberate management or manipulation to maintain optimal treatment performance, but restored wetlands provide substantial water purification without active management. The latter also support additional values such as flood control, habitat, educational and recreational functions.

Hammer (1992) contends that the most efficient approach to controlling agriculturally related non-point source pollution is to employ a combination of accepted Best Management Practices (BMPs) for waste handling and erosion control, along with constructed and natural or restored wetland systems, in the hierarchical system depicted in **Figure 12**. Ideally, each farm has on-site control recovery systems (see Section 4.1.9), and each drainage line has strategically located in-stream systems such as grassed waterways and farm ponds. Final polishing is provided by systems consisting of large natural or restored wetlands in the lower reaches of the catchment.

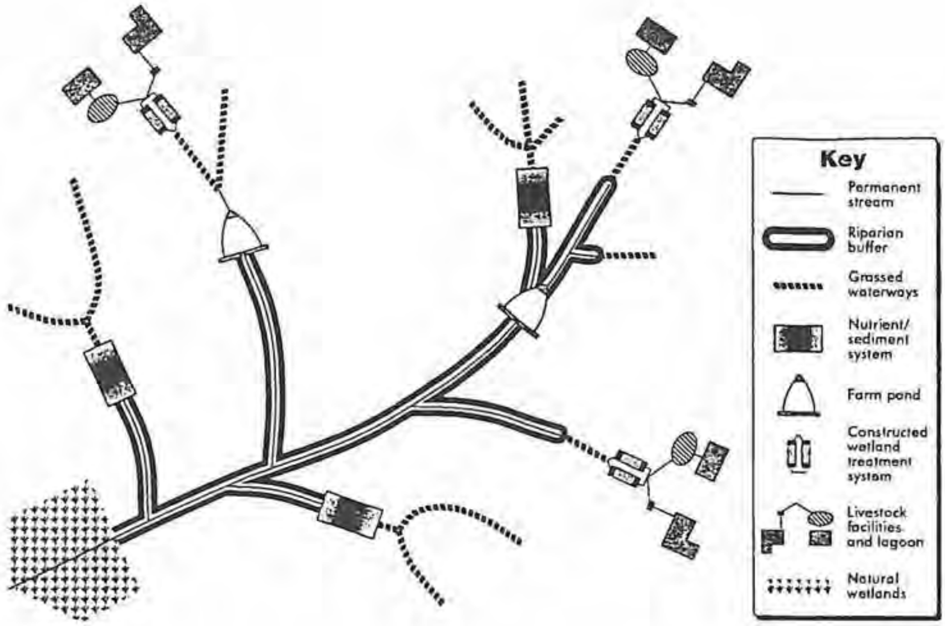

Figure 12: Generally accepted best management practices for controlling agriculturally related non-point source pollution outside of Western Australia (Hammer, 1992).

4.1.9 Recycling

Although yet to be properly investigated, there is the potential to constructively use water that is already polluted by nutrients. This could be achieved by recovering (or harvesting) the run-off from agricultural enterprises, in storage basins or subsurface water recovery systems, and reusing it on farmland or pastures.

Although dependent on crop uptake, land application methods such as trickle and spray irrigation (for soils with low infiltration) and flood irrigation (for deep permeable soils) could be used to renovate (i.e. cleanse by biological and chemical transformation processes) what would otherwise amount to wastewater. Apart from the possible economic advantages, which could include eliminating the need to apply more fertiliser and increasing crop yields or livestock production, the importance of the concept lies in the recognition that agricultural run-off can be treated as an asset, rather than a nuisance. This has been recognised in a recent

recycling demonstration system installed at the Gladalan Nursery in the Canning catchment.

4.1.10 Land capability assessment

Land capability assessment is a planning procedure that can make a substantial contribution to the resolution of natural resource utilisation problems in the SCRS catchment. This is particularly important where the intention may be to solve problems *before* they eventuate, rather than afterwards. By determining how the natural processes operating in a landscape offer opportunities and constraints for land utilisation, land capability analysis is aimed at identifying and specifying the most and least suitable landuses (Clark, 1983). In essence, the aim is to match the development intensity with the landscape tolerances and to arrive at the least cost:greatest benefit solution to land utilisation.

Land capability and suitability assessments typically involve the analysis of climatic, topographical, hydrological, pedological and biological data to gain an understanding of the drainage and movement of water. The effects of water run-off from development are estimated and strategies for holding run-off, increasing percolation and maintaining natural features, such as wetlands, are also incorporated. Vegetation data are interpreted for composition, habitat value and tolerance to change, and recommendations are made for the size and location of wildlife corridors.

All of these considerations are necessary to undertake a comprehensive land capability assessment. However, land capability must also be integrated with land suitability in order to promote the best planning of developments. For example, a site in a riparian zone may be capable of sustaining horticulture, but it is unlikely to be suitable in that location. Therefore, the best planning, which minimises environmental degradation and future conflict, utilises land capability assessments in conjunction with land suitability considerations to make the best-informed decisions.

4.1.11 Catchment management planning

From a catchment management perspective, the importance of landuse planning cannot be over-emphasised, regardless of whether this be undertaken on a catchment-wide regional (or sub-regional) scale or on a detailed, farm specific scale. Ideally, a 'hierarchy of plans' is necessary to ensure that planning at a local level conforms with that considered appropriate on a regional scale.

In an effort to combat soil and fertiliser loss within the rural catchments of the SCRS, farm planning at the lowest on-the-ground scale would involve making an overall assessment of the physical properties of a farm. This would involve input from the landowner and would utilise aids such as contour maps, soil maps and aerial photographs to design the most appropriate layout for fence and roadway alignment, as well as the most suitable places for stock access and watering points. Simultaneously, a suitable framework of protective structures, terraces, grade banks, isolated valley bottoms, grassed waterways and natural drainage lines would be developed to ensure the long-term productivity of the farm, without diminishing soil resources or causing the degradation of downstream resources such as rivers and estuaries.

Farm Plans are then integrated, in a hierarchal manner, with catchment-wide natural resource management considerations, which are in turn integrated with rural strategies, town planning schemes and regional development schemes.

4.2 Urban catchment management

4.2.1 Water-Sensitive Urban Design

Water-Sensitive Urban Design (WSUD) provides a way of integrating water resource management into landuse planning. As the main thrust of WSUD is to reduce the discharge of stormwater (surface run-off) from urban areas, it is an invaluable tool for ICM in urban catchments. The Integrated Local Area Planning (ILAP) process adopted for the Middle Canning catchment (Evangelisti & Associates, 1995) holds similar prospects, as does the Western Australian Planning Commission's (WAPC) "Community Design Code" (Ministry for Planning, 1997). The water sensitive planning and management principles used by Whelans *et al.* (1993) and G.B. Hill & Partners (1995), to develop Best Planning Practices (BPPs) for urban development in the Perth metropolitan area, are also effective tools for ICM.

There is a strong need for the adoption and implementation of these guidelines and, because of their relevance to water resource management in the rural catchments of the SCRS, there is a requirement to develop a similar set of design guidelines for rural areas (see Section 5.3). The guidelines envisaged would also reinforce the shared policy position and water resource management goals that have been adopted by the WAPC, the MfP, the EPA, the Water Corporation, the DEP, the WRC, and the Western Australian Municipal Association (WAMA).

As a compliment to WSUD guidelines, performance standards relevant to specific projects and developments also need to be developed. This will allow performance of WSUD features to be tested and improved over time.

4.2.2 Land drainage planning

From the point of view of the SCCP, it is encouraging to see that the MfP, the WRC and the Water Corporation's approach to future development in the NE Corridor (Ellen Brook) area (**Figure 13**) is based on WSUD principles (Department of Planning and

Urban Development, 1994). The drainage strategy that has been developed to ensure that:

- all surface and subsurface drainage pipes should be placed no lower than the average annual maximum groundwater level;
- all existing natural watercourses, together with their fringing vegetation, are retained as an integral part of the drainage system;
- in the interests of flood protection and prevention, no development or filling should be allowed within the 1:100 year average recurrence interval flood level of natural watercourses;
- arterial drainage should be incorporated into multi-use corridors that provide other functions to the community besides drainage;
- a combination of existing (degraded) wetlands, constructed wetlands and infiltration basins are used to detain flows and control pollution; and
- existing wetlands are protected.

Evangelisti & Associates (1995) have also developed similar strategies, on behalf of the WRC, for the Middle Canning catchment. The next stage of the process is to address the management of urban riverine wetlands within the cities of Armadale, Canning and Gosnells, as part of the SE Corridor Urban Water Management Project (P. Hart, *pers. comm.*).

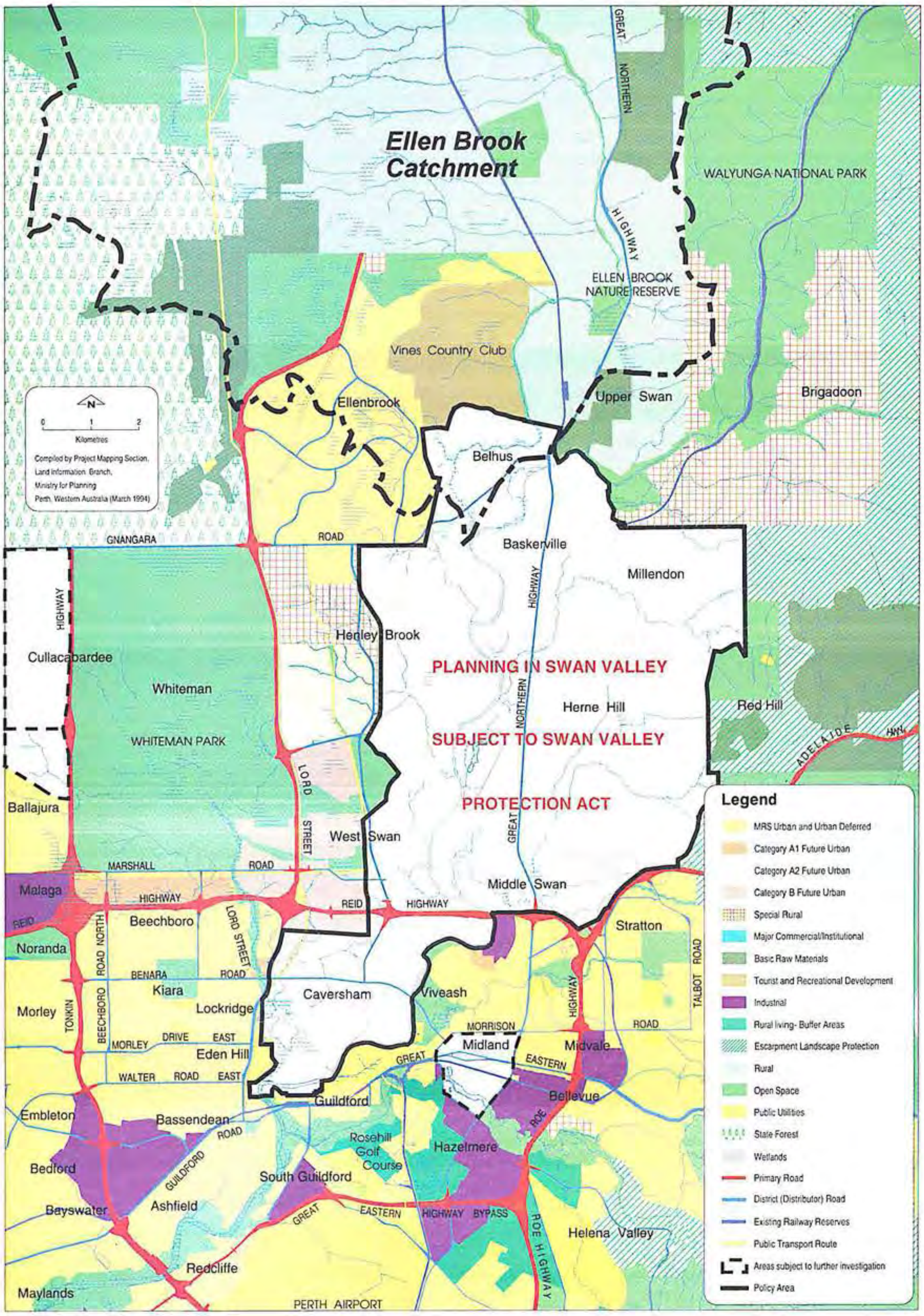

Figure 13: Development intentions in the NE Corridor (Ellen Brook area) prior to current review and proposed extension to the NE Corridor of the Metropolitan Region Scheme

4.2.3 Wetland protection

In order to benefit from the water-cleansing function of wetlands, it should be the policy of every management agency and/or ICM group in the catchment of the SCRS to ensure that the continuum of wetland types identified by Semeniuk *et al.* (1990) remains functionally intact. The following constraints will be necessary to carry out the policy.

- The drainage of wetlands, including areas that are regularly flooded or have a permanent or seasonally high water table, requires careful consideration prior to approval.
- To provide sufficient filtration and purification of surface run-off from developed areas already existing within a natural wetland catchment, buffer strips of natural soil and vegetation must be maintained around all open water areas, including river channels (Davies & Lane, 1995; Cooperative Research Centre for Catchment Hydrology, 1997).
- There should be no excavation in wetlands because vegetation would be obliterated, water flow disrupted, soil layers destroyed, and drainage and drying out of the system would occur.
- There should be no filling of wetlands because the soil cover would physically obliterate them, change elevation, alter the water regime and generally disrupt their function.
- There should be no land clearing or removal of natural vegetation in wetlands.
- There should be no solid-fill roads or other structures in wetlands because they obstruct water flow. Unavoidable roadways through wetlands should be elevated on pilings rather than placed on fill.
- The discharge of new stormwater and drainage into natural wetlands is not advocated and may be prohibited by the *Environmental Protection Policy for the Swan Coastal Plain and Lakes (1992)*.

4.2.4 Cluster housing

Clustering, or the utilisation of a formal process to allow developers to build at higher densities than would normally be permitted, has considerable merit as a management tool in the catchment of the SCRS. In reality, density-compensated transfers of development are simply another form of Water-Sensitive Urban Design (Whelans *et al.*, 1993). However, there is ample precedent for its application in the catchment of the SCRS due to the high-density of drainageways (rivers, streams, creeks, drains, swamps and lakes) in the area (**Figure 5**).

Due to the nature of the terrain in the catchment of the SCRS, cluster and nodal development would go a long way towards shifting conflicting landuses away from environmentally sensitive areas such as wetlands, sumplands and damplands.

4.2.5 Multiple use (strategic) corridors

Since 1928, there has been a firm policy that a 30 to 50m reserve should be created along all permanent watercourses in the Perth metropolitan area (Poole, *pers. comm.*). These have subsequently been incorporated into the Metropolitan Region Scheme using Section 5a of the *Town Planning and Development Act of 1928*.

However, over the past decade, the idea of creating multiple use (strategic) corridors (MUCs) along either side of major drainage lines has been advocated by several other major role players in the SCRS catchment area:

a) The State approved of the progressive implementation of the EPA's and the Western Australian Water Resources Council's recommendations for the establishment of a system of interlinking linear and regional parks along major watercourses such as the Swan, Canning, Helena, Avon and Brockman Rivers (Environmental Protection Authority, 1993; Fielman Planning Consultants, 1987; State Planning Commission, 1989).

b) The Strategic Drainage Plans developed by the WRC, for urban areas in the Perth metropolitan region, are based on the development of multiple use (strategic) corridors along natural drainage lines. These are gradually being adopted by the Water Corporation and Local Authorities throughout the area (Department of Planning and Urban Development, 1994).

c) The WRC (Anon, 1996b) has repeatedly advocated that, because of the different ways in which catchment processes can affect the status of wetlands and natural watercourses throughout the area, the establishment of multiple use (strategic) corridors is an overriding priority. These corridors facilitate the preservation of ecosystem functions, and sustain the societal benefits that are associated with the protection of water resources.

4.2.6 Fertiliser management

As in the case of rural catchments (Section 4.1.1), there are several methods available to avoid the overuse of fertilisers in the urban catchments and, in the process, reduce water pollution in the catchment of the SCRS.

Soil testing and the subsequent use of slow release fertilisers such as dicalcium phosphate (which is sixty times less water soluble than monocalcium phosphate) for golf courses, gardens and lawned recreation areas would considerably reduce phosphorus inputs from urban areas into the waterways of the SCRS. The provision of better guidelines for fertiliser use in urban areas would have similar effects.

4.2.7 Erosion control

Many engineering techniques are available to control urban/rural erosion and sediment release. These control measures include rock gabions for embankment erosion; kerbing for roadside erosion; sediment fences for sheet erosion and road verge construction; sandbag sediment traps for sediment laden water; energy dissipaters for steeply inclined drains; as well as techniques for the compacting of newly filled trenches (Lloyd, 1997 and 1998). Hence, engineering controls, in combination with the wise use of selective vegetation, provide a powerful tool to facilitate erosion control in the catchment.

However, as with the situation elsewhere in Australia and other parts of the world, the effectiveness of erosion and sediment control measures ultimately depends upon the extent to which levels of awareness and education can be raised amongst the relevant government agencies, local authorities, utility agencies, private contractors and communities that are responsible for resource management in the area.

4.2.8 Catchment management planning

Catchment management planning in the urban catchments of the SCRS is a vitally important management tool for achievement of the goals and objectives of the SCCP (Mouritz Environmental Services, 1995). Urban catchment planning provides opportunities to reduce nutrient losses and enhance urban landscapes by linking State, local government, business and private residential development initiatives.

As in the case of farm planning (see Section 4.1.11), catchment management in urban areas aims to develop mechanisms to minimise adverse impacts; to encourage cooperation and liaison between landusers and land managers in all parts of an individual catchment; to foster cooperation within and between all tiers of government (particularly at a local level); and to reduce the threat to the long-term availability, productivity and integrity of natural resources. It is possible that the WAMA is the organisation best suited to facilitate the coordinated approach necessary for catchment management planning in urban catchments of the SCRS.

4.3 Engineering options

In the context of this report, "engineering options" are regarded as intervention techniques that can be employed to reduce nutrient export in the catchment of the SCRS. When viewed in this light, they can be linked directly to the management options described for the Swan–Canning Estuary in the 'River Intervention Technical Report' which forms part of the SCCP Action Plan.

4.3.1 Compensation basins/detention ponds

Compensation basins or detention ponds are widely used throughout the world to retard and attenuate stormwater run-off from developed areas, in order to off-set the increase in peak flows caused by the urban, suburban and agricultural use of land (Clark, 1983;

Athanas, 1987; Evangelisti & Associates and Landvision, 1994; G.B. Hill & Partners, 1995). In simple terms, a detention pond is a device that receives run-off, temporarily stores a portion of the run-off, and results in benefits such as:

- reduced flooding in downstream areas;
- reduced sedimentation and turbidity in downstream areas; and
- additional floodplain storage.

Detention ponds do not normally provide significant benefits in terms of nutrient uptake. However, with careful attention given to the size of the pond, soil type, water table relationships and outlet conditions, especially with aid of chemical intervention (see Section 4.3.5), they can be made to act as biofilters by performing a water cleansing function. If naturally vegetated, modified through landscaping or surrounded by planted trees, they can also become very desirable elements of open-space areas both visually and environmentally. A system of detention ponds has been developed for a large portion of the NE Corridor, by G.B. Hill & Partners (1995), for the Water Corporation (formerly the Water Authority of WA). As developers are required to incorporate these ponds in development proposals, they are expected to greatly assist in the reduction of nutrient outputs from the Ellen Brook catchment. However, largely due to the confounding influences of insufficient space and monitoring, their effectiveness has yet to be proven.

4.3.2 Retrofitting of existing drainage systems

Although extremely costly, the remodelling/reconstruction of old, poorly designed drainage systems, in such a way as to become more sympathetic to the environment, is another form of Water-Sensitive Urban Design that has merit in the urban catchments of the SCRS. For this reason, the preparation of a retrofitting plan, targeting drains that are known to carry high nutrient loads, would be very worthwhile in the catchment.

For example, with minor modifications to the design of conventional road-crossings over low-lying areas or streams, it is possible to utilise roadways as part of a stormwater management system (Miles, 1979). By allowing the approaches to the stream crossing to act as a dam wall, a detention pond is created upstream. Furthermore, by modifying the inlet structure of the culvert, to form a type of spillway with openings in the side walls, the pond can be designed to slowly drain and, thereby, allow natural settling and uptake processes to take place before flowing further downstream. However, such modifications may require approval and support from local government authorities or Main Roads WA. Furthermore, if salinity is an issue in the area, retrofitting modifications may not be appropriate.

4.3.3 Groundwater interception

The interception of polluted groundwater by deep trenching (or the creation of borrow pits), downslope of the source areas, has been proposed as a possible way of trapping nutrients prior to their removal with the aid of aquatic macrophytes and sediment deposition. However, due to the great number of possible contaminants and the diverse ways by which they may be introduced into the groundwater system, each potential groundwater pollution hazard in the catchment of the SCRS needs to be evaluated in terms of the longevity of the contaminant, its toxicity, its concentration, its point of entry into the groundwater flow system and the local and regional hydrogeology (Clark, 1983). Groundwater interception is not possible, for example, in low-lying, high-density urban areas.

Unless properly designed and maintained, the waterbody created by trenching has the potential to become so polluted that it ends up being more of a liability than an asset. After a few years, an anaerobic zone of ooze and decaying plants normally develops on the floor of the trench, causing oxygen levels within the water column to fall to substandard levels. Thus, carefully integrated and holistic management approaches must be undertaken before groundwater interception is utilised as a means of nutrient control. An up-to-date survey of the catchment of the SCRS is also required to assess whether adoption of this technique is fully warranted.

4.3.4 Deep sewerage of residential and industrial areas

At a community level, the need for deep sewerage in the industrial and residential areas of the Bayswater Main Drain catchment has been assigned a high priority to prevent the disposal of liquid waste to septic tanks and soakwells (Klemm & Switzer, 1994). However, as yet, no government-funded program exists to confirm that the deep sewerage of industrial areas will, in fact, occur (Glass, *pers. comm.*). Having shown that there is a close relationship between nutrient loss and the percentage of unsewered areas in the Canning catchment, Wong & Morrison (1994) have placed a similar priority on the need for deep sewerage in areas of high septic tank density throughout the catchment area (see Section 3.2.7).

Although much depends on the hydrology of the area, the concept of deep sewerage as a 'solution to pollution' needs to be approached with caution (**Figure 14**). Apart from the massive capital investment required for deep sewerage, once deep sewers are established in vacant lands (open-space) they can create a strong pressure for development regardless of whether the community or local government has planned for it. Furthermore, if not properly designed and operated, deep sewerage systems may only accomplish a transfer of pollution from dispersed sources within the catchment to a concentrated point source elsewhere (e.g. offshore).

Therefore, from a nutrient pollution point of view, merit can be seen in identifying areas within the catchment of the SCRS that are prone to contributing leachates to the river system. Areas of this nature should then be designated as 'critical' for future deep sewerage programmes in the region. In fact, the current Infill Sewerage Program is prioritised according to public health and environmental concerns.

4.3.5 Chemical intervention

Although of no real practical value as a long-term measure for nutrient reduction on a catchment wide scale, in certain 'crisis' situations nutrients can be 'stripped' from detention ponds by chemical means. This process involves the addition of chemicals, such as alum or lime, to precipitate (or flocculate) colloidally suspended silt particles from the water. In the process, pollutants which have become physically bound to fine mineral particles, such as phosphorus, are effectively removed and confined to the floor of the pond. However, the contribution of phosphorus and nitrogen mobilised from anoxic sediments, to the internal loading of the pond, can still be substantial and can negate the effects of initial stripping (Gerritse *et al*, 1998). At the same time, this can be alleviated to a large extent by regular removal of sediment build up.

Providing there is no horizontal movement of water through the pond, dosing with specifically formulated activated clays and high phosphorus retention wastes (such as fly ash) can have similar effects by accelerating phosphorus uptake in the water column (Humphries, *pers. comm.*). Recently, trials of this nature using modified clays have been successfully undertaken by the CSIRO in Lake Monger (Douglas *et al.*, 1998).

Figure 14: Sewered areas of the study area

4.4 Policy options

From the preceding sections of this report it is apparent that the eutrophication problems of the upper reaches of the Swan Estuary and the lower reaches of the Canning River are due to activities external to them. The root cause is inappropriate development and land practices in the catchment, at a time when a knowledge and awareness of the downstream consequences was limited.

In order to exercise control over landuse activities in the catchment of the SCRS, four policy options need to be considered by the management agencies responsible for providing and maintaining the socially and environmentally important values of the estuary. These are:

- *direct control*—i.e. the regulatory approach to controlling landuses that have the potential to pollute the river system, through the enforcement of existing regulations, increasing legislative powers and increasing penalties for non-compliance;
- *government acquisition*—i.e. government and local authority intervention, by acquiring those resources in the catchment which formerly protected the estuary from eutrophication;
- *fiscal measures*—i.e. a non-regulatory approach intended to provide the monetary incentives needed for private landowners to allow resources, which have the potential to protect the estuary from eutrophication, to be used in a different manner; and
- *community involvement*—i.e. a participatory approach to conservation of the catchment's resources, based on understanding and mutual cooperation.

For the past 70 years all four options have been exercised with varying degrees of success and, through the Metropolitan Region Improvement Scheme (MRIS), are becoming increasingly effective (Poole, *pers. comm.*). Although very dependent on population densities and cultural attitudes to the environment, it is recognised that in a democratic society, a certain amount of freedom from interference by government is recognised as a civil liberty. However, this increases the government's overall burden of responsibility through the need for costly enforcement. *Direct control* is one option recommended elsewhere for catchment management purposes.

Changing a particular landuse (such as horticulture) on so-called "high-risk lands" that have a naturally low P retention capacity and are prone to overland flow, is a policy option that should not be disregarded. However, it is acknowledged that the different perspective of urban and rural communities is one of the main problems. The former generally maintain that direct control over landuse in rural areas is highly desirable from a downstream user's point of view, but rural communities seldom share this concern.

Many of the implications associated with the direct control over landuse activities also apply to the idea of *government acquisition* as a management option. There has been a reluctance in the past, by the State and local authorities, to consider protecting foreshore areas by purchasing land (Water and Rivers Commission, 1996b). This is especially true in rural areas where landuse decisions are traditionally regarded as a private right. Furthermore, the public ownership of land can be a costly exercise, both in terms of acquisition (in the short-term) and management and maintenance (in the long-term). Numerous management problems on adjoining land, such as fire and weed management, which are equally demanding of time and money, can also arise. Finally, acquisition mechanisms such as those associated with the MRS will need to be explored for areas outside the Metropolitan Region Area.

The CAC consider that, providing a legally enforceable basis exists for achieving the goals of the SCCP in the form of an Environmental Protection Policy (see Section 5.4), a combination of *fiscal measures* (elaborated on in Section 4.4.1 below) and *community involvement* approaches to catchment management (elaborated on by the Task Force Advisory Committee for Community Awareness Involvement in a separate technical appendix to the SCCP) stand the best chance of success. This outcome is likely, simply because the latter are both designed to encourage rather than require conservation efforts. However, the combination of measures adopted is still ultimately dependent upon the degree of degradation and significance of the resource to society and government.

4.4.1 Fiscal measures

A fiscal approach to catchment management allows landowners to choose and develop a scheme that reflects their own preferences, and allows administrators to tailor management requirements to individual situations. Secondly, by offering a reward for conservation efforts, private landowners are likely to adopt a positive attitude to exercising the landuse changes needed in the catchment (see Section 5.6.3). A brief review of the fiscal measures that the SCCP Task Force may wish to consider is presented below:

Servitude agreements (or easement contracts)

In this case, the Minister for Water Resources would elect to charter (or lease) land of particular interest, e.g. lands characterised by a high risk of flooding (and, hence, the export of nutrient due to the removal of particulate matter) or by soils with a low capacity for phosphorus and nitrogen retention. The owner retains title to the property, but signs an agreement restricting rights to use the land in ways which have altered the water cleansing function that the land previously performed in its natural state (**Figure 15**). It is possible that funding for the agreements prepared could be generated by the revenue derived from the Waterways Improvement Tax (of $10 / household / yr) proposed by Harman & Hertzler (1998).

The drawbacks associated with establishing servitude agreements over high-risk lands in catchments such as Ellen Brook include the following:

- there is no yardstick available, at present, by which to determine a fair price for leasing the land concerned;
- the saleability of property may be negatively affected;
- payment must not only be rationally determined, but also be sufficient to compensate for the non-productive use of the land;
- due to variation in the profitability of farming, the incentive for entering into servitude agreements may change from year to year, i.e. when commodity prices are depressed, farmers may be receptive to the idea but, once commodity prices are high, they may change their minds;
- the costs of surveillance and management of the land acquired through servitude negotiations are high, and arguments can arise over boundary delineation, stock losses, fire, weed and wildlife control; and
- the management agencies responsible for the servitudes acquired often do not have the manpower, or the funds, to administer the contracts efficiently or effectively.

However, all of these drawbacks can be managed if the appropriate policy and legal changes are made.

Foreshore Management Agreements

In terms of bringing about desirable landuse changes in the catchment, Foreshore Management Agreements are, in essence, not dissimilar to servitude agreements. The only difference is that the agreements prepared specify how riparian habitats are to be managed and by whom. Foreshore Management Agreements can be legally binding documents that are drawn up between landowners and a government agency, such as the WRC or AGWEST.

The drawbacks associated with establishing Foreshore Management Agreements are similar to those already listed above for servitude agreements, but they are further complicated by the fact that the WRC do not, as yet, have a specific foreshore policy (Water and Rivers Commission, 1998b).

Conservation Covenants

Conservation convents are voluntary agreements between a landowner and an agency capable of receiving the covenant (i.e. CALM, National Trust of Australia (WA) and the Soil and Land Conservation Council), which protect and enhance the natural, cultural and/or scientific values of land. The covenant can be modified for each property, is registered on the land title and binds all future owners (for a fixed term or in perpetuity). Each covenant is unique, and may cover all or part of a property. A conservation covenant may include the preparation of a management plan for the property, and the agency involved may provide funds to assist in its development and implementation. The agency involved in the covenant can also direct landowners to grants, which offer financial assistance and subsidies, to facilitate the protection of remnant vegetation.

Benefits of conservation covenants include:

- protection of native and riparian vegetation;
- protection of rare or endangered species;
- preferential access to funding;
- advocacy;
- potential for tax-deductable fund raising; and
- Stewardship support.

Subsidy schemes

In this case, a scheme is developed to induce landowners to convert marginal lands, used for annual cropping or pastures, to wetland. This would be encouraged by subsidising the costs involved, and compensating for the lost income resulting from non-productive use of the land.

Tax incentives

Tax incentive schemes are designed to benefit landowners, who agree to allow pastures (or cropland) to revert their natural state, by preferential tax treatment (Kusler, 1983).

Other options which the SCCP Task Force may choose to explore include bank loan and crop insurance suspension (Hollis, 1988). As most farming operations depend on loan finance from banks, the latter can be involved in catchment management issues by loaning money for development on the condition that appropriate steps are taken to allow pastures (or cropland) to revert to wetland or bushland. Similarly, insurance companies can be drawn into the issue by disallowing insurance claims for crop losses on high-risk lands, or for flood damage to cropland in wetland areas.

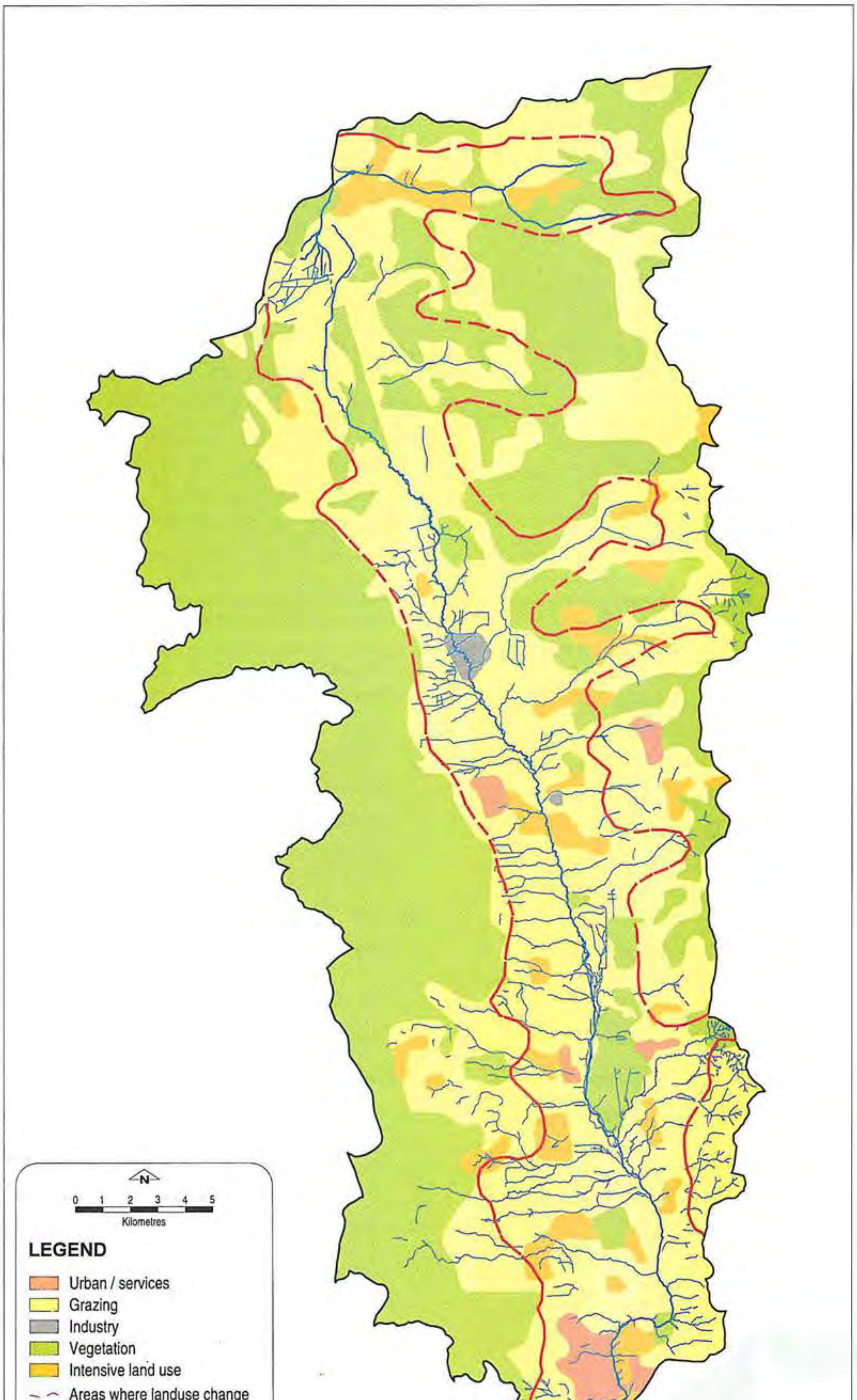

Figure 15: Landuse and high-risk lands for nutrient loss in the Ellen Brook catchment

4.4.2 Review of town planning schemes

Metropolitan Region and Town Planning Schemes are potentially the most powerful and readily available tools for catchment management in the SCRS. Consequently, the CAC sees merit in making a concerted effort, with the aid of GIS technology, to methodically and strategically review Town Planning Schemes to ensure that they are environmentally sustainable and incorporate nutrient reduction principles. Where necessary, such schemes may require amendment in order to enable local councils to more effectively manage the areas under their jurisdiction.

It is suggested that consideration be given to forming a *Catchment Management Liaison Unit* to facilitate the review process. This would impress upon Local Authorities the significance of Town Planning Schemes as a catchment management tool and to develop a system, according to the requirements of each Council, which provides clarity on issues such as soils types, conforming and non-conforming landuses, appropriate zoning of critical areas for conservation and optimal areas for development. It is expected that the review process will also prove to be an effective mechanism for incorporating natural resource management, nutrient reduction principles and water sensitive design policies into the planning process.

4.4.3 Making catchment management a cooperative venture

Despite the formation of the WRC in January 1996 to create a single organisation concerned with the management of the State's water resources (Anon, 1996b), at the local level there is still a proliferation of agencies, both perceived and real, each responsible for a different function. Such functions range from water supply and sewerage services, to matters such as river bank stabilisation and flood mitigation works.

The functions of these agencies are so inter-related and intrusive that the only way to develop and implement policies for the long-term productive use of the land and water resources in the catchment is to establish clear and binding policies that will direct individual efforts towards a common goal. Therefore, in order for appropriate action to be taken on a uniform basis throughout the catchment of the SCRS, there is a compelling need to create a Forum comprising all the key role players in the catchment. This Forum would enable those key players to discuss and negotiate land and water resource matters of mutual interest.

The formation of an *Interdepartmental Catchment Management Forum* would also provide a means by which to scrutinise development proposals with the potential to adversely affect hydrological processes in the catchment. The Forum would also enable joint assessment of development applications, by all key role players in the catchment, to determine those that should be subject to Environmental Impact Assessment (EIA) under Part IV of the *Environmental Protection Act 1986*.

5. Conclusions and recommendations

5.1 Overall approach to catchment management

The ultimate (long-term) solution to the control of phytoplankton blooms and poor water quality, in the upper reaches of the Swan Estuary and the lower reaches of the Canning River, will depend on the extent to which nutrient export from the catchment can be effectively controlled. This can only be achieved by reducing fertiliser inputs, increasing nutrient uptake and changing specific types of landuse within the catchment area (Gerritse, 1996; Kin *et al.*, 1997b).

Therefore, it is recommended that the four catchments of the SCRS that are presently contributing the largest pollution load to the estuary (see Section 5.6.2) are targeted, and that State Cabinet endorsement is sought for implementation of the Action Plans outlined in Section 5.6.3.

In order to ensure that future rural and urban landuse practices are as compatible as possible with the goals of the SCCP, it is recommended that the approach to management in the catchment should be directed at '*source management*', by means of a participative planning process. This entails:

- the introduction of an innovative program of economic incentives designed to reduce the excessive application of nutrients in the catchment of the SCRS;
- changing landuse in areas with a naturally low P retention capacity, that are vulnerable to overland (or sheet) flow;
- identifying best fertiliser management practices and research gaps;
- increasing precipitation uptake and restoring the natural run-off pattern in the catchment through land drainage planning;
- increasing and protecting wetland and bushland resources in the catchment in order to increase sediment and nutrient uptake; and
- improving planning and development controls to manage erosion and sediment input into waterways.

The aforementioned approach is consistent with the State Cabinet's decision in 1984 to implement the System 6 recommendations of the EPA. These recommendations included the establishment of conservation buffer zones along major rivers on the Swan Coastal Plain, in order to maximise the amenity and scenic values for river systems (Department of Conservation and Environment, 1981). The approach is also in line with the Water Corporation's strategic stormwater management plan that is intended to retard run-off by creating multi-use corridors in which to locate detention ponds, to restore wetlands and incorporate floodways (Department of Planning and Urban Development, 1994; G B Hill & Partners, 1995). The planned approach is consistent with the MfP's integrated water resource management/ landuse planning policy; the MfP's strategic plan for Perth's Greenways (Alan Tingay & Associates, 1998); and the WRC's policies for foreshore management, and the protection of important wetlands, watercourses and water supply catchments (Water and Rivers Commission, 1996b). It is also consistent with the environmental management strategies of the WAMA and of Local Councils, such as the Shires of Mundaring and Kalamunda (Eastern Metropolitan Regional Council, 1996). Finally, the approach is consistent with the policies of community-based non-government organisations, such as Greening Australia, to strategically retain and restore environments needed to ensure the long-term health of natural resources.

5.2 Building of a shared vision

The key to fostering a coordinated and sustainable use of the SCRS catchment relies upon the development of a shared vision of catchment management.

For consensus to be achieved and confidence to be placed in the direction that catchment management should take, the views and aspirations of all stakeholders will need to be accommodated and balanced accordingly. Therefore, in developing an Action Plan that will facilitate joint decision making, it is recommended that:

- The Technical Advisory Committees, that are responsible for Community Awareness and

Involvement and Catchment Management, work much more closely together in development of the Action Plan.

- WSUD principles are incorporated in all new land development proposals and in any new planning initiatives in the metropolitan area.
- Every possible form of assistance and encouragement is given to the formation of Integrated Catchment Management Groups, and to their ongoing support during the implementation phase of the plan. For example, to facilitate rapid changes in the problematic sub-catchments of the SCRS, support in the form of professional planning services would be of enormous assistance to local authorities and ICM Groups.
- An Interdepartmental Catchment Management Forum and a Catchment Management Liaison Unit are created, to serve as a basis for determining permissible and priority land and water uses in the catchment.
- Landusers are encouraged to communicate their needs and to participate in the catchment management process.
- Wastes that are not suitable for deep sewerage or disposal in the drainage network are regulated and licensed, to ensure that they are disposed of in an environmentally acceptable manner.

5.3 Enhancing community awareness

With the realisation that catchment management is essentially a political process which requires an informed public to succeed, it is recommended that urgent consideration is given to:

- appointing experienced resource managers to act as catchment coordinators within each of the priority catchments identified in Section 5.6.2;
- inviting Local Councils that are not yet involved in the SCCP to participate;
- developing an environmental indicator program at a farm level, to allow the farmers themselves to follow trends in catchment condition based on the techniques developed by Walker & Reuter (1996);
- preparing a definitive set of catchment management guidelines, based on water sensitive design principles, for the rural catchments of the SCRS; and
- providing Local Councils with the funds needed to appoint Environmental Officers to facilitate community awareness programs; to help formulate locally prepared natural resource management strategies; provide assessment and advice on development proposals and local government activities; and to ensure that local government policies become operational on the ground.

5.4 Improving landuse controls

While the CAC recognises the resentment that some people feel about government interference with their activities, it also recognises the view that many people see government involvement as essential to control the activities of some who degrade the environment for their own purposes. Thus, the committee feel that one of the most powerful ways of underpinning the goals of the SCCP is to introduce the same sort of protection policies that were successfully used for management of the Peel-Harvey coastal plain catchment (Government of Western Australia, 1992). The latter took the form of a Statement of Planning Policy and an Environmental Protection Policy, which had the full force of the *Environmental Protection Act 1986* behind them, together with legally binding environmental conditions and management commitments by the agencies involved.

Consequently, it is strongly recommended that the existing landuse controls in the catchment of the SCRS are improved by:

- undertaking a systematic review of Metropolitan and Town Planning Schemes in the catchment area to ensure they are environmentally sustainable and, most importantly, incorporate nutrient reduction principles;
- preparing a Statement of Planning Policy for the SCRS, to direct appropriate development within the Metropolitan Region Scheme and local Town Planning Schemes;

- defining the responsibilities of the various regulatory agencies involved (this could be a part of the proposed Comprehensive Management Plan of the *Swan-Canning EPP* gazetted in 1998);
- adopting a consistent regulatory definition of the lands that are considered to be high-risk or critical areas in the catchment;
- dealing with landuses, such as horticultural enterprises, that are not adequately addressed at present by legislation or planning policy;
- utilising the *Environmental Protection Act 1986* to delegate the powers needed by an agency, such as Agriculture WA, to regulate fertiliser use if required in areas of the catchment that are deemed of concern for environmental reasons; and
- adopting a fiscal approach to catchment management by actively pursuing the suggestions made in Section 4.4.1 to develop servitude and/or foreshore management agreements with landowners that currently utilise lands with a low capacity for phosphorus and nitrogen retention.

5.5 Research and information needs

The catchment of the SCRS is unique in terms of resource distribution, landuse and administrative controls. Consequently, a holistic 'systems approach' to environmental management, as well as the use of predictive science, will be of considerable importance for the long-term resolution of the environmental problems in the area.

To more effectively manage land utilisation and exercise better control over nutrient ingress into the SCRS, it is recommended that, with the aid of both State and NHT funding, the following research projects are undertaken:

- quantifying the nutrient balance, in relation to changes in WSUD, for the urban catchments of the SCRS;
- quantifying the sediment yield (i.e. loads of suspended particulate matter) flowing from each of the major sub-catchments of the SCRS;
- identifying the source of the sediment loads revealed;
- quantifying fertiliser usage on turf farms and on parks and gardens in high-density residential areas;
- developing ecotoxicology testing as a means of rapidly assessing the impacts of source pollution;
- evaluating the significance of historical landfill sites, in terms of nutrient inputs into the SCRS via groundwater;
- evaluating the pollution significance of contaminated sites in the industrial areas of the Metropolitan region;
- developing a biological indicator program to assess ecosystem condition in the SCRS drainage network;
- reviewing the use of fire, as a means of fuel load reduction, in riparian areas in the catchments;
- conducting an audit to determine the economic costs associated with management of wetlands which have inadequate buffer zones in the major catchments of the SCRS (a suggestion made by Davies & Lane, 1995);
- water balance in catchments; and
- soil structure decline.

5.6 Catchment management planning

5.6.1 Key issues

The catchment management issues described in Sections 3.1 and 3.2 are virtually all inter-related. However, only **six** are regarded by the CAC as key environmental issues. These are:

- nutrient ingress (eutrophication);
- surface water and groundwater contamination;
- soil erosion;
- salinity;
- the extent of wetland and bushland loss; and
- the substantial loss of biodiversity.

5.6.2 Priority catchments

In addition to the Avon catchment, which is a major source of phosphorus, nitrogen and sediment and for which an Action Plan is being independently prepared by the SAICMCG (Swan-Avon ICM Coordinating Group, 1997), there are four sub-catchments in the catchment of the SCRS that warrant priority attention. The results of the water quality monitoring program undertaken by the SRT suggests that the major sources of nitrogen and phosphorus are: the **Ellen Brook catchment** (664 km^2), which yields 36% of the P load and 10% of the N load; and the **Southern–Wungong River catchments** (149 km^2), which yield 8% of the P load and 5% of the N load (Anon, 1996a). The **Bayswater Main Drain** (27 km^2) also discharges a variety of metals, nutrients and hydrocarbons, and is the most polluted urban source to the Upper Swan Estuary; and the **Upper Canning catchment** (90 km^2), which yields a significant amount of sediment (Lloyd, 1997).

It is recommended that, for the foreseeable future, these four sub-catchments (totalling 930 km^2) should become the main focus of the SCCP Task Force's attention, through the development of catchment management plans.

5.6.3 Development of a typical Catchment Management Plan

The following section presents a brief step-by-step outline of the sort of activities required to develop an Action Plan for the focus catchments of the SCRS. However, it is recommended that each step be reviewed, accepted and costed by the participants involved.

(a) Objectives

An appropriate range of management objectives could well include the need:

- to reduce the orthophosphate (FRP) load entering the upper reaches of the Swan Estuary, by at least 50%, within the next five years;
- to achieve the proposed targets set in the EPP, in order to reduce the annual nutrient load;
- to take full advantage of the detailed hydrochemical, hydrological, morphological and modelling studies that have been applied to certain parts of the catchments;
- to promote appropriate soil conservation measures and fertiliser application practices for the soils of the region;
- to promote the use of phosphorus-free detergents in unsewered areas of the catchment;
- to establish projects to develop and demonstrate the benefits of Best Management Practices (BMPs);
- to establish the feasibility of inter-linking public open space, remnant vegetation and river corridors with adjacent catchments and across local government boundaries;
- to reduce and ameliorate environmental degradation of the catchment;
- to establish environmentally sustainable development throughout the catchment area;
- to restore wetland in areas with a naturally low P retention capacity or at risk of overland flow;
- to develop education and communication programs involving residents, local businesses, local Councils and government agencies with interests in the area; and
- to improve community awareness and encourage community involvement during preparation and implementation of the plan.

(b) Strategy

The sort of strategy that would typically be adopted in the preparation of an Action Plan is as follows.

- Reviewing any previous attempts to produce a catchment management plan.
- Determining data voids (if any).
- Compiling a comprehensive land/water management database, with specific emphasis on the location of high-risk lands and the ownership thereof.
- Defining the optimal extent of multiple-use corridors (MUCs) along the major tributaries.
- Developing a provisional basis for servitude and/or foreshore management agreements, and undertaking an attitude survey designed to test community acceptability of the idea.
- Developing a provisional Action Plan.

- Preparing an initial assessment of the potential environmental impacts associated with implementation of the Action Plan.
- Preparing a discussion document to serve as a basis for a consultation program and, with community agency and local government involvement, reviewing the Action Plan.
- Drawing up formal servitude agreements and/or Foreshore Management Agreements with willing participants.
- Identifying areas in which to implement the first phase of the Action Plan.
- Commencing with on-ground remedial work of buffer zones through the:
  - restoration of wetlands;
  - fencing of creeks and remnant vegetation;
  - restoration of foreshore reserves; and
  - revegetation of cleared farmland and riparian zones.
- Providing financial assistance to landholders for implementation of best management practices on each individual site.
- Monitoring water quality, and recording changes in landuse with the aid of low level aerial photography and ground-truthing.

(c) Participants

The range of organisations that would normally participate in the development of a catchment management plan would be:

- existing Integrated Catchment Groups;
- Land Conservation District Committees (LCDCs);
- the Swan Catchment Council;
- relevant local Shires/member Councils;
- government agencies (Water Corporation; Agriculture WA; SRT);
- River Care Groups;
- special interest groups;
- land owners; and
- a team of natural resource consultants (eg. this could include an environmental lawyer or resource economist).

5.7 Water quality targets

As nitrogen is a key nutrient responsible for phytoplankton blooms in the upper reaches of the Swan estuary, it is recommended that limits be set for nitrogen and phosphorus in the catchment of the SCRS. In the event that targets are not specified in the future Comprehensive Management Plan for the Swan-Canning EPP, it is recommended that the SCCP Task Force develops and publishes its own nutrient targets for the Cleanup Action Plan.

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7. Appendices

7.1 Glossary

7.1.1 Acronyms and Abbreviations

AGNPS	Agricultural Non-Point Source (Model)
AGWEST	Agriculture Western Australia
ANZECC	Australia and New Zealand Environment and Conservation Council
AQUIFEM	Aquifer Finite Element Model
ARMCANZ	Agricultural and Resource Management Council of Australia and New Zealand
ASPAC	Australian Soil and Plant Analysis Council
BMP	Best Management Practices
BPP	Best Planning Practices
CAC	Catchment Advisory Committee (**Catchment Management Technical Advisory Committee**)
CALM	Department of Conservation and Land Management
COAG	Council of Australian Governments
CMP	Comprehensive Management Plan
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCE	Department of Conservation and Environment
DEP	Department of Environmental Protection
DPUD	Department of Planning and Urban Development
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority
EPP	Environmental Protection Policy
FEFLOW	Finite Element Flow model
FRP	Free Reactive Phosphorus (orthophosphate)
GIS	Geographical Information System
GL	Gigalitre
ICM	Integrated Catchment Management
ILAP	Integrated Land Area Planning
LASCAM	Large Scale Catchment Model
LCDC	Land Conservation District Committee
MoU	Memorandum of Understanding
MUC	Multi-use Corridor
MfP	Ministry for Planning
MRS	Metropolitan Region Scheme
N	Nitrogen
NATA	National Association of Testing Authorities
NHT	Natural Heritage Trust
P	Phosphorus
PRI	Phosphorus Retention Index
PUWBM	Perth Urban Water Balance Model
SAICMCG	Swan-Avon Integrated Catchment Management Coordinating Group
SCCP	Swan–Canning Cleanup Plan
SCEPP	Swan–Canning Environmental Protection Policy
SCRS	Swan–Canning River System

SCULP	Swan Catchment Urban Landcare Program
SRT	Swan River Trust
UWA	University of Western Australia
WAMA	West Australian Municipal Association
WAPC	Western Australian Planning Commission
WC	Water Corporation (formerly known as the Water Authority of Western Australia)
WRC	Water and Rivers Commission
WSUD	Water-Sensitive Urban Design

7.1.2 Terms

Aeolian	Pertaining to or caused by wind.
Alluvial	Deposited or formed by running water.
Biocide	Chemical used to inhibit or control a population of troublesome microbes. [1]
Bioremediation	Application of the natural ability of microbes to use waste materials in their metabolic processes and convert them into harmless end products.[1]
Biosolids	Primarily organic sludges or by-products of wastewater treatment that can be beneficially recycled. [1]
Calcite	Widely distributed rock-forming mineral, that is a stable form of calcium carbonate. [2]
Catchment	The area of land which intercepts rainfall and contributes the collected water to surface water (streams, rivers, wetlands) or groundwater.
Colloid	An extremely fine-grained material, either in suspension or that can be readily suspended, commonly having special properties due to its extensive surface area. [2]
Compensation basin	Many stormwater drains discharge directly into compensation basins and detention ponds (refer to definition below) to allow temporary storage of run-off and reduce the need for large capacity storm drains.
Constructed wetland	Artificial water bodies constructed to meet a number of human purposes.
Denitrification	The process by which microorganisms break down nitrate to nitrogen gas, under anaerobic or aerobic conditions.
Detention pond	A device that receives run-off, temporarily stores a portion of the run-off, and results in benefits such as reduced downstream flooding, reduced sedimentation and turbidity in downstream areas and additional floodplain storage.
Dewatering	Discharge of water to lower the water table to enable construction to occur.
Duplex soils	A soil in which there is a sharp change in soil texture between the A and B horizon, such as loam overlying clay. [3]

Ecosystem	Unit including a community of organisms, the physical and chemical environment of that community, and all the interactions among those organisms and between the organisms and their environment. [4]
Ecotoxicology	Field of science dealing with the adverse effects of chemicals, physical agents and natural products on populations and communities of plants, animals and microorganisms. [8]
Eutrophication	An increase in the rate of supply of organic matter to an ecosystem, caused by unnaturally high loads of nutrients (primarily nitrogen and phosphorus) to that ecosystem. [5]
Evapotranspiration	Sum total of water lost from land by evaporation and plant transpiration. [7]
Fertigation	Fertilising and irrigating crops at the same time.
Flocculation	The process of forming aggregates or compound masses of particles, for example, the settling of clay particles in water. [2]
Floriculture	The cultivation of flowers.
Fluvial	Of, or pertaining to, rivers.
Friable	Pertaining to a rock or mineral that can be disintegrated into individual grains by finger pressure. [2]
Geomorphic	Pertaining or related to the form of the Earth or its surface features. [2]
Gneiss	Foliated metamorphic rock formed under conditions of high-grade regional metamorphosis. Gneisses are usually coarse-grained and characterised by a layered appearance. [2]
Groundwater abstraction	The removal of groundwater from human use.
Hydrogeology	A branch of geology dealing with underground and surface water.
Hydrological	Pertaining to the location and movement of inland water, both frozen and liquid, above and below ground. [2]
Hydrophobic	Water-repellent soils that resist wetting when dry. Drops of water do not spread spontaneously over their surface and into pores. This characteristic is mainly a feature of some sandy soils (topsoils), and is generally attributed to organic coatings on the sand grains which resist water entry into the soils. [3]
Impervious area	A hard surface (e.g. parking lot) that prevents or retards the entry of water into the soil, thus, causing water to run off the surface in greater quantities and at an increased rate of flow.
Laterite	A soil residue composed of secondary oxides of iron, aluminium or both. [2]
Leaching	The removal in solution of the more soluble minerals and salts by water seeping through a soil, rock, ore body or waste material. [3]
Lithified	Converted from sediment to sedimentary rock through physical and chemical processes. The main processes involved include compaction of grains, and the cementing of grains together by growth of new minerals deposited through by

	percolation of groundwater. [2]
Nitrification	The process by which microorganisms convert ammonia compounds to nitrate under aerobic conditions.
Pedological	Pertaining to soil formation, or the morphology, origin or classification of soil. [2]
Percolation	The slow, laminar movement of water through any small openings within a porous material. [2]
Peri-urban	Areas of land under agriculture or forestry subjected to pressure from expanding urban areas. [8]
Phytoplankton	Microscopic algae (microalgae) and bacteria that photosynthesise, and are usually single celled plants that live and float in water.
Potable water	Water suitable for drinking. [5]
Retrofitting	To incorporate changes and developments introduced after construction.
Riparian vegetation	Vegetation situated on or belonging to a river or streambank. [6]
Run-off	The portion of precipitation (rain, hail, snow) which flows across the ground surface as water; major agent of water erosion. [6]
Sedimentation	Material of varying size, both mineral and organic, deposited away from its site of origin by the action of water, wind, gravity or ice. [6]
Siliceous	Containing abundant silica (silicon dioxide), particularly as free silica.
Soil amendment	The alteration of the properties of a soil by the addition of substances such as lime, gypsum and sawdust, for the purpose of making the soil more suitable for plant growth. [3]
Superphosphate	A fertiliser made by treating phosphate rock with sulphuric or phosphoric acid.
Topography	The general configuration of a land surface, including size, relief and elevation.
Turbidity	A measure of the amount of suspended of solids (usually fine clay or silt particles) in water and, thus, the degree of scattering or absorption of light in the water. [5]

NOTES

1 Pankratz, 1996

2 Farris Lapidus, 1990

3 Soil Conservation Commission of New South Wales, 1992

4 Department of Environmental Protection, 1998

5 State of the Environment Advisory Council, 1996

6 Environmental Protection Authority, 1997

7 Krebs, 1985

8 Gilpin (1990)

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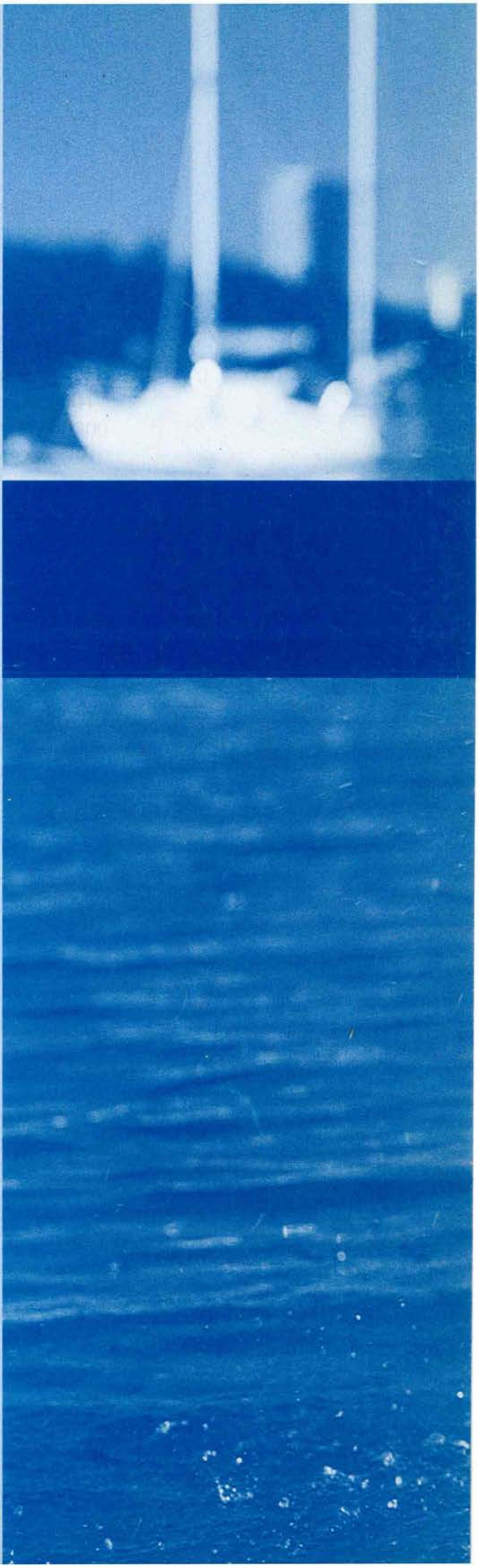

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