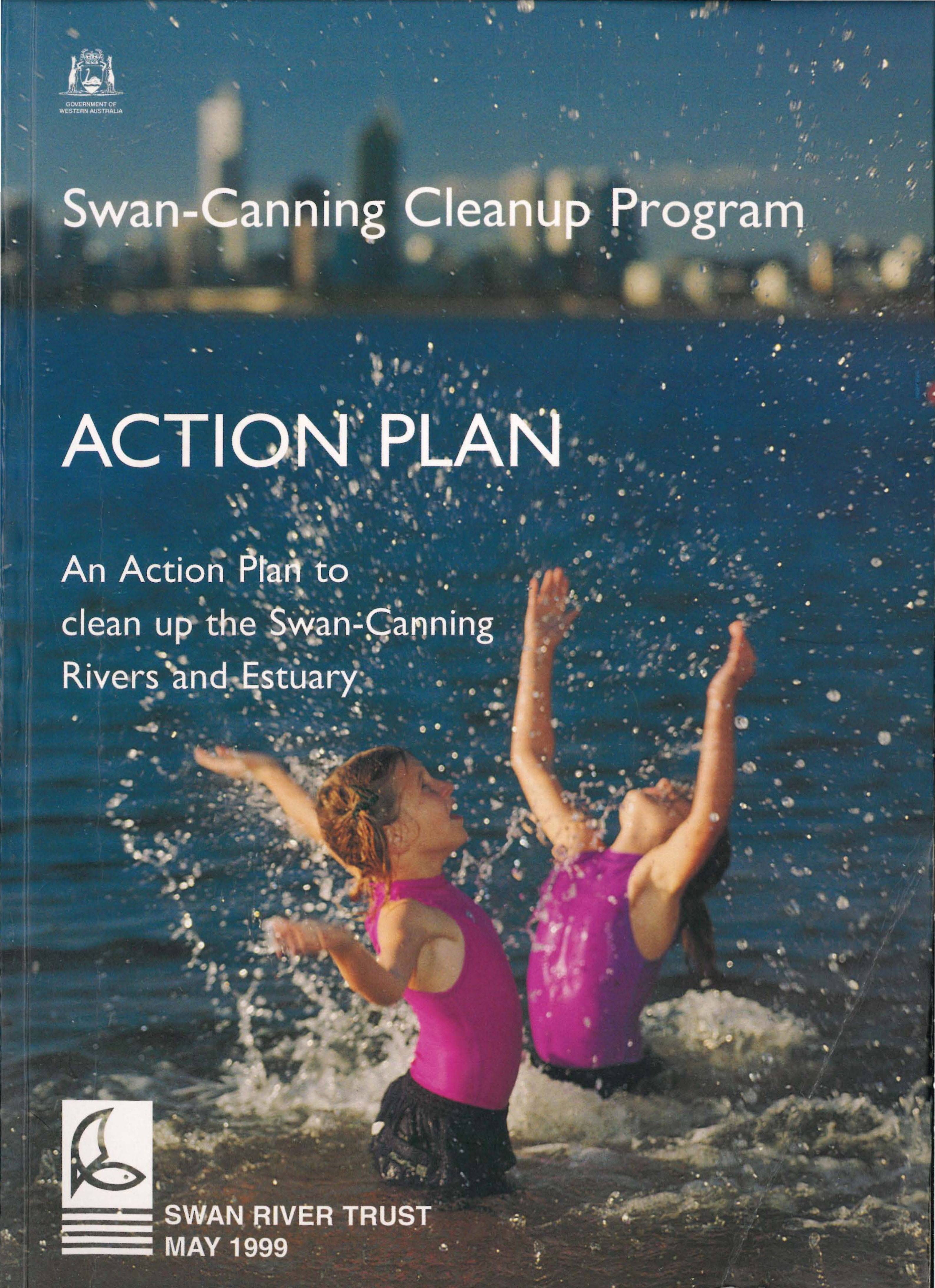
GOVERNMENT OF WESTERN AUSTRALIA

Swan-Canning Cleanup Program

ACTION PLAN

An Action Plan to clean up the Swan-Canning Rivers and Estuary



SWAN RIVER TRUST

MAY 1999

SWAN RIVER TRUST
Hyatt Centre, Level 3
87 Adelaide Terrace
East Perth
Western Australia 6004
Telephone (08) 9278 0400
Facsimile (08) 9278 0401
Website http://www.wrc.wa.gov.au/srt

Swan-Canning Cleanup Program (SCCP):

Task Force Members
Des Lord, Chairman (D A Lord & Ass. Pty Ltd)
Robert Atkins (SRT)
Chris Barber (CSIRO)
Terry Blanchard (WAMA)
Bruce Hamilton (WRC)
Pat Hart (Swan-Avon Integrated Catchment Management Coordinating Group)
Rod Hughes (WRC)
Jorg Imberger (WAERF)
Gerry Parlevliet (AGWEST)
Max Poole (MfP)
Clive Robartson (WAMA)
Barry Sanders (Water Corporation)
Rob Sippe (DEP)
Bev Thurlow (WRC)
Bill Till (WRC)
Harry Ventriss (WRC)

Task Force Deputies
Geoff Bott (DEP)
Darryl Miller (SRT)
Hugh Rule (Water Corporation)
Jeff Turner (CSIRO)
Ivan Unkovich (Water Corporation)
Clare Walsh (WAMA)

Technical Advisory Committee Chairpersons
David Hamilton (Centre for Water Research, UWA)
Karen Majer (WRC)
Gerry Parlevliet (AGWEST)
Malcolm Robb (WRC)
Tom Rose (SRT)

SCCP Manager, Executive Officer and senior editor
Tom Rose (SRT)

AGWEST	Agriculture Western Australia
DEP	Department of Environmental Protection
MfP	Ministry for Planning
SRT	Swan River Trust
WAMA	Western Australian Municipal Association
WAERF	Western Australian Estuarine Research Foundation

ISSN 1328-3715 ISBN 0-7309-7333-6
Printed on recycled stock
May 1999

WATER AND RIVERS
COMMISSION

Agriculture
WESTERN AUSTRALIA

Department of
Environmental Protection

WATER
CORPORATION

West Australian
Estuarine Research
Foundation

WESTERN AUSTRALIA
MUNICIPAL
ASSOCIATION

CSIRO

Ministry for Planning
WESTERN AUSTRALIA

Swan
Avon
INTEGRATED
CATCHMENT
MANAGEMENT

SWAN RIVER TRUST

Swan-Canning Cleanup Program

ACTION PLAN

An Action Plan
to clean up the
Swan-Canning Rivers and Estuary

WATER AND RIVERS
COMMISSION

Public submission summary

The draft Action Plan to clean up the Swan-Canning Rivers and Estuary was released to the public for comment in July 1998. Fifty-three submissions were received on the Action Plan encompassing 350 comments. Overall, the submissions provided strong support for the Action Plan with fifty-two submissions supporting the Plan. One submission recommended the Plan be rewritten in a more comprehensive and realistic manner. A number of submissions provided specific comments of support, requested specific clarification, or strengthening of the proposed actions.

In response, thirty-five changes have been made to the draft in compiling the final version of the Action Plan.

Analysis of Public Submissions and Question and Answer documents can be obtained from the Swan River Trust (see inside of front cover for contact details).

What's in the Action Plan

Section 1 explains why and how the Action Plan was developed through the Swan-Canning Cleanup Program.

Section 2 sets out the Cleanup Program objectives.

Section 3 describes the river environment and the causes of algal blooms. This provides the basis for developing management options.

The approach to managing algal blooms is explained in Section 4. This section outlines the issues of nutrient management in both rural and urban catchments, and identifies actions needed to improve water quality.

The recommendations endorse strong management in the catchments, supported by intervention within the estuary and rivers at specific sites. Management action is guided by the provision of targets of water quality to be achieved in each catchment.

Recommendations range from those that are broad in nature, such as the development of catchment management policies, to specific actions to reduce nutrient losses. The Action Plan recognises that community awareness and involvement are vital to the success of the Plan, and includes recommendations for training, education and support for community involvement. The responsible parties for the implementation of each of these recommendations are identified.

The recommendations are summarised into a four-point Action Plan. Cost estimates of implementing the Plan are provided in the Executive Summary.

I Foreword

This Action Plan to improve the health of the Swan and Canning rivers is the culmination of over five years of research, trials, computer modelling, expert input and community debate. Its release marks an important milestone for the Swan River.

It is no wonder that the people of Perth, and visitors who enjoy the attractions of Perth's riverside lifestyle, place such importance on protecting the Swan-Canning river system. The river gives Perth its special character. It is the scenic and recreational heart of the city. It is a place that everyone can enjoy. Whether it is the sight of early morning rowers on the misty water, picnics on the foreshore, lamplight prawning parties, jogging on the foreshore, sailing among colourful yachts and windsurfers on a summers day, or fishing with the family from an old wooden jetty, most people have a story to tell about why they value the river.

Community concern about the health of the river, and involvement in its management, go back a long way. In the 1940's, urban drainage and wastes from a sewage treatment plant caused algal blooms that rotted with a stench that permeated city streets. In 1943, the Director of Public Works and five yacht club commodores formed the Swan River Reference Committee. It had no statutory powers, but gave the community a voice in managing the river.

The Swan River Conservation Board, formed in 1958, had statutory powers and gradually reduced the number of discharges into the river. Their work was carried on over the years by the Swan River Management Authority and then the Swan River Trust. These bodies had powers to control pollution and were responsible for bringing the major 'point' sources of pollution under control, including industrial discharges and foreshore rubbish tips. Safe use of the river for fishing and aquatic recreation was ensured.

Unfortunately, however, while the more discrete pollution sources were being brought under control, the growing city and its rural hinterland were contributing ever-increasing amounts of nutrients, especially from fertilisers and animal wastes, from all over the extensive catchment. This pollution was subtle, building up a store of nutrients in the river sediments over decades before symptoms, in the form of algal blooms, became apparent. It was also much harder to bring under control. This widespread, diffuse pollution presents a special challenge to river managers today.

In response to the increasing number of algal blooms, and community concern about deteriorating health of the river, the Government announced the Swan-Canning Cleanup Program in 1994. This Action Plan to restore the health of the Swan-Canning river system is the result.

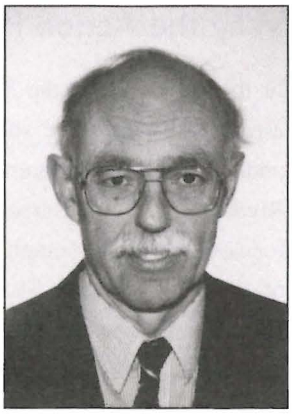
The community has continued to play a leading role in determining the rivers' future. Through representation on the Swan-Canning Cleanup Program Task Force and Swan River Trust, leadership in Integrated Catchment Management and volunteer projects, and comments on the draft Action Plan, they have helped to steer directions for management of the river and its catchment. As we begin to implement the Action Plan recommendations, community involvement will still underpin success. We need to raise awareness across the whole community about our responsibility, personally and as a community. We need to develop effective partnerships between all sectors of the community, including all levels of government and industry. We need to explore a range of funding options, such as joint ventures and sponsorship, as well as government funding. We must also find new and better ways of working together, recognising the links between catchment activities, urban development, and waterway management.

The Action Plan shows us that efforts will need to be long-term and sustained to clean up the Swan-Canning system. All of the recommendations need to be implemented as soon as possible. To have a significant, positive influence on the long-term health of the system recommendations are arranged so that the first ones are implemented immediately due to the length of time they will take to be effective. The initial recommendations will require more time to establish the framework for their implementation while those recommendations listed towards the end can be implemented within one-two years. As models are developed for the Swan-Canning system they will help prioritise future actions and recommendations. Realistically this will occur after the first five-year period of this Action Plan. The Task Force recognised that efforts to clean up the Swan-Canning system will take at least 20 years to reverse over one hundred years of degradation.

The Action Plan provides the framework to move forward. I commend it to you and encourage everyone to play their part in creating a healthy future for our river.

Dr Kim Hames MLA
MINISTER FOR WATER RESOURCES

II Task Force chairman's preface



The Swan-Canning Cleanup Program (SCCP) Task Force was established by the Minister for Environment in 1994 to develop an Action Plan to reduce algal blooms in the Swan and Canning Rivers and Estuary. At present the Swan-Canning system is still largely in a healthy state, but over the last 15 years the frequency and duration of blooms has increased in the upper reaches of the Swan and Canning rivers. Nutrient levels in the water are also consistently above recommended levels to minimise algal blooms. Purposeful management is needed now to reverse these trends and to provide a robust and resilient estuary for Perth's future.

The Task Force brought together all of the main groups responsible for and interested in the system's health. The Action Plan was developed progressively by the Task Force, drawing on the expanding knowledge that was being generated about the role of nutrients in fostering algal blooms. These investigations were funded by SCCP and have allowed a number of very important conclusions to be drawn:

- The main pathways by which nutrients enter the system is from runoff in winter and spring, and from groundwater and sediments in summer.
- It is nitrogen rather than phosphorus that normally limits algal growth; it is known that there is usually enough phosphorus present in the water.
- Controlling both nitrogen and phosphorus is essential for effective management.

The Task Force recognised that the key to improving the water quality in the system in the future was through a comprehensive program of reducing nutrient releases from the catchment. Catchment action is known to take a long time to be effective and it may be 20 years or more before its influence is fully realised. Clearly these actions need to commence now. The Task Force also recognised that there are some very specific intervention actions that can be taken at selected sites in the river to reduce blooms, such as river oxygenation and sediment remediation. These techniques have undergone trials in the river, have shown definite promise, and are being developed further. The Task Force believes that ultimately good river management will require comprehensive catchment management including improvements to statutory planning and decision-making supplemented by selected intervention techniques where and when appropriate.

The Action Plan was released for public comment in July 1998. The response was enormous, with virtually all submissions strongly supporting the Plan. The comments made about the draft Plan have enabled the Task Force to significantly enhance the Action Plan.

There is no doubt the Action Plan is ambitious, and when implemented will rank among the most responsible and forward thinking programs of its kind in the world. We are indebted to the Task Force for their enormous efforts in completing the Plan, and to government officers and community members who contributed so much to its development.

Dr Des Lord
TASKFORCE CHAIRMAN

III Executive summary

Why the Action Plan came about

In the early 1990s, the Swan and Canning rivers and estuarine basins were showing the signs of a system under stress. Algal blooms and fish deaths in the Swan River and toxic blue-green blooms in the Canning River focused community attention on the deteriorating health of the river system. The level of algal blooms was clearly unacceptable. Purposeful action was needed to ensure that the rivers and estuary — the scenic heart of Perth — were restored and protected for this and future generations. Despite these symptoms of stress, the Swan–Canning system is still in reasonable condition. Worldwide experience from programs dealing with major environmental problems has shown, however, that prevention is better and cheaper than waiting until more serious problems arise. The Swan–Canning Cleanup Program was launched by the State Government in May 1994 as a five-year project to study the problem, find out how to reverse any deterioration that had occurred and develop a program for the effective clean up of the Swan–Canning system. Responsibility for it rested with the Swan River Trust, but the program relied on the work and interaction of many State and local government bodies, university and other research groups and business and community projects. It was designed to work with and build on existing initiatives wherever possible.

The issue

Monitoring in the Swan–Canning system has shown that algal blooms are being fuelled by high concentrations of nutrients entering the river from its catchment. The two main nutrients are nitrogen and phosphorus, which feed algae and make them grow. By far the biggest sources of these nutrients are fertilisers and animal wastes from rural and semi-rural land, which are washed into rivers by rain. Other sources are urban gardens, parks, golf courses, unsewered residential areas, roads, light industrial areas and former rubbish tips, where nutrients are captured by a myriad of drains that discharge into the rivers. A large proportion of the nutrient load derives from non-point sources spread throughout the rural and urban catchment.

In the spring and summer of 1993–94, the Swan–Canning system suffered several wide-scale and severe water quality problems. In particular, toxic blue-green blooms developed in the Canning River upstream of the Kent Street Weir. These blooms lasted throughout spring and summer and posed a threat to public health, severely limiting swimming and other recreational uses of the river. During the same period green and "red tide" blooms occurred in the Swan River. In the years following these outbreaks, the Swan River Trust has recorded large numbers of algal blooms, further toxic blue-green blooms in the Canning River and other water quality problems related to them.

Algal blooms are a natural feature of estuaries. They occur when favourable conditions — the right combination of nutrient availability, light and temperature — exist for the algae to reproduce and there is insignificant grazing by zooplankton and filter feeders. The timing, size and location of algal blooms in the Swan–Canning system varies from year to year, depending on river flow and climatic conditions. During the warmer months, algal blooms collapse and create low-oxygen conditions that can decimate resident aquatic animal populations. Animals in the bottom sediments and water are particularly vulnerable. Fish will normally swim away from unfavourable conditions but, in extreme events, they can also be killed. Other types of blooms are toxic and can restrict recreational use of the river. Over time, repeated excessive algal blooms and their collapse reduce essential diversity in the food chain, making it more sensitive to disruptions. In the long run, impacts are economic and social as well as environmental (e.g. tourism, recreation). The problem has highlighted how West Australian estuaries differ from many overseas situations because we have long periods of low water flow and high temperatures to 'cook' the estuary that help generate poor water quality.

The response

Through the Swan-Canning Cleanup Program, the Swan River Trust funded a large number of projects related to river and catchment monitoring and mapping, algae and nutrient research, computer modelling of estuarine dynamics, stormwater design, water quality management and Catchment Management Plans for key areas.

This work has shown how important improved environmental management across the catchment is to the health of the river system. From investigations in the life cycle of phytoplankton and nutrient buildup in the river sediments we have learnt more about the connections between various elements in the river system. Tidal changes, weather, nutrient availability, oxygen levels and the layering of fresh rainwater over saline marine water (stratification) all play a critical role in the production and intensity of algal blooms.

The Swan-Canning Cleanup Program Task Force — which reports to the Swan River Trust — brought together expertise from government agencies, scientific organisations, local government and the community to develop an Action Plan to reduce algal blooms in the river system.

The Action Plan recommends strategies to achieve the Cleanup Program's goals, which are as follows:

- **Public health and amenity:** Algal blooms are kept at a level where there is no threat to public health and amenity and they are not a nuisance to the community. Toxic algal blooms are kept to a minimum.
- **Ecological function:** Water quality in the Swan–Canning system is suitable for maintaining a healthy ecosystem. People can swim or catch fish at any time.
- **Catchments and targets:** Contaminants in stream runoff leaving the catchments are within set targets. Rural catchments are managed to be productive and profitable, and are attractive and affordable places to live.
- **New urban and industrial areas:** Areas are designed so that discharges have reduced contaminant levels and meet set targets before entering rivers, while they still remain attractive, affordable places to live and productive and profitable places to work.
- **Older urban and industrial areas:** These areas are modified over time to reduce contaminant levels so that drainage discharges meet set targets before entering the rivers.

These goals and the philosophy behind the precautionary principle, which is to err on the side of caution when there is doubt about adverse consequences to the environment, have guided the Task Force in identifying actions needed to address the pressures facing the river system. These in turn have led to specific, costed recommendations that are summarised in the Action Plan. The recommendations of the Action Plan are summarised in four points and are provided in the following pages.

The Task Force presented a draft Action Plan to government and to the community for comment in July 1998. The consultation period closed at the end of October 1998, and the 53 submissions resulted in improvement to the presentation and substance of the Action Plan.

The Action Plan recognises that a reduction of algae in the Swan-Canning system needs to be tackled using a three-pronged approach:

- reducing the level of nutrients entering the rivers from the catchment;
- preventing the nutrients in the river sediments from becoming available to trigger algal blooms;
- increasing public awareness of the underlying causes and the ways they can help improve water quality.

Some aspects of this approach entail long-term solutions that set the framework for better catchment management and planning. But, while long-term solutions will eventually deal with the underlying causes of algal blooms, more immediate river interventions are required to tackle symptoms and to temporarily take the pressure off the river and its ecosystem. For example, the build-up in the river of sediment rich in organic material has created a ready store of nutrients upon which phytoplankton feed. When the right conditions come into play, algal blooms, particularly in the upper reaches of the rivers, can grow to the extent of smothering the river and threatening its ecosystem. River intervention aims to break the extent and severity of these conditions and thereby reduce the intensity of algal blooms.

Recommendations therefore range from those involving town planning, regulation and policy to others focused on development of catchment plans and action at the farm level and better industry practices to improve on-the-ground management. They also include continued development of state-of-the-art river intervention techniques to improve the condition of the river environment. Community awareness and involvement are vital to long-term success, and recommendations to support community involvement and individual action underpin implementation of the Action Plan. The lead agency and other involved parties have been identified next to each recommendation.

Some of the recommendations are not new and are already being implemented. The Task Force believes that these are still relevant and endorse their further implementation. The Action Plan has not been developed in isolation but is part of State and Federal initiatives that address problems affecting the wider Swan–Avon catchment. The recommendations of the Action Plan draw together many of these existing initiatives with new approaches, developed as understanding of the system has improved, to form a cohesive plan that will result in measurable improvements in river health.

The Action Plan will have an important relationship with the Comprehensive Management Plan required by the statutory Environmental Protection Policy for the Swan-Canning rivers which is being developed by the Environmental Protection Authority. The Action Plan will allow immediate action on the river and catchment to continue while the Comprehensive Management Plan is developed. The consultation over the draft Action Plan and its proposed implementation assisted the definition of those elements which will be captured by the Comprehensive Management Plan.

The Action Plan includes an extensive list of recommendations for action. Parts of the Plan have been clearly defined as the core program with strong recommendations for these actions to be implemented. Firm budget proposals have been prepared for these recommendations. A second set of recommended actions called 'dependent' activities are presented. The exact nature of these actions will be defined during the early stages of the Action Plan. For example, it is unlikely that all of the trials of new techniques in river intervention will proceed to an implementation stage.

The core program has been estimated to cost $14 million over five years. Dependent programs are estimated to cost an additional $8 million over five years. A great deal of work has already begun that is directly relevant to the Action Plan recommendations, contributing an additional $10 million over the next five years from existing programs, other State and Commonwealth funded community programs and local government.

Finally, corporate support of catchment programs is being received to further enhance the successful implementation of the Action Plan (e.g. Alcoa, Swan-Canning Urban Landcare Program - SCULP).

A Senior Officers Group has been formed to coordinate an implementation strategy for the Action Plan.

They will ensure relevant agencies and parties meet the objectives of the recommendations and report outcomes to Government.

Four-point Action Plan summary

1. Support Integrated Catchment Management to reduce nutrient inputs
Core program cost over five years $ 10,000,000

- 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 land-holders, catchment and river groups, local government and the broad community in catchment and river management.
- Improve government coordination and support.

2. Improve planning and land-use management to reduce nutrient inputs
Core program cost over five years $ 500,000

- Use statutory mechanisms including regulations, by-laws, town planning schemes and statements of planning policy to modify land-use 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
Core program cost over five years $ 2,000,000

- 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
Core program cost over five years $ 1,500,000

- Adopt recommended water quality targets for the freshwater tributaries and complete development of targets for the estuarine portions 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.

Conclusion

The Swan-Canning system flows through a metropolitan area of over 1.4 million people. History has altered this system and catchment, and it would not be possible to return it to its original pristine state. It is possible, however, to restore many of the ecological and economic functions of the system to keep it healthy and robust.

The broad range of actions outlined in the Action Plan will require major commitment and effort from Government and the community over the long term. Some of that effort builds on current actions; some of it is new. In many cases, the rewards for such work will not be apparent for years to come. Some actions are designed to restore the rivers and others are preventive, with the aim of reducing and eliminating nutrients at their source. Despite the pressures facing it, the Swan–Canning system remains relatively healthy and clean — it is certainly an environment worth protecting.

This Action Plan provides the means by which the Government and community can ensure that protection. It represents the deliberations of the Swan–Canning Cleanup Program Task Force and the parties that have made contributions to it. It also reflects the strong wishes of the community.

The next step is to implement the Action Plan recommendations. This will be achieved using cooperation between the many parties with responsibility for planning and managing the Swan and Canning rivers and their catchments.

IV Abbreviated glossary of acronyms

A complete glossary of acronyms and terms can be found in the Appendix

AGWEST	Agriculture Western Australia
BICM	Bayswater Integrated Catchment Management
BMP	Best Management Practice
CALM	Department of Conservation and Land Management
CMP	Catchment Management Plan
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWR	Centre for Water Research
DEP	Department of Environmental Protection
EPA	Environmental Protection Authority
EPP	Environmental Protection Policy
ICM	Integrated Catchment Management
LCDC	Land Conservation District Committee
LCG	Local Community Group
LG	Local Government
MfP	Ministry for Planning
MOU	Memorandum of Understanding
MRS	Metropolitan Regional Scheme
NHT	Natural Heritage Trust
NIMP	Nutrient Irrigation Management Plan
NLP	National Landcare Program
PA	Partnership Agreement
SAICM	Swan-Avon Integrated Catchment Management
SCC	Swan Catchment Centre
SCCP	Swan-Canning Cleanup Program
SCEPP	Swan-Canning Environmental Protection Policy
SPP	Statement of Planning Policies
SRT	Swan River Trust
TPS	Town Planning Schemes
WAERF	Western Australian Estuarine Research Foundation
WAMA	Western Australian Municipal Association
WAPC	Western Australian Planning Commission
WC	Water Corporation
WRC	Water and Rivers Commission
WSD	Water-Sensitive Design
WSUD	Water-Sensitive Urban Design (a subset of WSD)

Swan-Canning Cleanup Action Plan

Table of Contents

Swan-Canning Cleanup Action Plan

Figures

Tables

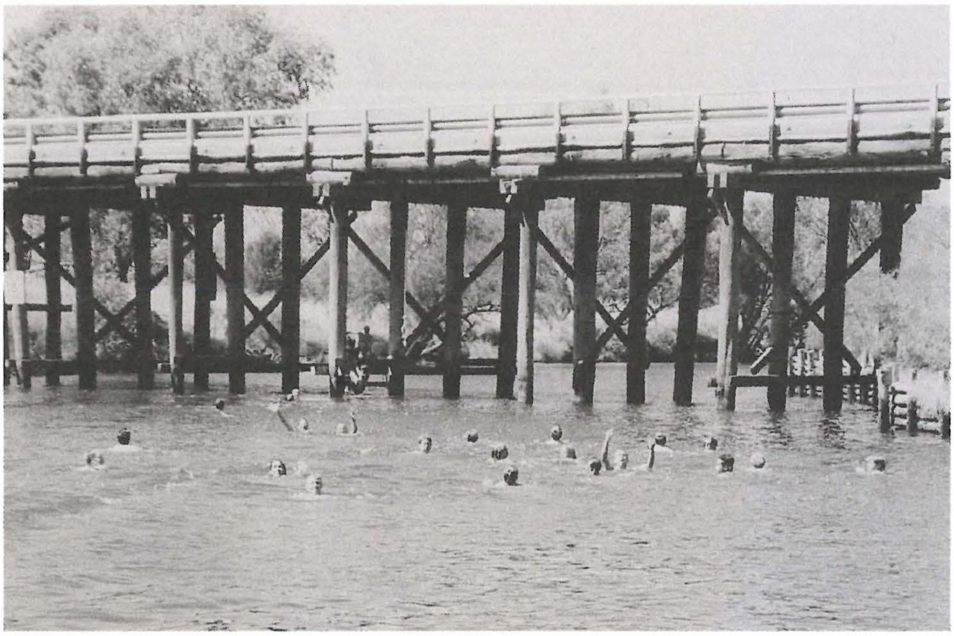
1. Why and how the Action Plan came about

1.1 An introduction to the Swan-Canning system

The Swan-Canning system and nearby coastal plain is an important historical, economic and recreational focus for Western Australia. The coastal portion of the Swan-Canning system occupies 2,117 square kilometres out of a total catchment of approximately 121,000 square kilometres. The Swan and Canning rivers flow through the heart of metropolitan Perth, a city of more than 1.4 million people (see Figure 1). The total estuarine portion of the Swan-Canning system, which includes the tidal portions of the tributary rivers and estuarine basins, occupies an area of 53 square kilometres.

During the last 10 years, algal blooms with associated fish kills have occurred in the Swan-Canning system. For example, in early 1994 a severe toxic blue-green algal bloom prevented recreational use of the Kent Street Weir for several months. Such events focused community concern on the deteriorating health of the river system. The level of algal blooms was unacceptable to the public. Monitoring showed that high concentrations of nutrients entering the river from its catchment were fuelling the blooms (see Figure 2).

Action was urgently needed to treat the environmental problems in the upper Canning, which was closed again to public contact in 1997-98, and to prevent further deterioration in the Swan River. A decisive response was needed to make sure that future generations can continue to swim, sail, windsurf, fish, picnic and catch prawns, and take pride in the sparkling waters that are the heart of Perth. In fact, having the Swan and Canning rivers flow through parklands and foreshores is an outstanding asset for a large cosmopolitan international city.



Swan River near Midland

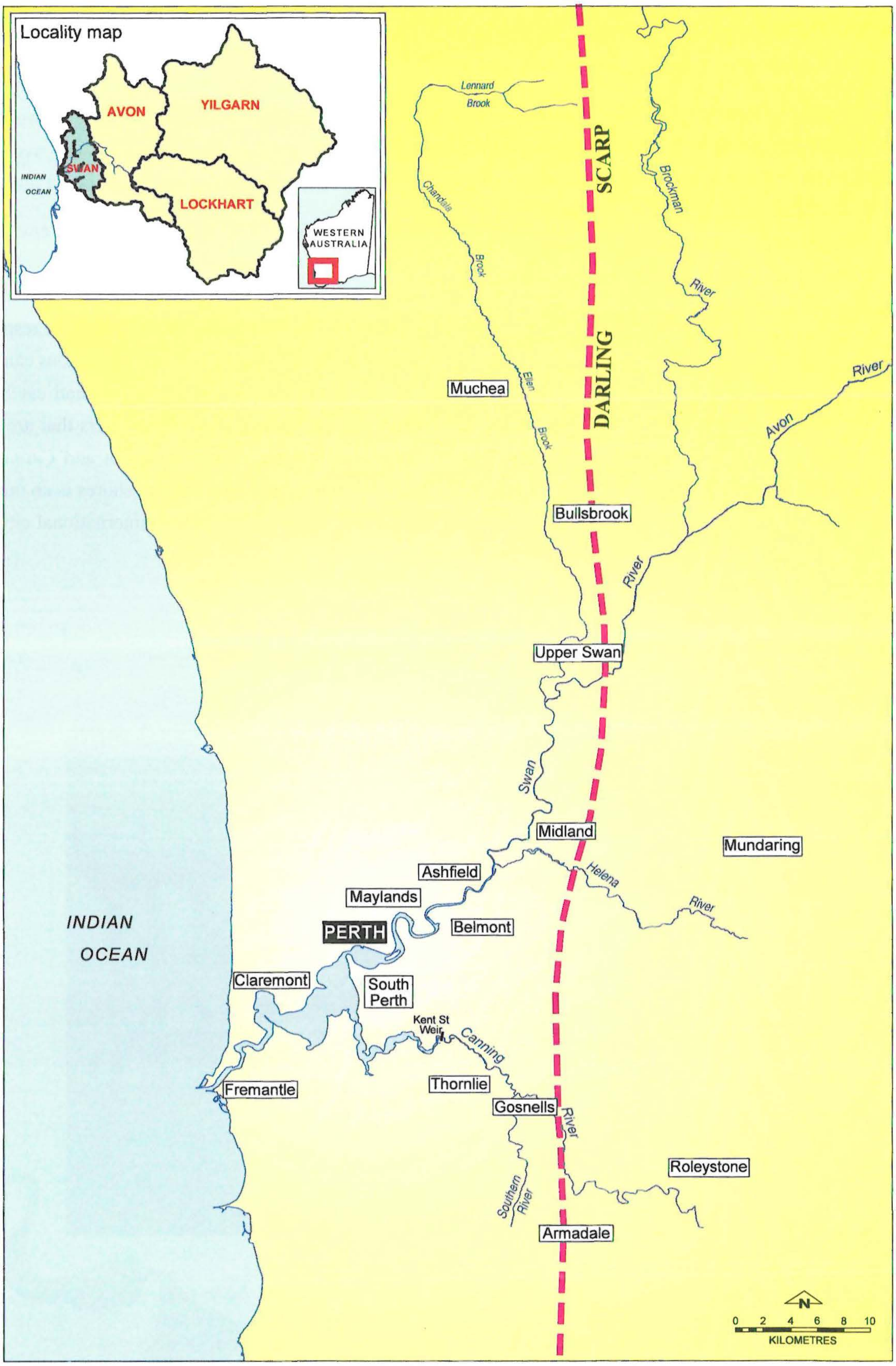


Figure 1: The Swan-Canning system locality map

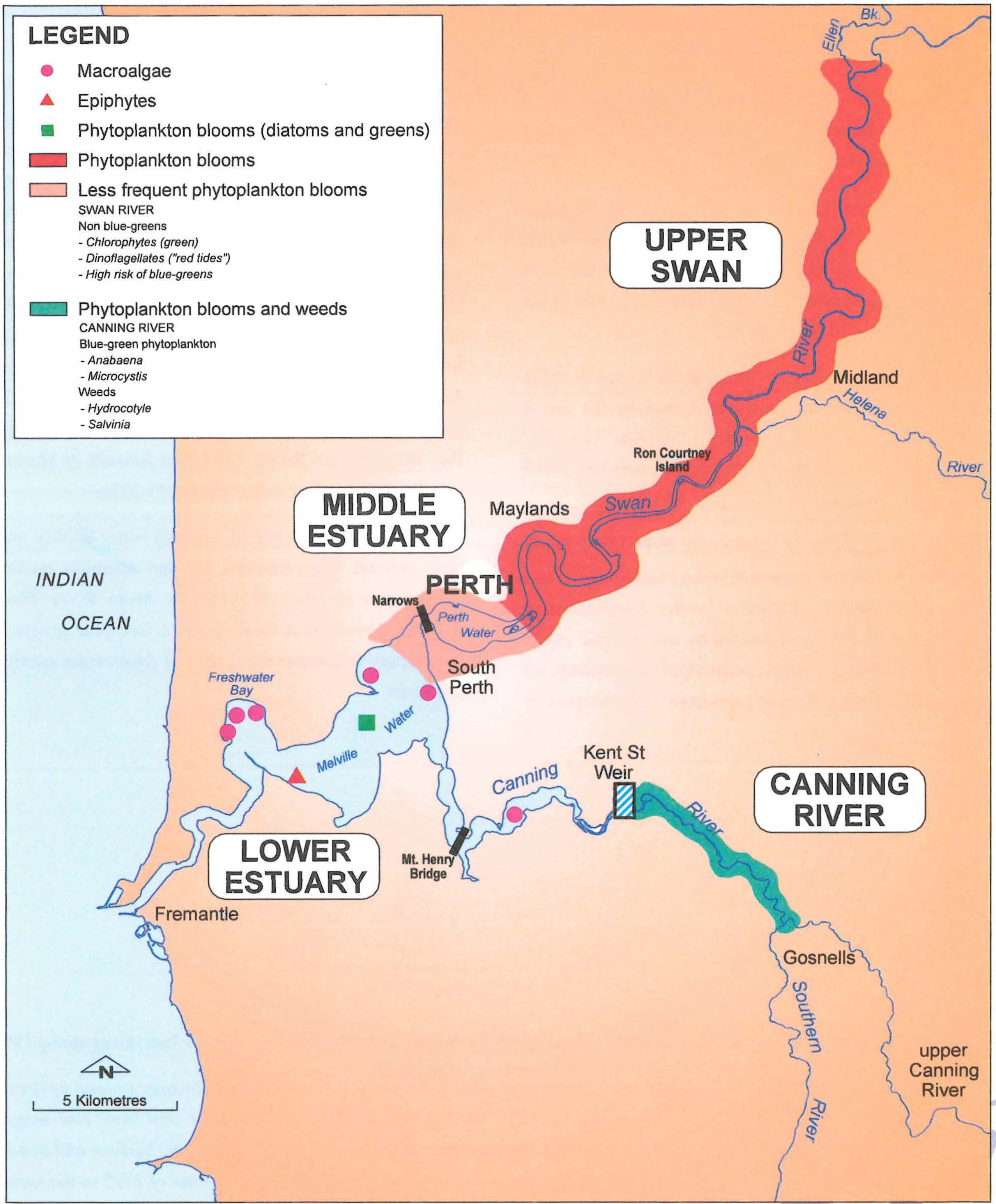


Figure 2: The Swan-Canning river and estuarine system and locations of problem areas

This map depicts the Swan-Canning river and estuarine system and the general water quality problems associated with each area. Toxic blue-green blooms and outbreaks of aquatic weeds are common upstream of the Kent Street Weir in the freshwater section of the Canning River. The estuary areas of the upper Swan and lower Canning experience a range of algal blooms, but extensive blooms of toxic blue-green cyanobacteria have not yet been recorded in these waters.

1.2 The problem: frequency and extent of algal blooms

In the spring of 1993 and the following summer the Swan-Canning system suffered a number of wide-scale and severe water quality problems.

Toxic blue-green blooms developed in the Canning River upstream of the Kent Street Weir. These lasted throughout spring and summer and posed a threat to public health, severely limiting swimming and other recreational uses of the river.

During the same spring, a bright green bloom of algae occurred upstream of Heirisson Island in the Swan River. Then, in summer, a non-toxic "red tide" bloom of algae, deep red and rust in colour, occurred in Perth Water and moved upstream into the upper Swan.

Prior to, during and after the summer of 1994, the Swan River Trust recorded large numbers of algal blooms and other water quality problems in the Swan-Canning system. The blooms were caused by microscopic algae, rather than the larger algae (macroalgae) responsible for blooms in the past. The change from large blooms of macroalgae to microscopic algae is considered an indication of advancing eutrophication.[1]

In addition, samples collected between 1987 and 1992 indicated that large amounts of plant nutrients, particularly phosphorus (estimate 72.5 tonnes per annum) and nitrogen (estimate 750 tonnes per annum) were entering the Swan and Canning rivers from the catchments of the coastal plain at concentrations that were substantially higher than those measured by CSIRO during the 1940s (e.g. Rochford, D.J (1951) Studies in Australian Estuarine Hydrology Part I: Introductory and Comparative Features, *Australian Journal of Marine and Freshwater Research*, Vol. 2, 1-116; Spencer (1956) Studies in Australian Hydrology Part II. The Swan River, *Australian Journal of Marine and Freshwater Research*, Vol. 7, 193-253).

The continuing evidence of lowered water quality and high nutrient concentrations focused attention on the estuary and its river. In 1994 the Swan River Trust received government funding for a five-year program specifically to address the causes of these water quality problems.

Figure 3 (adjacent page): Typical salinity, dissolved oxygen and water quality conditions in the upper Swan River during spring 1997

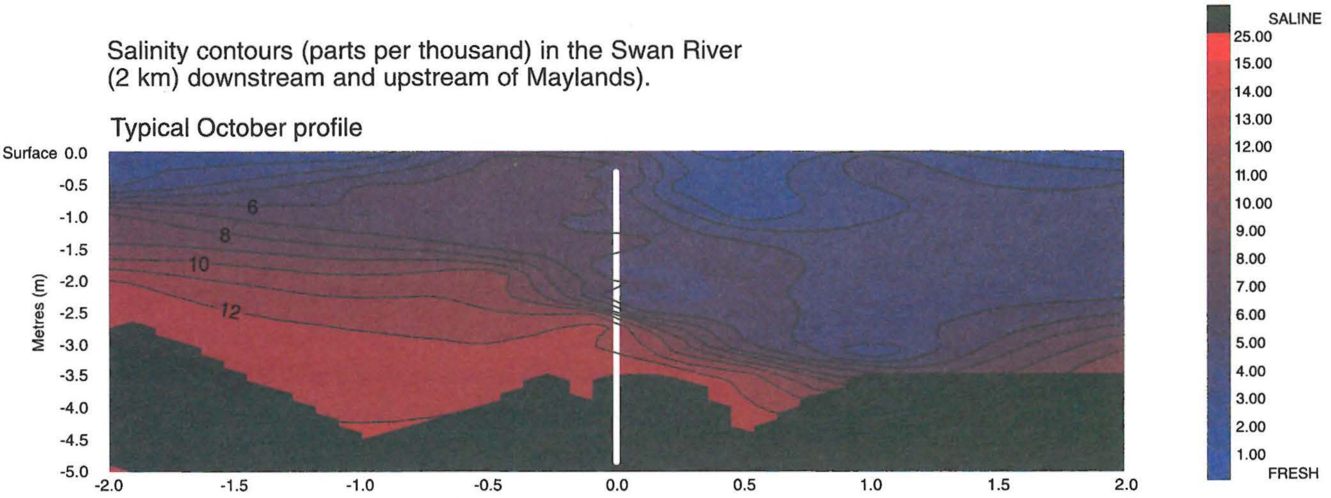
Typical water column profiles of salinity and dissolved oxygen during the month of October downstream and upstream of Maylands, which is indicated by the white bar. The salinity stratification of the water and very low oxygen concentrations in the deeper water during spring help contribute to the occurrence of algal blooms. Surface and bottom concentrations of total nitrogen, phosphorus and chlorophyll 'a' have been plotted from the winter of 1995 to the spring of 1997. They show consistently high levels in the upper estuarine portion of the Swan River. The chlorophyll 'a' plot offers an indirect measure of plant density.

The Australian and New Zealand Environment and Conservation Council (ANZECC) guideline levels are shown as a basis for comparison to indicate how poor water quality is in this part of the river. Algal blooms coincide with peaks in chlorophyll 'a' levels.

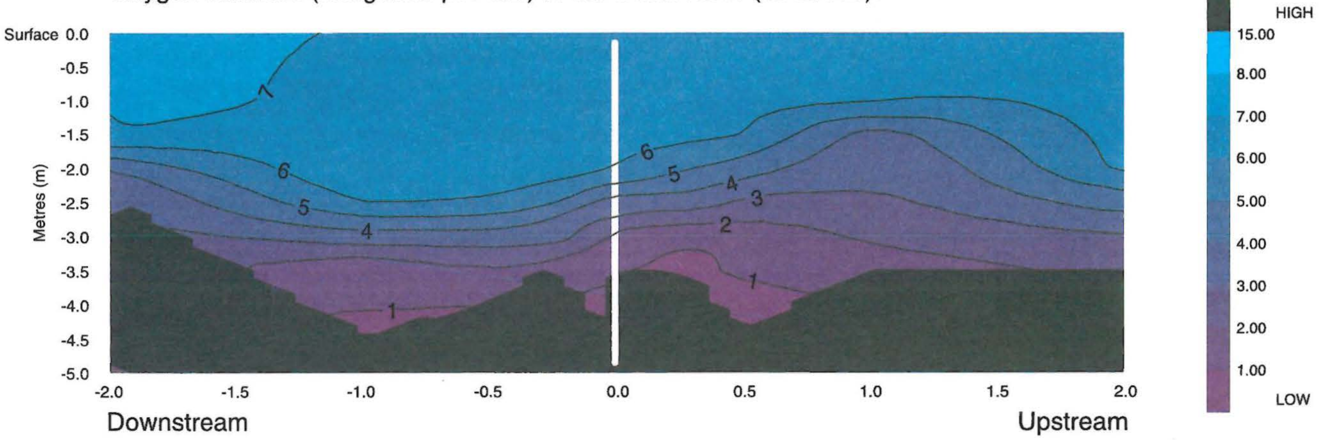
[1] Terms and processes are explained fully in Section 3. For quick reference the glossary in the Appendix may be consulted.

Salinity contours (parts per thousand) in the Swan River (2 km) downstream and upstream of Maylands).

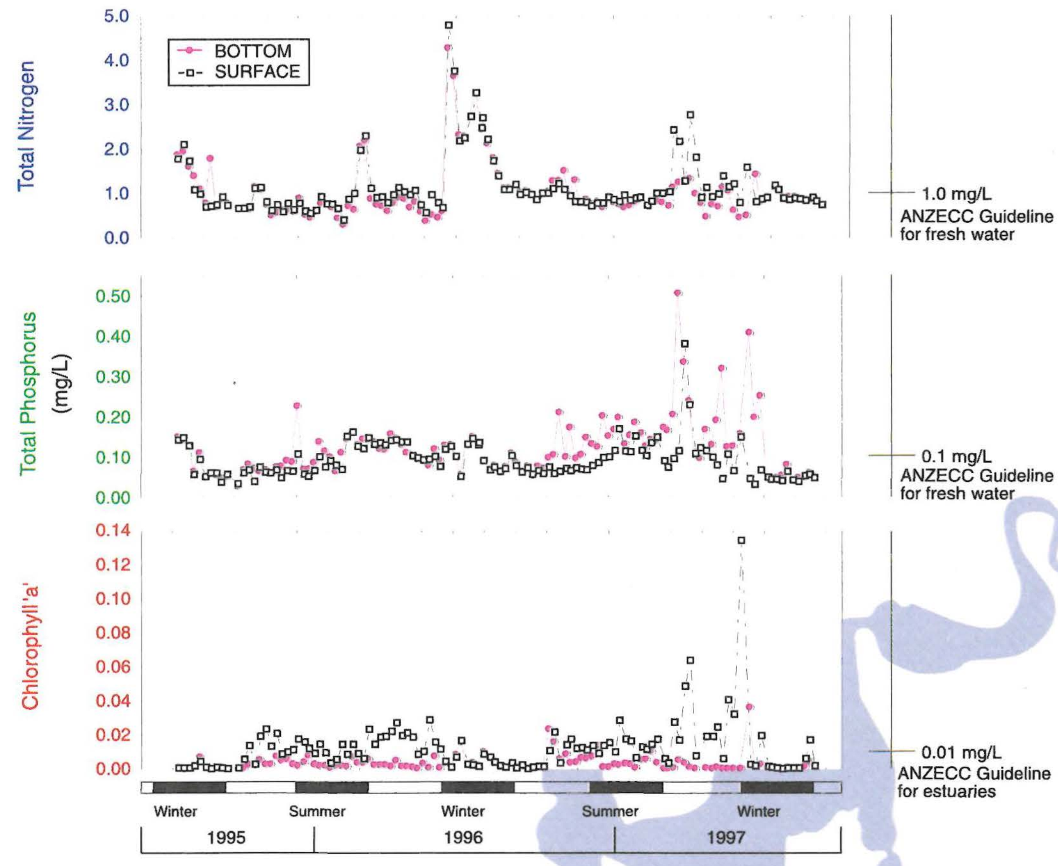
Typical October profile



Oxygen contours (milligrams per litre) in the Swan River (as above).



Upper Swan River



1.3 The Swan-Canning Cleanup Program and Task Force

In the autumn of 1994 the State Government commissioned the Swan River Trust to establish a five-year program to investigate and prepare a plan to reduce algal blooms. This became the Swan-Canning Cleanup Program (SCCP). A Task Force was established in late 1995 to advise on this program, to prepare an action plan and to report back to the Trust and Government.

Table 1: Task Force representatives

The Task Force includes representatives of:
Agriculture Western Australia
WA Estuarine Research Foundation
Ministry for Planning
WA Municipal Association
Water and Rivers Commission
Swan-Avon Integrated Catchment Management Coordinating Group
Swan River Trust
Water Corporation
Department of Environmental Protection
CSIRO Land and Water

The Task Force met regularly from 1995 to 1999 and had specialist technical committees to provide advice.

The Task Force reports to the Swan River Trust, which has endorsed this Action Plan and delivered it to the Government.

The Government allocated approximately $6.3 million over five years to the Swan River Trust for the program. Two million dollars of this was assigned to the Western Australian Estuarine Research Foundation (WAERF) to undertake research to improve understanding of the Swan-Canning estuary and other estuaries in south-west Australia. A major component of the WAERF research program includes the development of an interactive and predictive management model of the upper Swan River and estuary. Final reports on the WAERF program are due later in 1999.

The remaining $4.3 million has supported a range of SCCP projects across the areas of catchment management, monitoring, research, community awareness and trials to develop river intervention techniques. These projects have improved understanding of water quality and ways to measure the ecological health of the estuary and rivers. Many of these were carried out in partnership between organisations including the Water and Rivers Commission, Agriculture WA, the Ministry for Planning and local government. The SCCP has also worked in collaboration with national programs, especially the Swan-Avon Integrated Catchment Management program, which is funded through the National Landcare Program (now the Natural Heritage Trust).

2. Swan-Canning Cleanup Program objectives

The objectives of the SCCP are to:

- understand the mechanisms that trigger algal blooms and control their growth;
- identify how and where nutrients enter and cycle within the rivers and determine the best way to minimise these inputs;
- help maintain water quality both now and in the future by managing river sediments to reduce the store of organic material and nutrients;
- help change land-use categories and practices, planning processes and decision-making to reduce the amount and concentration of contaminants, especially nutrients, leaving rural and urban catchments; and to obtain greater community, government and business involvement in the catchments to reduce nutrient inputs;
- inform the community and involve it in developing the Swan-Canning Action Plan;
- reduce the frequency of occurrence of algal blooms.

The philosophy behind the precautionary principle, which is to err on the side of caution when there is doubt about adverse consequences to the environment, has been incorporated into SCCP projects and the decision-making processes associated with the program.

The program was required to provide a draft Action Plan after three to five years, and to produce a final five-year Action Plan, including an implementation strategy, by the end of the five-year period, in 1999.

GOALS

- **Public health and amenity:** Algal blooms are kept at a level where there is no threat to public health and amenity and they are not a nuisance to the community. Toxic algal blooms are kept to a minimum.
- **Ecological function:** Water quality in the Swan-Canning system is suitable for maintaining a healthy ecosystem. People can swim or catch fish at any time.
- **Catchments and targets:** Contaminants in stream runoff leaving the catchments are within set targets. Rural catchments are managed to be productive and profitable, and are attractive and affordable places to live.
- **New urban and industrial areas:** Areas are designed so that discharges have reduced contaminant levels and meet set targets before entering the rivers, while they still remain attractive and affordable places to live and productive and profitable places to work.
- **Older urban and industrial areas:** Older urban and industrial areas are modified over time to reduce contaminant levels so that drainage discharges meet set targets before entering the rivers.

3. The Swan-Canning river system environment

3.1 Geology and climate

The Swan Coastal Plain around Perth is over 100,000 years old. During this time much of the original sediment has been highly leached. The surface sediments now consist mainly of sand with poor nutrient-binding abilities. The coastal plain is quite flat; therefore its watercourses flow relatively slowly.

The lower reaches of the Swan-Canning system form an estuary created by geological conditions that prevailed over 10,000 years ago. Open, sunny, slow-moving, shallow river conditions and sandy soils with poor nutrient-binding properties are ideal for algal growth and make the Swan-Canning system naturally susceptible to blooms.

A large amount of fresh water from winter rains accumulates underground every year because of the porous, sandy soil. This fresh water is contained within the older and less pervious rocks and sediments, such as limestone, sandstone and shale, which underlie the coastal plain. The depth of the groundwater is often less than five metres in low-lying areas, and it contributes significantly to the numerous wetlands on the coastal plain. As it overflows from these underground storages, groundwater flows into river courses. Deep groundwater is also a major source for drinking water in the metropolitan area. Both shallow and deep groundwater can be easily contaminated by fertilisers and industrial waste, but shallow groundwater is particularly vulnerable.

The Swan-Canning system is in an area that experiences a Mediterranean-type climate characterised by wet winters and dry hot summers (see Figure 4). Rivers flow with fresh water during the winter and dry out in the summer. The Avon provides a very large share of the flow to the Swan River. Although surface waters dry out, groundwater often enters the larger rivers throughout the year. However, the quantity of groundwater entering watercourses is substantially less than that of winter surface water runoff.

Cyclical changes in low and high pressure systems affect the weather, tidal levels and wind patterns. Winds are dominated by southwesterlies and northwesterly storm fronts, which also influence wave patterns and shore erosion. Seasonal rainfall and weather patterns, combined with the removal a century ago of the limestone sill (barrier) at the mouth of the estuary in Fremantle to permit the entry of ships, allow the ocean tide and salty marine water to enter the estuary when river flows start to decrease in spring.

Tidal portions of the Swan-Canning system oscillate between being a fresh-to-brackish estuary in winter and a salty ocean-like estuary in summer. It takes from several weeks to two months of rainfall in the sub-catchments in late autumn/early winter before freshwater discharge is substantial enough to push the summer salt water downstream to the middle-to-lower regions of the estuary. Conversely, in spring, as rainfall decreases, the catchment dries out and freshwater discharge decreases, allowing salt water to move upstream.

There are 31 major sub-catchments in the coastal portion of the Swan-Canning system (see Figure 5). Drainage patterns from each of these are influenced by local climate and catchment characteristics.

Catchment: The area of land which intercepts rainfall and contributes the collected water to surface water (streams, rivers, wetlands) or groundwater.

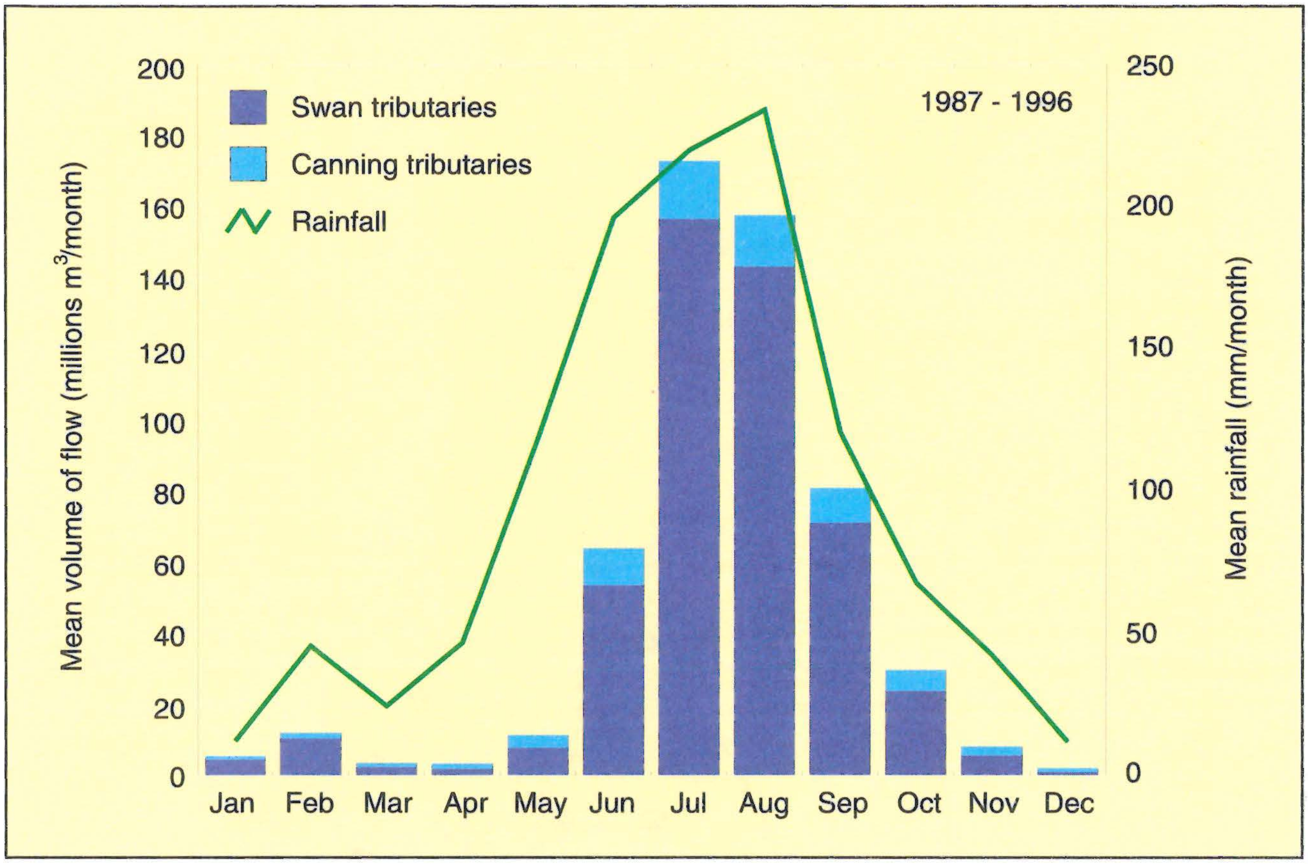


Figure 4: Mean volume of flow and rainfall for the Swan-Canning system (1987-96)

This figure shows average rainfall and river flows into the Swan-Canning system, indicating peaks during the winter and early spring. The flow from the Swan River (which receives flow from the Avon) is approximately 15 times greater than that from the Canning.

3

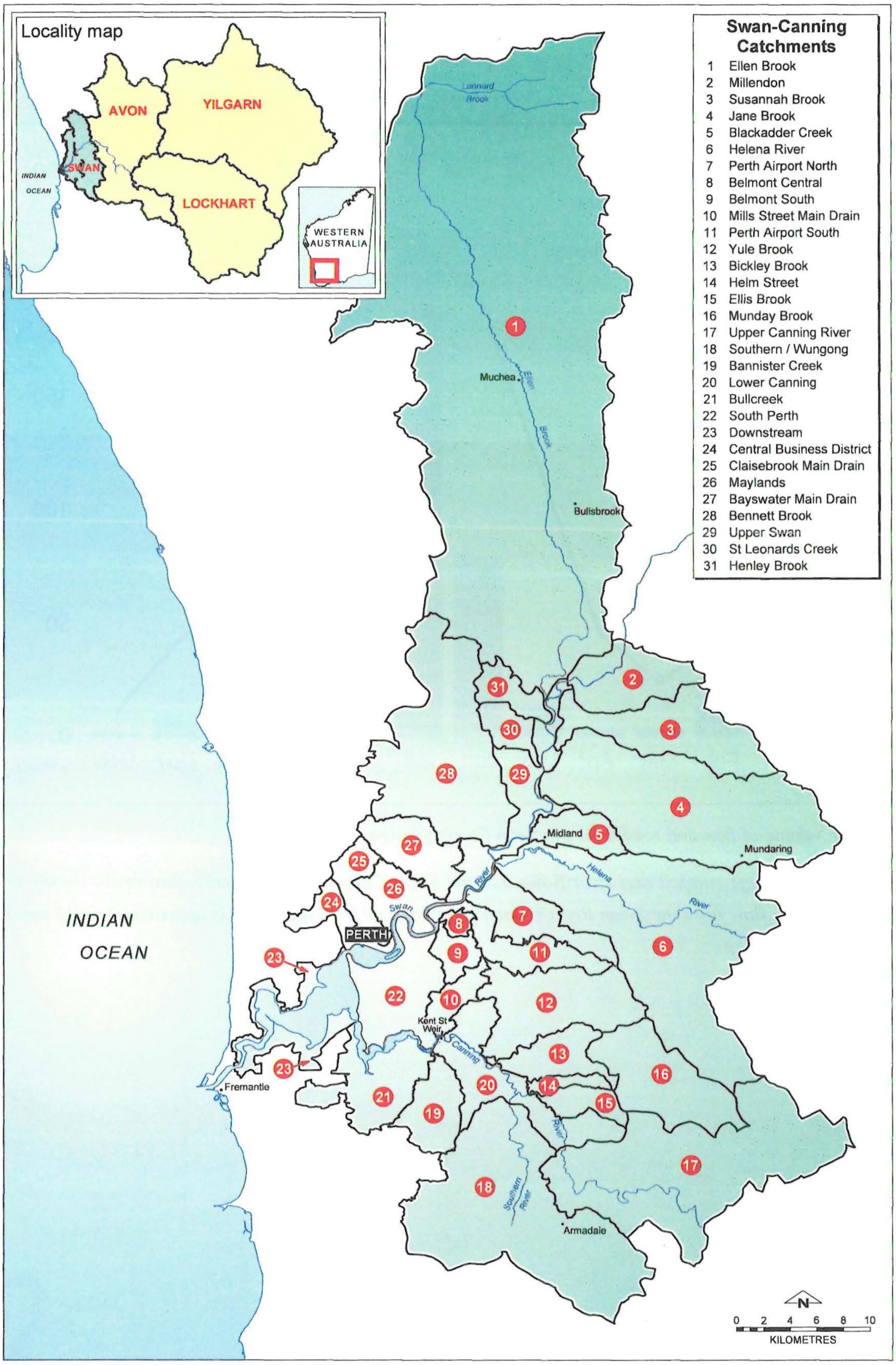


Figure 5: Catchments of the Swan-Canning system on the coastal plain

Thirty-one major sub-catchments exist in the Swan-Canning system. Community catchment groups and Integrated Catchment Management groups in both urban and rural settings have been organised around these sub-catchment boundaries. Many of the sub-catchments are based on urban drainage systems and have a number of small drainage catchments and drains that flow into the rivers and have been grouped into one general area, for example South Perth, Bullcreek and lower Canning.

3.2 The salt wedge and stratification in the estuary

Prior to human intervention the Swan River was mostly brackish, with a tidal amplitude of about one-fifth of that experienced at Perth coastal beaches which currently have a tidal range from 10 centimetres to 90 centimetres. Since the removal of the Fremantle sill and dredging of the large flood delta nearby, about four-fifths of the ocean tide is transmitted into the estuary. The Swan-Canning system is now a permanently open estuary which changes from fresh-to-brackish conditions in the winter and spring, to salty conditions during the summer and autumn.

Salt wedge: Since saline water is dense it tends to sit on the bottom of the river. When tides are strong and active it travels upstream along the river bottom as a wedge, while the lighter fresh water flows downstream on top.

When river flow declines at the end of winter, sea water moves progressively up the estuary, assisted by the tides, reaching the upper Swan - Maylands area and the Kent Street Weir in spring to early summer. In dry years substantial salty water often remains in the system over winter. The layering of fresh water over heavier, denser salt water is called stratification. This restricts mixing of the bottom waters with the surface waters, preventing oxygen replenishment from surface to bottom. Such conditions lead to a situation where the bottom waters become low in oxygen as decomposition of organic matter consumes any remaining oxygen and there is insufficient replenishment from the surface. This leads, in turn, to conditions where the sediments release nutrients into the water column and dissolved nutrients accumulate in the stagnant salty waters at the bottom.

The lower Canning River behaves similarly to the Swan River. However, the upper Canning is separated from tidal flow and marine water by the Kent Street Weir. During winter, wooden boards are removed from the upper level of the weir to allow the river to flow downstream and reduce the potential for flooding. In the summer, the boards are replaced to maintain the fresh water section for a larger duration, and to prevent salt water moving upstream. Consequently, during the summer the upper Canning River is impounded and behaves like a freshwater pool. Any stratification that occurs is due to temperature and not salinity.

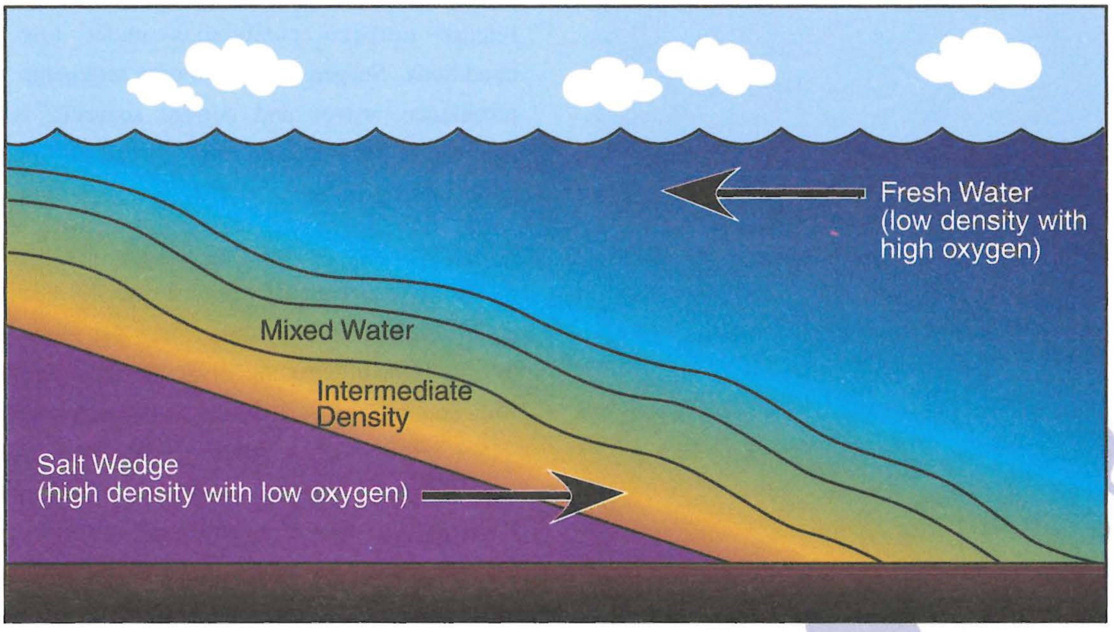


Figure 6: Wedge and water column stratification

Every spring a dense wedge of salty water moves upstream while lighter fresh water flows over the top as the summer progresses. The wedge moves upstream according to tidal and barometric influences, and freshwater flows reduce. The leading edge of the salt wedge often has very low oxygen and high nutrient levels.

3.3 Plant nutrients: sources, sinks and processes

The nutrients (principally phosphorus, nitrogen and carbon) that enter the Swan-Canning system come from a wide range of diffuse agricultural, urban, industrial and domestic sources. The highest concentrations of dissolved phosphorus and nitrogen are often found in runoff from Ellen Brook, the Southern-Wungong River and the South Belmont and Mills Street main drains, while soil-bound phosphorus is believed to come largely from the Avon River catchment and probably the hill catchments around the Darling Scarp.

Contrary to earlier assumptions, the algal blooms in the Swan River are limited more by the availability of nitrogen than the presence of phosphorus, so an understanding of nitrogen cycling is important for management purposes. The availability of nitrogen in runoff is one of the major factors determining the extent and frequency of algal blooms during the spring, summer and early autumn. The SCCP has therefore adjusted its emphasis from managing phosphorus to managing both nitrogen and phosphorus. Coupled reductions in the two nutrients are necessary to limit algal blooms in the Swan-Canning system.

Phytoplankton are microscopic algae (microalgae) and bacteria that photosynthesise. They are usually single-celled plants that live and float in water. They often colour the river and estuary green or brown because of pigments in their cells. Some stain swimsuits and cause skin irritation, and some are toxic to humans and other animals if ingested. Phytoplankton are essential to the food chain. They release oxygen to the water and atmosphere, and are only a problem if they bloom excessively, are toxic or decompose. When this happens, micro-organisms eat the dead cells, using oxygen in the process, removing it from the water and creating conditions that allow nutrients to be available for further plant growth.

Zooplankton are small free-floating or swimming animals that graze on algae and other plankton. They are essential to the food chain and help keep algal blooms under control.

The current understanding of nutrient processes is that a large amount of nitrogen enters the Swan-Canning system in dissolved form. This fuels the spring algal blooms and is converted to organic nitrogen (mostly as algal cells), which falls to the sediment when the algae die. In the sediments, the nitrogen is converted through decomposition by microbes to ammonia and then to nitrate. Both ammonia and nitrate are available for uptake in the summer by algae. Some algae (such as dinoflagellates) now dominate the summer algal blooms because they can migrate to the river bottom through stratified conditions during the night to take up nutrients. They then return to the surface to photosynthesise during the day. This process of cycling occurs repeatedly throughout the summer.

A large amount of phosphorus enters the Swan River in the form of dissolved phosphorus, mainly as a result of fertiliser runoff, and phosphorus attached to soil particles. Under oxygenated conditions, phosphorus can be retained in the sediment by forming compounds with iron, manganese, aluminium and calcium.

Both phosphorus and nitrogen are released back into the bottom water during periods of very low oxygen. This occurs because the phosphorus-metal compounds are more soluble in low oxygen conditions. Microbes also release nitrogen compounds under low oxygen conditions. Suspension of bottom sediments by wind turbulence, waves and current scouring is another mechanism for releasing nitrogen and phosphorus into the overlying water.

There is a net annual groundwater discharge to the Swan River between Guildford and the Causeway of about 80,000 cubic metres (m^3) per day, or about 29.2 million m^3/year. In 1996, the total surface water flow entering the Swan River from the Avon was about 715.9 million m^3, so that groundwater discharge is approximately four per cent of the total river flow. Nutrient concentrations, particularly of ammonia, within the sediment pore fluids underlying the river are often very high relative to concentrations in the river.

Groundwater also plays an important role in the release of nutrients from bottom sediments, at least at several locations along the Swan River. High flows of nutrient-rich groundwater have been shown to occur at three sites along the Swan River. There could well be more such groundwater sources to the system.

Flows of groundwater move nutrient-rich water out of the pore spaces between particles in the bottom sediments into the river water. The overall contribution of nutrients from groundwater reaching the river is estimated to be less than 16 per cent of the total nutrients entering the estuary, the majority, especially nitrogen, entering from surface flows. In addition, however, localised inputs of nutrient-rich groundwater along the margins of the rivers may be important for stimulating algal blooms along sections of the Swan-Canning system, particularly during summer when surface flows are reduced.

The incoming dense water of the salt wedge also displaces nutrient-rich water from the microscopic pores in the sediment. Both the salt wedge and groundwater processes appear to help fuel part of the spring and summer algal blooms through release of nutrients from sediments.

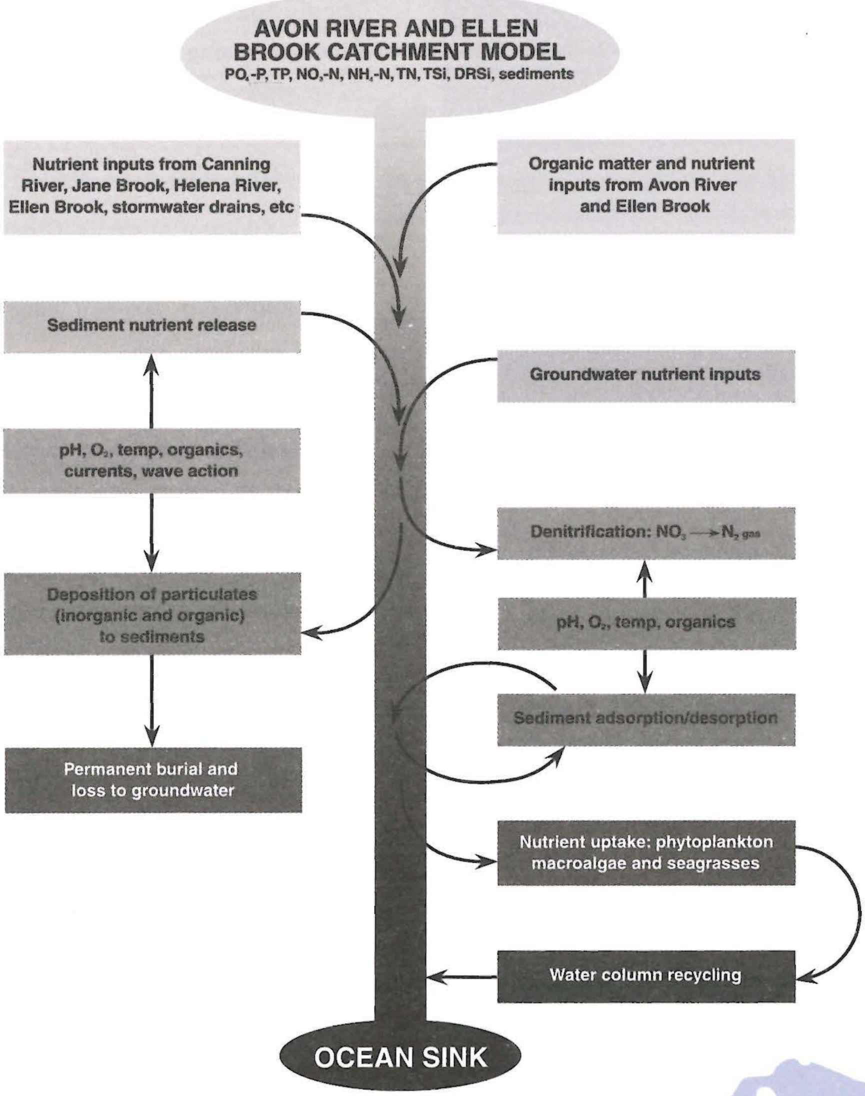


Figure 7: Major estuarine biogeological chemical processes

The processes by which nutrients enter the Swan-Canning system, their interactions and their cycling make up a complicated picture. This illustration shows the number of cycles nutrients and sediments undergo before they are permanently buried, are removed by plants and animals or enter the Indian Ocean at Fremantle (PO_4-P: phosphate; TP: total phosphorus; NO_3-N: nitrate; NH_4-N: ammonium; TN: total nitrogen; TSi: total silicon; DRSi: dissolved reactive silicon; temp: temperature).

3.4 The fate of nitrogen and phosphorus

Nitrogen can only be lost from the system through uptake by living organisms (which then must be physically removed from the system), by deep burial in the sediments, by export to the ocean or by the very important process of denitrification. Denitrification is a microbial process which converts nitrate to nitrogen gas. The nitrogen gas is then exported to the atmosphere, removing it from further use by algae.

Nitrification is the process by which micro-organisms convert ammonia compounds to nitrate. It takes place only under oxygenated conditions. Denitrification is the process by which micro-organisms break down nitrate until nitrogen escapes to the atmosphere as gas. This part of the process takes place under conditions with or without oxygen.

Oxygen essential	Oxygen not essential
Nitrification	Denitrification
Ammonium to nitrate	Nitrate to nitrogen gas
$NH_4^+ \rightarrow NO_2 \rightarrow NO_3$	$NO_3 \rightarrow N_2$

Given the high nitrogen loads entering the rivers and estuary and the low nitrogen concentrations in the estuary water column, it appears that the process of denitrification is active. However, for denitrification to occur, nitrification must occur first, and this requires oxygen. Low oxygen conditions in the bottom waters therefore reduce the rate at which nitrogen can be removed to the atmosphere. Infilling of tidal flats has reduced much of the habitat where nitrification occurs, and this has worsened the situation.

Phosphate applied in fertilisers is usually soluble. In most soils phosphate is immobilised by combining chemically with iron, magnesium, calcium and aluminium to form less soluble compounds or by being adsorbed onto the surfaces of clay and silt particles and organic matter in soil. It is then said to be "bound". Once bound, phosphate is much less mobile. It is not leached into the groundwater and is only exported from the catchment as part of the soil. However, when phosphate fertilisers are applied to the coarse sandy soils of the Swan Coastal Plain, very little is bound because these soils contain few binding metals and little clay, silt or organic matter. In this case phosphates can be mobile, and a high percentage may be leached into ground and surface waters.

We have a poor understanding of the rate at which these reactions occur in the Swan-Canning system, and know little of the microbial communities that are so important in these reactions. Little is known also about the microscopic bottom-dwelling plants that are critical to nitrogen cycling in estuaries. These questions will need to be addressed by future research.

3.5 Land use and water quality

In pre-settlement Australia there was relatively little loss of nutrients from the natural bush. Natural leaching of soils contributed some nutrients, but levels in the water would have been low.

With European settlement and the clearing of the catchments for agriculture, fertiliser application, sewage disposal and other land-use practices led to greatly increased inputs of nutrients to the river system, particularly phosphorus and nitrogen. At the same time the amount of organic matter delivered to rivers, lakes and estuaries increased and changed in type from predominantly eucalypt to more easily decomposed leaves, soft pasture plants and animal manure.

The altered systems exhibited greater nutrient fluctuations, increased amounts of nutrients, increased loss of nutrients and faster decomposition and recycling of nutrients between the sediment and water column. Australian aquatic fauna appear to be generally poorly adapted to the newer types and quantities of organic matter available, and this helped allow sediments rich in organic constituents to build up.

Industrial and urban development in the Perth area also changed the water quality in the Swan-Canning system, while the removal of the limestone sill in Fremantle changed it to a much more salty water body. Dams on some of the Swan's tributaries reduced water flows in the winter and retained any that occurred in the summer, but flows from the Avon River remain relatively unchanged. Dams built on the Canning River and its tributaries have significantly altered its water flows throughout the year.

The combination of clearing in the catchments for "modern agriculture" together with urbanisation and industrialisation led to water quality becoming poor between the 1920s and 1960s, resulting in macroalgal accumulations which often blanketed beaches and clogged much of the middle and lower basins of the estuary.

"...and so it is with regret that we say farewell to the beautiful Swan - rich in rare perfumes and rubbish dumps."

Figure 8: Rigby cartoon, 1957
Courtesy West Australian Newspapers Ltd

The Swan-Canning system has been an historical source of environmental concern and humour since the Swan River Colony was founded in 1829.

Government policy from the 1930s encouraged the relocation of heavy industry and sewage treatment plants away from the metropolitan area and this eliminated large point sources of nutrients and industrial wastes, particularly between 1950 and 1980. Those efforts helped to eliminate excessive growth of macroalgae in the lower and middle Swan-Canning estuary, and water quality in that part of the system is now significantly better. The current problem is one of growth of microalgae in the upper Swan and Canning rivers.

3.6 Eutrophication

The term **eutrophication**, or excessive nutrient enrichment of an estuary, river or water body, refers to the effects of sudden increases in nutrient inputs caused by human activity in the estuary and its catchment. Estuaries naturally accumulate nutrients and sediments from their catchments, but this takes place slowly over thousands of years, giving time for the plants and animals to change and adapt. Rapid changes caused by human-induced eutrophication lead to extreme responses in the biota, such as sudden accumulations of macroalgae and large phytoplankton blooms, including toxic blooms that threaten human health. This results in poor water clarity and lowered oxygen levels, and often leads to fish deaths and unpredictable water quality.

As the abundance of phytoplankton increases in response to increased nutrient availability, there is usually an increase in zooplankton, which "graze" (eat) the algae. Zooplankton are critical to establishing a balance between algal bloom conditions and better water quality. They are also important to the food chain. Aside from helping to control blooms, zooplankton grazing is important in the cycling of nutrients to the sediment. In the upper Swan, numbers of large zooplankton organisms that can eat a variety of algae are low, and they appear unable to help control algal blooms. The reason for this is complicated and probably related to seasonal and inter-annual salinity differences.

As eutrophication progresses, there is a general change in the algae present from small plant forms to larger bloom-forming species, which are harder for zooplankton to eat.

Under eutrophic conditions, large algal blooms tend to collapse when the nutrients are exhausted rather than from grazing pressure. Dead and dying algal cells fall to the river bottom and decompose, adding to the nutrient store in the sediments and, in the process of decomposition, removing oxygen from the water. This process may occur several times during each spring and summer. The consequent nutrient release from sediments may fuel subsequent algal blooms.

Australian inland waterways tend to have low ratios of nitrogen to phosphorus; toxic cyanobacteria (blue-greens) therefore often dominate due to their ability to utilise atmospheric nitrogen. Although estuarine portions of the Swan-Canning system have not experienced blue-green blooms or elevated cell counts for over 15 years, they occur in the Canning River (most notably in 1994 and 1997-98), in river pools of the Avon and in Ellen Brook.

3.7 The algae problem: its history and causes

3.7.1 Symptoms

The number of algal blooms in the Swan River has remained at levels that the public believe are unacceptably high. Unlike earlier occurrences, which were composed of macroalgae, current blooms are composed more of phytoplankton. In contrast to the situation in the early to mid 1900s, current water quality problems are due to nutrient enrichment from diffuse and smaller point sources across the urban and rural catchments of the Swan-Canning system. These are much harder to control and manage than large point sources.

River managers' concern that toxic algae would become established in the Swan River and the estuary is reinforced by the fact that toxic blooms already occur in fresh water upstream of the Kent Street Weir in the Canning River.

Table 2: Common nuisance phytoplankton, blue-greens (cyanobacteria) and plant species found in the Swan-Canning system

Nuisance phytoplankton, blue-greens and plant species	General criterion for health alert cells/mL of water	Comments
1. *Heterosigma* phytoplankton	> 15-20,000	Slimy layer - nuisance warnings and potential to kill fish.
2. *Scrippsiella, Gyrodinium* dinoflagellate phytoplankton	> 15-20,000	Red tide - nuisance warnings, some adhere to body.
3. *Rhizoclonium* macroalgae	no health threat	Unaesthetic appearance and temporary loss of recreational amenity.
4. *Anabaena* blue-green phytoplankton	> 20,000	Blue-green - unsafe for recreation - prevalent in the upper Canning River.
5. *Microcystis* blue-green phytoplankton	> 20,000	Blue-green - unsafe for recreation - prevalent in the upper Canning River.
6. *Anabaenopsis* blue-green phytoplankton	> 20,000	Blue-green - unsafe for recreation - prevalent in the upper Canning River.
7. *Hydrocotyle* plant	no health threat, any growth eradicated	Introduced - gazetted, noxious plant - occasional outbreaks in the Canning River.
8. *Salvinia* plant	no health threat, any growth eradicated	Introduced - gazetted, noxious fern-like plant - most common in the Canning River.

These algae and cyanobacteria species often elicit health alerts and public complaints, while introduced plants require immediate eradication. The blue-green Nodularia *and microalga* Alexandrium minutum *are currently rare in the Swan-Canning system.*

3.7.2 Algal bloom cycles in the Swan-Canning system

A cycle of algal blooms occurs in the Swan-Canning system naturally every year.

When toxic cyanobacterial (blue-green) species are recorded at lower levels in the water (>500 cells per mL of water) and where numbers are increasing, this requires the Swan River Trust to increase monitoring frequency to assess the potential of bloom growth. Brief cyanobacterial blooms were recorded in the upper Swan River in 1978 (e.g. cf *Anabaena*) and 1981 (e.g. *Nodularia*). Dense *Rhizoclonium* blooms were a common macroalgae species at Peppermint Grove. They required weed harvesting to be carried out in the late 1970s and early 1980s. They still remain an annual occurrence in the lower Canning River at the Riverton Bridge. This species was particularly abundant in the spring of 1996 when the worst bloom in the lower Canning was recorded, extending as far downstream as Mount Henry Bridge.

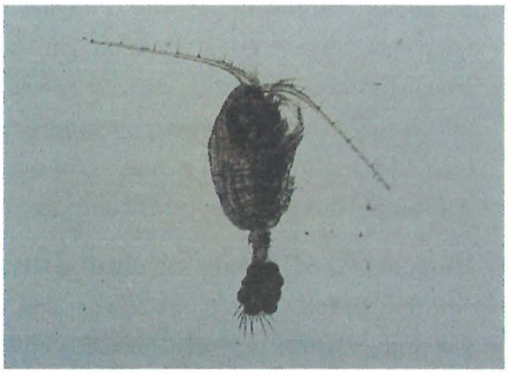
The toxic dinoflagellate *Alexandrium minutum* occurs in many Western Australian coastal and estuarine waters and is sometimes detected in the lower Swan River at very low levels.

3.7.2.1 Swan River

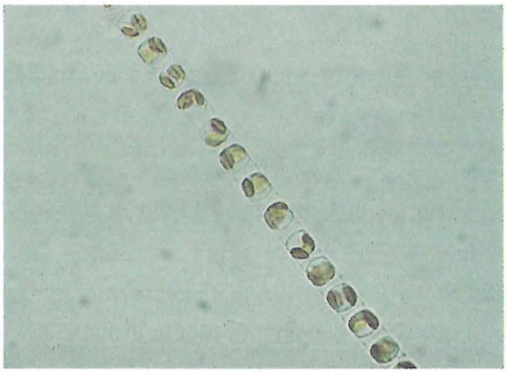
The succession patterns of algae in the upper Swan and lower Canning (below the Kent Street Weir) are very much affected by nutrient input patterns for the year, changes in salinity and the timing and movement of the salt wedge.

1. **Blooms of green chlorophytes** (green single-celled algae with flagella - whip-like propellers - e.g. *Chlamydomonas* species) occur in late winter and early spring when the water is still fresh. These blooms are primarily stimulated by nutrients in the water column following winter rains rather than nutrients in the sediments.
2. **Pioneering spring-marine species composed mainly of diatoms** (algae with cell walls consisting largely of silica, e.g. *Skeletonema* spp.) are mostly associated with the leading edge of the salt wedge in mid spring. They are often opportunistic, reaching high numbers for a short period of time, are usually not harmful and are often beneficial to the food chain.
3. **Rusty coloured blooms of dinoflagellates** (algae with big flagella, e.g. *Gymnodinium* spp.) occur in late spring. These are often mixed with blooms of diatoms (e.g. *Skeletonema*, *Chaetocerus* spp.) making the water appear brown. Dinoflagellates and diatoms often produce algal blooms when the water is brackish and the salt wedge is moving through. These species bloom initially in response to high levels of nitrogen in brackish bottom waters and often include a number of nuisance species requiring health alerts.
4. **Brown and red coloured blooms of dinoflagellates and cryptophytes** (small single-celled algae with flagella, e.g. *Gyrodinium* and *Crypotomonas* spp.) often occur in mid-summer after the water has turned salty. The size of these blooms may be influenced to a large extent by the amount of nutrients released and regenerated from the bottom sediments. Some of these algae are nuisance species requiring careful monitoring.
5. **Blooms composed of opportunist algae, such as diatoms, dinoflagellates and marine algae,** often occur in autumn. They flourish before winter rains flush out the salty river water or they bloom following early autumn rains, which bring into the river high levels of nutrients from runoff. They may also bloom as a result of nutrients being released from the sediments. Nutrients associated with rain events can encourage species that are good for the food chain as well as nuisance species that may have health implications.

Common phytoplankton and zooplankton in the Swan-Canning system (magnified, photos courtesy W. Hosja and S. Griffin).



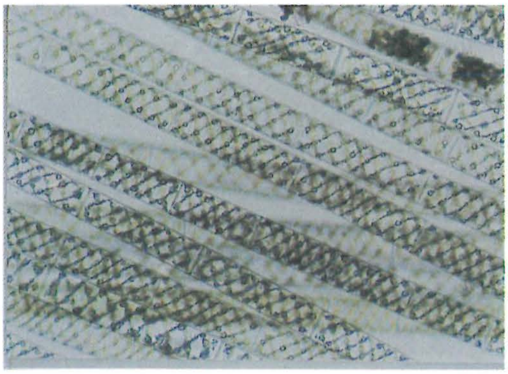
Gladioferens imparipes - zooplankton



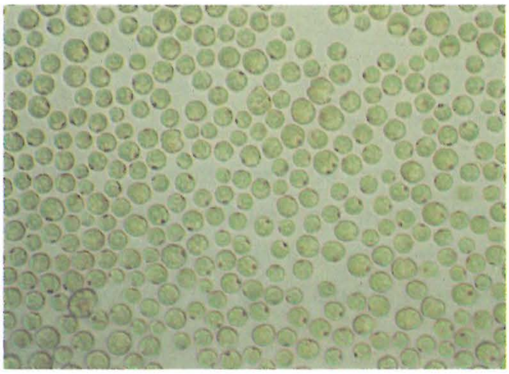
Skeletonema diatom

Anabaenopsis - blue-green

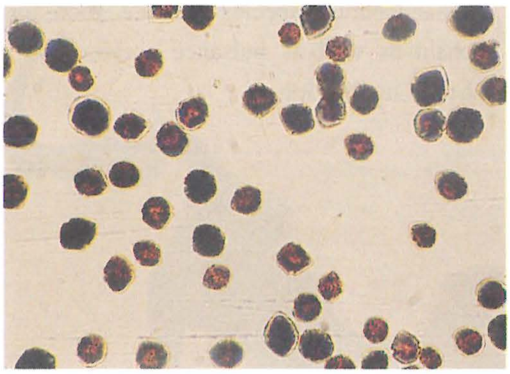
Eutreptiella Euglenophyte



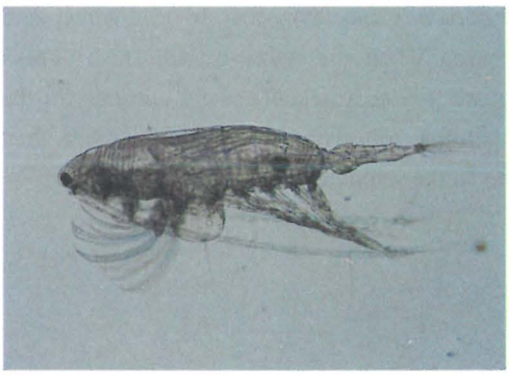
Spirogyra Chlorophyte



Chlamydomonas Chlorophyte



Scrippsiella dinoflagellate



Sulcanus conflictus - zooplankton

3.7.2.2 Canning River

In the Canning River upstream of the Kent Street Weir, water quality is also affected by high concentrations of nutrients and other factors listed earlier, but rarely by salinity. Because the upper water column stays fresh due to the weir, which holds fresh water upstream, the succession of phytoplankton is affected by temperature and light differences between the top and bottom water rather than by salinity.

In the Canning River, the stagnant, fresh bottom water becomes low in oxygen through decomposition and decay of organic material. It is believed that this releases nutrients from the sediments into the water column, where algae then bloom. In the Swan River the release process is the same, except that the stagnant bottom water is saline.

The upper Canning River undergoes blooms of green algae (chlorophytes) in the spring. However, in the late spring and during summer, when the water warms up but remains fresh, it can suffer blooms of potentially toxic blue-green cyanobacteria (e.g. *Anabaena* spp.). Because the water is fresh, the Canning River has a wide range of freshwater algae that bloom in cycles that are different from those of species in the brackish and marine waters of the Swan River.

In the lower sections of the Canning River upstream of the Kent Street Weir, larger freshwater plants (macrophytes) such as pond and "duck" weeds can become abundant. This was a common occurrence before 1993. Macrophytes and duck weeds can both shade the surface of the water and compete for excess nutrients, thus reducing prolonged phytoplankton blooms and possibly controlling cyanobacterial blooms. Freshwater macrophytes are mostly absent from the Swan River; instead the plants are species that are tolerant of brackish and salt water. Although the public often complain about macrophytes in the upper Canning River, they are beneficial insofar as they provide bird habitat and shade out phytoplankton blooms, as well as compete with cyanobacteria for nutrients.

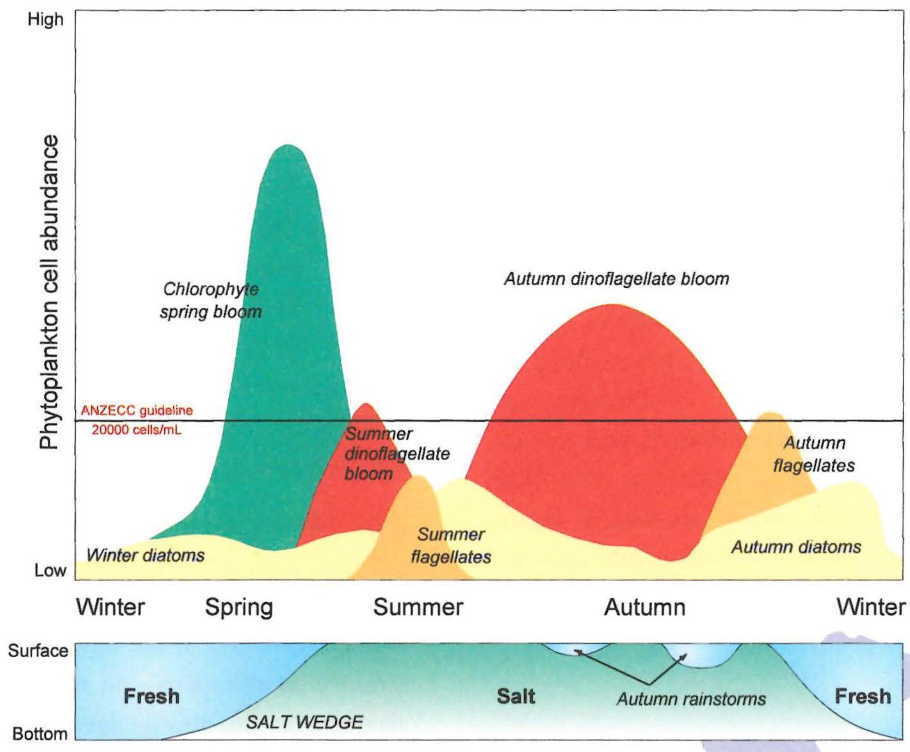


Figure 9: Algal succession and relative abundances in relation to salinity and the timing of the salt wedge

This illustration shows the relative abundance of phytoplankton and the scale of blooms in the upper Swan compared with the seasons of the year and the timing of the salt wedge. Salinities in the water of the upper Swan region are shown under the seasons. The ANZECC guideline for blooms indicates the relative magnitude of blooms in the upper Swan.

3.8 Ecology of the Swan-Canning system

Estuarine plants and animals respond to their physical and chemical surroundings. Life in the Swan-Canning system is no exception. The large seasonal range in salinity in the estuary and the lower sections of the Canning River (below the Kent Street Weir) severely restricts the numbers of animal and plant species and the durations for which they become established. The effect is that the aquatic communities in the estuary change with changes in salinity. Species diversity is lower than where there is a more consistent salinity. There, the flora and fauna have become well established in response to the continuity of salinity conditions.

Three kinds of animal and plant communities live in the Swan-Canning estuary and along the tidally- and salt-affected estuarine and river foreshores.

1. **The freshwater community**. Freshwater fish, algae and other living organisms washed downstream become briefly established in winter and spring when the rivers are fresh. They can only survive in fresh water. Their numbers are limited by the length of time the system stays fresh. Because freshwater conditions usually occur during winter, productivity is low.

2. **The estuarine community**. As river flows diminish, flora and fauna become increasingly dominated by estuarine organisms that are tolerant of the wide range of salinities (fresh-brackish-marine). Many of the animals live in the estuary throughout the year and can reach very high numbers during spring and summer. Although molluscs, invertebrates and smaller fish are prolific, the number of species is low. The system has a highly productive food chain supporting these communities, and there is a large recreational and commercial fishery (fish, crabs and prawns) as well as large flourishing bird populations.

3. **The marine community**. These animals and plants become established later in summer and autumn as salinities approach those of the ocean. The animals are often seasonal visitors that remain in the tidally affected Swan-Canning system as long as conditions are marine and leave when winter rains return. Fish such as tailor and mulloway are in this category. Many marine plants such as macroalgae die when salinity falls in winter.

Table 3: Typical salinities associated with different animal and plant communities

Freshwater community	0-5 parts per thousand (ppt) salt
Estuarine community	2-40 ppt salt
Marine community	30-40 ppt salt
Sea water averages 35 ppt salt in south-west Australia.	

Estuaries are naturally productive. Calm conditions and the mixing of fresh and marine waters predispose them to healthy growth and blooms of macro- and microalgae. The timing, size and location of algal blooms in the river varies from year to year, depending on river flow and climatic conditions.

In the Swan-Canning system during the warmer productive months, frequently occurring algal blooms "collapse" as explained in Section 3.6, creating low-oxygen conditions which can decimate resident animal populations. Animals that inhabit both the bottom sediments and the water are particularly affected. Zooplankton are small, weakly swimming animals, which cannot survive low-oxygen conditions. Fish, which are more mobile, tend to swim away from unfavourable water conditions. In extreme events less agile fish also die, leading to local fish kills.

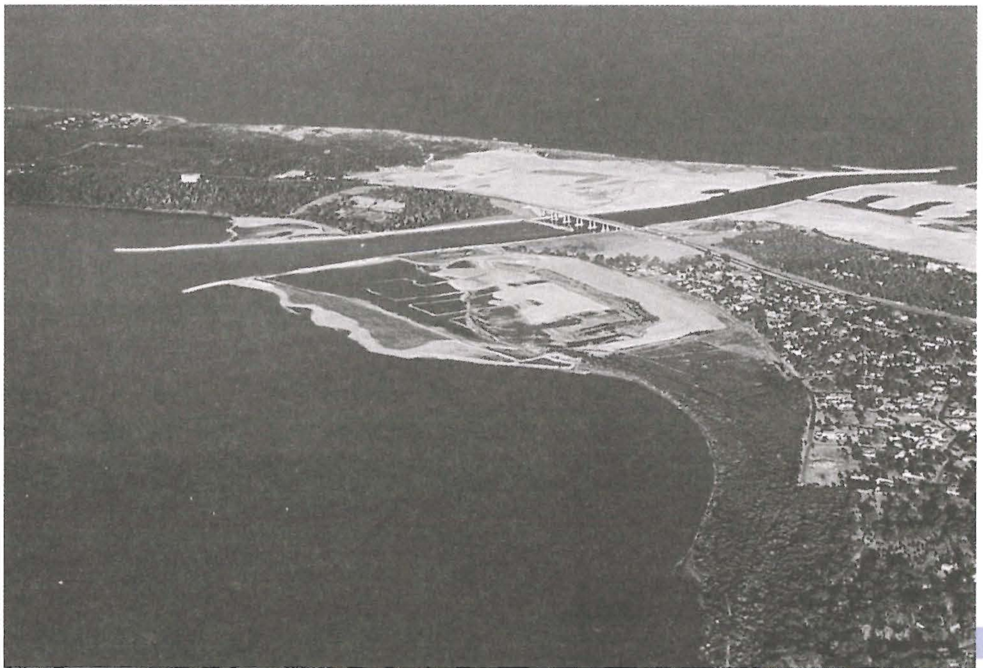
Algal blooms are a natural feature of estuaries and nearshore environments. However, over time repeated excessive algal blooms and their collapse reduce essential diversity in the food chain, making it more sensitive to disruptions. In these extreme situations, algal blooms also directly threaten the system's fish and other wildlife.

3.9 Prevention and the Peel-Harvey lesson

If not stopped, accumulations of nutrients in rivers and the estuary will continue, increasing the frequency and extent of algal blooms. For example, excessive nutrient enrichment in the basins of the Peel-Harvey led to toxic blue-green blooms of *Nodularia*, severely limiting recreation and fishing for several months each year during the spring and summer. At other times, extensive growths of macroalgae clogged the system. When the weed decomposed it created unpleasant smells on the beaches, and rafts of living weed blocked navigation in boat channels. A similar situation in the Swan-Canning system would have a severe impact on Perth's environmentally "clean" reputation and its recreational and tourist industries.

The Dawesville Channel was built at a cost of over $65 million to help solve the problems of the Peel-Harvey estuary. The location and physical dimensions of the Swan-Canning system do not make it amenable to such an engineering solution nor are the problems of the Swan-Canning system as severe yet as those that were experienced in the Peel-Harvey. Although construction of the Dawesville Channel was the major short-term action taken to clean up the estuary, catchment management is also necessary for the long-term health of the system.

The point is that it is much more effective to take preventive action rather than attempt to restore a collapsed estuarine system. If the health and efficient nutrient-processing of the Swan-Canning system can be ensured now, it will have a much greater ability to meet the pressures imposed by an expanding Perth population. Maintaining the health of the system will ensure that it can be managed and the demands of the population of Perth equitably addressed.



"Dawesville Channel April, 1994." Peel-Harvey estuary. Photo courtesy L. Mannix

4. Issues, options and actions needed

4.1 Approach to managing algal blooms

Algal blooms in the Swan-Canning system are caused by excessive levels of nutrients in estuarine waters and sediments. Broadly speaking, there are two sources of nutrients - internal and external. The internal sources are the sediments within the estuary, which, under some conditions, become available to fuel algal blooms. More important are the external sources, which deliver nutrients in a number of ways. A portion is dissolved in the streamflow that enters the system; another part is bound to clay and silt particles washed from the catchment; yet another source is organic matter - such as leaf litter and animal wastes - carried in the streamflow.

The Action Plan recommends actions that will:

- reduce the supply of nutrients, particularly phosphorus and nitrogen, from the catchment;
- reduce the supply of nutrients from sediments;
- modify conditions in the river so that blooms are less likely to occur.

4

Worldwide experience from programs dealing with major environmental problems has shown that prevention is the preferable management action. This is especially so where a system like the Swan-Canning is still in a reasonable condition (although the upper Canning River is in poor condition). The Action Plan strongly emphasises a long-term nutrient management and prevention program because there is a direct link between current nutrient loads and concentrations entering the Swan-Canning system and our ability to maintain the health of the river system or to meet Australian and New Zealand Environment and Conservation Council (ANZECC) water quality guidelines for estuarine and fresh rivers.

The plan aims to reduce nutrient input from rural and urban runoff and groundwater flows, prevent erosion of catchments and degradation of foreshores, control specific high-nutrient-generating land-uses, and manage leaching from landfill sites. It adopts a whole-ecosystem approach and emphasises that community awareness and involvement are essential to achieving sustainable change.

These aims can be achieved through a combination of reform in land-use planning, statutory controls, improved land management and restoration practices, river intervention and catchment management.

Long-term preventive measures such as catchment and foreshore restoration and Integrated Catchment Management may take up to 20 years to produce marked benefits in river health. Even so, it is crucial that they be fully supported and implemented now.

In the short term (three to five years), specific actions to modify conditions in the rivers could reduce the occurrence of algal blooms, for example by treating sediments or maintaining high oxygen levels in the water to lock up and remove nutrients that would otherwise trigger a bloom. Short-term intervention methods can be implemented quickly with State and local government resources. In contrast, long-term catchment management needs to be driven by a combination of community, local, State and Commonwealth government support.

The current focus is to support local government, community and catchment group initiatives, to form partnerships, for example with industry, and to develop mechanisms for entrenching nutrient-reduction practices at all levels of planning and management and land-use activity.

Much work has already been done through the Swan-Canning Cleanup Program to gather data on nutrient flows, explore options for river intervention, conduct river trials and implement catchment plans. In conjunction with the Swan-Avon Integrated Catchment Management Program, support has been provided for significant expansion of community-based ICM initiatives and for raising awareness of river management issues.

The Action Plan includes recommendations to extend and build on these achievements, and to implement new initiatives to combat nutrient enrichment and fully restore the Swan-Canning system to health as a treasured community asset.

4.2 Managing nutrient inputs

4.2.1 Catchments and their contribution to the Swan-Canning system

The nutrient concentrations in freshwater systems can range from low through high to extreme (see Table 4). The low category corresponds with the draft ANZECC guidelines for the protection of freshwater systems.

Table 4: Classification of nutrient concentrations and ranges found in catchment tributaries (mg/L - milligrams per litre)

Phosphorus range (mg/L)	Category	Nitrogen range (mg/L)
<0.1	Low	<1.0
>0.1 < 0.2	Moderate	>1.0 < 2.0
>0.2 < 0.3	High	>2.0 < 3.0
>0.3 < 0.5	Very High	>3.0 < 4.0
>>0.5	Extreme	>>4

Contributions from the 15 catchments entering the Swan-Canning system have been classified using this system and results are illustrated in Figure 10 for nitrogen and Figure 11 for phosphorus. For nitrogen, only four of the catchments meet the low category. These are:

- Avon River
- Helena River
- Jane Brook
- Upper Canning River

For phosphorus, 11 of the catchments meet the low category. Ellen Brook, Mills Street Main Drain, Southern-Wungong River and South Belmont Main Drain exceed the guidelines for low dissolved nitrogen and are priority areas for action.

Monitoring results for all of these catchments from 1987 to 1997 indicate that action has enabled phosphorus discharges from some of the catchments (such as Bayswater Main Drain) to be reduced substantially. For nitrogen the trend is reversed, with historical evidence showing an overall increase in concentrations of nitrogen from catchments.

This classification approach led to the recognition that the following four catchments, based on 1994 data at the start of SCCP, were the most significant nutrient contributors to the Swan-Canning system:

- Ellen Brook
- Southern-Wungong River
- Canning River (above the Kent Street Weir)
- Bayswater Main Drain

Further, the following eight catchments are major nutrient contributors:

- South Belmont Main Drain
- Bennett Brook
- Bannister Creek
- Mills Street Main Drain
- Yule Brook
- Blackadder Creek
- Bickley Brook
- Susannah Brook

Both the Ellen Brook and Bayswater Main Drain Catchment groups have been implementing catchment management and restoration works which have been effective in reducing nutrient exports from their catchments, particularly for phosphorus. This is evidence that properly targeted catchment management and restoration initiatives can reduce phosphorus and, with some changes, nitrogen inputs.

4.2.2 Reducing inputs

Nutrients and other contaminants enter waterways from surface and subsurface drainage. This drainage often intercepts runoff or soakage from single point sources such as industrial and commercial premises that generate large quantities of nutrients, or from intensive agricultural enterprises such as piggeries, poultry farms and market gardens, which generate nutrient-rich wastes or apply large amounts of fertilisers. Many activities that generate point sources are licensed by the Department of Environmental Protection or have been approved by local governments, not necessarily with any controls that affect the export of nutrients and other contaminants.

Drainage can also collect small amounts of nutrients and other contaminants from runoff and soakage generated from activities on a large number of different properties, premises and homes in rural and urban settings. These are referred to as diffuse sources. Sometimes drains collect nutrients from diffuse sources, concentrating them as they flow. When the drains reach the river they discharge contaminated water with high concentrations of nutrients. Diffuse sources are an environmental threat when cumulative discharges of nutrients and contaminants from many sources exceed the capacity of receiving water bodies to assimilate and process them, with consequent impacts on ecology and human use. The Swan-Canning system is approaching such a situation.

Best Management Practices are the best practical methods of meeting long-term objectives such as good water quality. BMPs usually set out a series of steps to follow, and are a structured way of reaching desired performance. Many BMPs are still being developed, but it is the process of development that leads to the evolution of the best practical methods to manage serious environmental issues. Codes of Practice should not be confused with BMPs, as they are considered as being half way between a BMP and a regulation. The process of preparing BMPs, however, is likely to become a statutory requirement as part of the Comprehensive Management Plan in the Swan-Canning Environmental Protection Policy, which was gazetted in 1998. BMPs in themselves may not lead to instant improvements in water quality but, if properly developed, evaluated and adopted, they will help reduce the chances for nutrient and other contaminant runoff to enter the waterways.

Management of point sources of pollution requires effective licensing, understanding codes of practice relevant to the business, and implementation of Best Management Practices. On the other hand, management of diffuse sources requires changes to human practices such as how we use the land, fertilise and water our gardens, treat our gardens for pests, wash down our cars and clean our roads and parking lots. It also requires the use of BMPs that will help establish water-sensitive and non-polluting landscape and drainage designs. Legal mechanisms that may be used to control the kinds and amounts of nutrients, fertilisers and other contaminants in the catchment include town planning and development provisions and the use of pollution prevention licences.

Management of point and diffuse sources of pollution can have both short-term and long-term benefits if action is taken now. Some actions, such as the use of legal mechanisms and the requirements of BMPs in future developments, may take several years before they significantly benefit downstream water quality. Other actions such as minimising contaminated runoff, using water and garden fertilisers sparingly, planting more deep-rooted plants and establishing vegetation buffers along drains and streams may have more immediate positive effects on nearby water quality.

Appropriate land-uses are those that do not export nutrients, sediments and other contaminants into the waterways and groundwater beyond "natural" levels. To minimise the export of nutrients, appropriate land-uses often maintain natural hydrological and vegetative features of land. This is done by matching land-use with land capability and suitability, which lowers the risk of nutrients being exported to waterways. **Inappropriate land-uses** generate high levels of nutrient export from the land, and the environment becomes degraded to the point where erosion occurs, there is little natural vegetation cover and the hydrology of the area is highly modified - in short, environmental values of waterways for future generations are compromised.

Planning and development in Western Australia operate under the *Town Planning and Development Act*, the *Western Australian Planning Commission Act* and other associated legislation (see Appendix 5 for an outline of the planning process). Land-use, development control and subdivision are managed through statutory regional planning schemes and town planning schemes prepared by the Western Australian Planning Commission and local government respectively. The regional planning scheme for the Perth Metropolitan Area is the Metropolitan Region Scheme.

Through town planning schemes prepared under the *Town Planning and Development Act*, local government controls land-use and development in shires, towns and cities throughout WA. Many decisions made in the past were without the benefit of current understanding of the environment. Land-uses and development were approved that resulted in environmental degradation and pollution of waterways by nutrients and contaminants. The Action Plan recommends steps to reverse the damage that has been done and prevent further degradation.

Community and catchment groups can play a critical role in reducing nutrient inputs. In rural areas they are composed of concerned individuals who are willing to establish demonstration sites, fence and revegetate foreshores and undertake better management practices on their properties. These individuals and groups create the initial changes leading to source reduction and increased community awareness.

Community and catchment groups also establish links with local government and State agencies, which helps to improve decision-making and reduce the number of land-holders and businesses generating nutrient inputs to the system. Community groups also provide the impetus and labour to rehabilitate parks, foreshores and streams and thereby improve the quality of life in their neighbourhoods, suburbs and rural areas.

4.3 Rural land use and catchment management

4.3.1 Rural catchment management

The only long-term and permanent solution to the problems of algal blooms in the Swan-Canning system is to reduce nutrient flow into the rivers. Although there is no possibility that the river can be returned to its pristine, pre-European settlement condition, it can be made into a healthier, and more resilient system.

Agricultural practices affect water quality mainly through fertiliser and pesticide application and soil loss from erosion. Another factor is that nutrients in grazed plants are mobilised from faeces of farm animals.

Significant areas of vegetation have been cleared from the catchment and along watercourses to support agriculture. This has contributed to poor water quality by increasing nutrient-enriched runoff.

In the rural catchments of the Swan-Canning system, fertilisers and manure are applied to significant areas of coarse sandy soils. Most of the applied nutrients quickly leach below the root zone. When this happens they may enter the shallow groundwater, which reaches surface water by lateral flows and eventually enters the Swan-Canning system. Excess fertiliser is also washed away by rainfall and surface runoff, and nutrients may be moved across waterlogged flats adjacent to streams and eventually enter the system.

There is little conventional broadacre cropping in the coastal rural catchments of the Swan-Canning system, but horticulture, turf farms, vine and tree crops and grazing enterprises are common. There are also intensive pig and poultry farms. Other major fertiliser users are golf course operators.

The runoff from agricultural activities is often intermittent and diffuse. As a result nutrient flow is difficult to monitor and control. Usually, though, nutrient runoff is high in initial stream flows at the onset of winter rains.

Options for managing the Ellen Brook catchment, which has the highest nutrient concentrations and contributes the greatest nutrient load to the Swan-Canning system, include: legislation to control all nutrient-generating and land-degrading enterprises; extending the use of slow-release fertilisers; restoration of watercourses; and, possibly the construction of artificial wetlands to strip nutrients before they enter natural watercourses. The fact that parts of Ellen Brook are developing rapidly makes this catchment conducive to the process of matching land-use to land suitability. Clearing controls, improved management of development sites to reduce erosion and incorporation of Water-Sensitive Design principles in new and existing developments would reduce nutrient losses. Some or all of these options can be included in a comprehensive Catchment Management Plan. Such plans require community, local and State government support to be successful. This is discussed in more detail in Section 5.1.2.

Water-Sensitive Design principles aim to:

- manage water balance;
- maintain or enhance water quality;
- encourage water conservation;
- prevent erosion caused by water;
- maintain water-related environmental values;
- maintain water-related recreational and cultural values.

A subset of Water-Sensitive Design is that which relates to better water management in the urban environment; this is referred to as Water-Sensitive Urban Design (WSUD).

Water-Sensitive Design may incorporate "treatment trains" using swales, "trash racks" (for litter entrapment), sediment traps, ponds and constructed wetlands in combination or in a linear sequence. It also incorporates these treatment trains in multiple-use corridors, which combine several water features with different purposes to achieve improved water quality and efficient irrigation and return water to the soil rather than drain it off site.

4

Actions needed

- *Institute direct catchment management aimed at dealing with the sources of degradation by means of a participative planning process which incorporates planning and development controls.*
- *Ensure Water-Sensitive Design principles are incorporated in catchment management guidelines for all new land development proposals and infill development, and for any new planning initiatives.*

4.3.2 Individual farming and part-time farming activities

Farming activities in the Swan Coastal Plain include cattle and horse grazing, intensive livestock enterprises, vegetable and fruit growing and viticulture. Many properties are also run as part-time or "hobby" farms rather than as commercial enterprises. Part-time farmers often have small land-holdings and differ radically in both experience and motivation from traditional farmers. They may not need to make a living off the land and often have a different approach and attitude to using it.

Farm activities can seriously affect the environment by denuding vegetation and accelerating erosion as a result of overstocking. Their impact can best be managed through town planning scheme controls on clearing, building locations and permitted land-uses, and through education of land-holders. Farming activities on a larger and more traditional scale, such as cattle grazing, can minimise their impact on the catchment and environment by adopting farm management plans that identify methods and set goals to reduce erosion, over-fertilising and vegetation clearing. Farm management plans can also guide revegetation activities (see Section 5.1.2).

Actions needed

- *Encourage development of farm management plans that ensure sustainable land-uses.*
- *Provide guidelines and Best Management Practices for part-time farm activities to reduce erosion and nutrient losses.*

4.3.3 Aquaculture

Overflow of nutrient-rich water from yabby and marron dams and fish ponds has the potential to affect river water quality. Accidental escapes of exotic fish can also occur. Current problems caused by aquaculturalists are minimal. Development and implementation of Best Management Practices would address and help eliminate future problems.

Action needed

- *Encourage development and adoption of Best Management Practices by aquaculturalists by facilitating their preparation and distribution.*

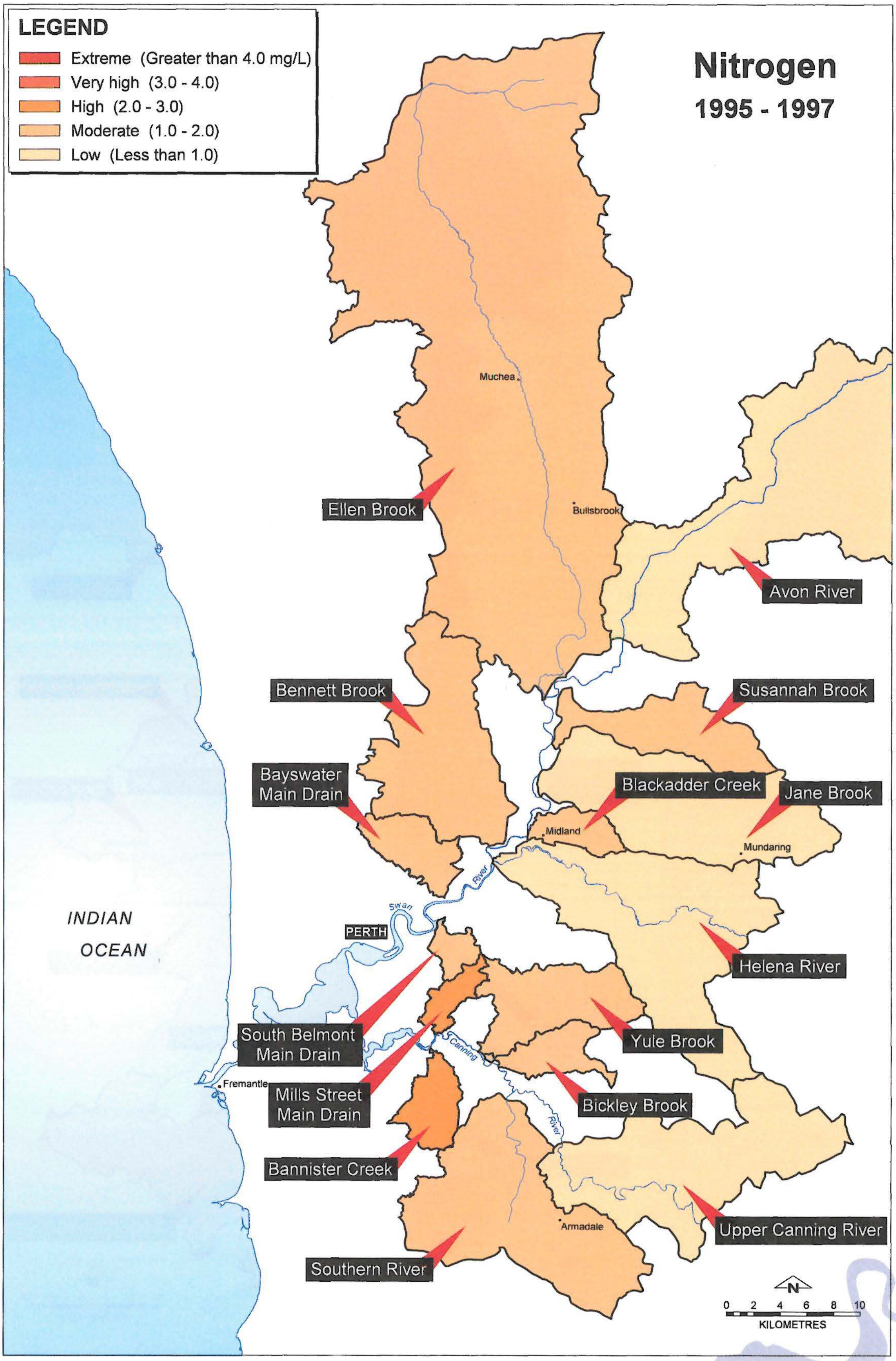


Figure 10: Classification of the sub-catchments of the Swan-Canning system based on total nitrogen concentrations between 1995 and 1997

Sub-catchments of the Swan-Canning system have been classified according to total nitrogen concentrations measured in their freshwater streams and drains between 1995 and 1997. Concentrations of total nitrogen are measured in milligrams per litre (mg/L) and median concentrations have been used to classify the sub-catchments. Algal blooms in the upper Swan are considered nitrogen "limited", not phosphorus limited, and thus the timing and availability of total nitrogen can trigger their onset.

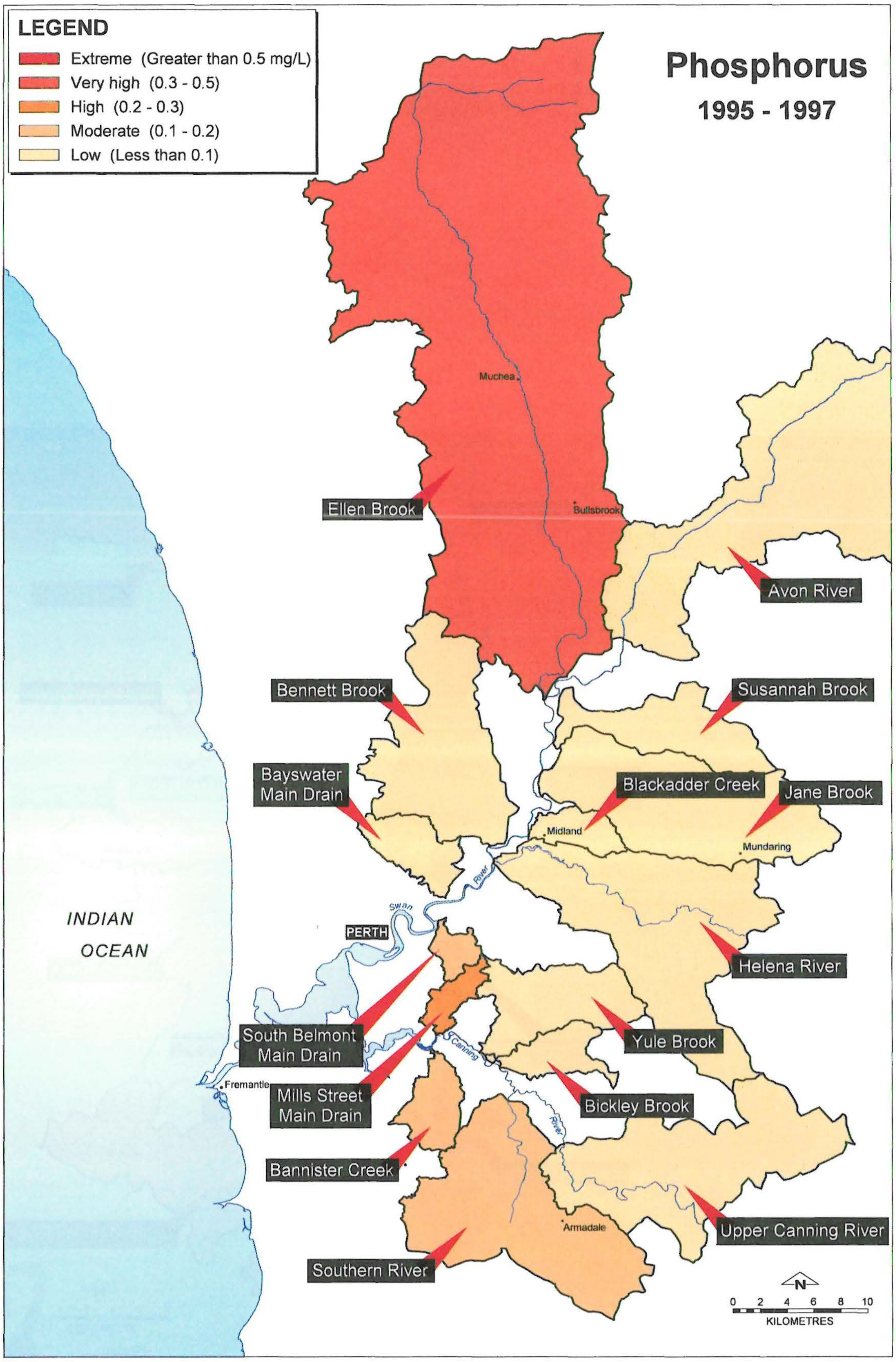


Figure 11: Classification of the sub-catchments of the Swan-Canning system based on total phosphorus concentrations between 1995 and 1997

Sub-catchments of the Swan-Canning system have been classified according to total phosphorus concentrations measured in their freshwater streams and drains between 1995 and 1997. Concentrations of total phosphorus are measured in milligrams per litre (mg/L) and median concentrations have been used to classify the sub-catchments. Although algal blooms in the upper Swan are considered nitrogen "limited", simultaneous reductions in both total nitrogen and total phosphorus are required to ensure better water quality.

4.3.4 Grazing enterprises

Most pastures in the Ellen Brook and Southern-Wungong River catchments are on former wetlands and are well known for being susceptible to fertiliser leaching during wet periods. Pastures are largely based on nitrogen-fixing clover, so nitrogen is rarely applied as fertiliser. However pasture plants on the sandy soils respond well to potassium and sulphur. In the past superphosphate, which contains sulphur as well as phosphorus, was widely applied. This stimulated plant growth but also resulted in excess phosphate, which entered surface runoff and groundwater.

Soil testing to accurately determine the nutrient needs of crops and the use of slow-release fertilisers would help to reduce fertiliser use in the Swan-Canning rural coastal areas. There is a need for a greater range of specific fertiliser products which cater to the unique nutrient requirements of the soils in the Swan Coastal Plain. The relatively small market may, however, make this economically difficult to achieve, and special liaison with the fertiliser industry is required.

Cattle, in particular, prefer areas close to streams because of lusher pasture, shade and easy access to water. Animal wastes contain nutrients and organic matter which may directly enter waterways, particularly if watercourses are unfenced and unvegetated. Cattle destroy the vegetation around unfenced streams by soil compaction and removal of herbage, and trample stream banks causing soil erosion. As a result soluble phosphate, nitrogen and soil particles are exported from grazing properties into the drainage system.

Fencing that restricts cattle and sheep access, and planting of trees and other vegetation as buffer zones around streams and along fence lines, would do much to reduce the damage done by grazing animals. The reservation of foreshores on all permanent watercourses for parkland in regional planning schemes should be one long-term objective.

Actions needed

- *Provide financial and technical support to encourage land-holders to fence watercourses to restrict livestock access and to rehabilitate damaged drains and watercourses.*
- *Provide land-holders with encouragement and support for using slow-release and nutrient-specific fertilisers where appropriate and for increasing their use of soil testing to determine the optimum timing and rate of fertiliser application.*

4.3.5 Intensive livestock enterprises

Feedlots, stockyards and intensive livestock enterprises such as piggeries, stables, poultry farms and dairies are frequently point sources of pollution. Animal wastes can flow directly or indirectly into surface waters. Although larger enterprises are licensed and controlled, not all animal effluent is adequately disposed of, and small enterprises are often unregulated.

Former livestock enterprises may remain a potential source of pollutants after operations have ceased, due to accumulation of nutrients in disused treatment ponds, paddocks or local groundwater.

Extension of the regulatory system (e.g. licensing) to enterprises not adequately covered and the development and more widespread adoption of Best Management Practices (BMPs) for handling livestock (e.g. sealed floors and drains, roofed sheds) and their effluent will help to reduce this problem. Local governments need to be capable of overseeing livestock operations.

Codes of Practice for dairies and piggeries are also necessary for better management, and are currently being prepared jointly by the Department of Environmental Protection, the Water and Rivers Commission and Agriculture Western Australia. They can be a legally enforceable code, halfway between a BMP and a regulation. Ultimately codes might be developed into regulations whereas BMPs would not. Codes would be more effective if adequate penalties are developed for non-compliance.

Actions needed

- *Develop, adopt and implement codes of practice and BMPs for housing animals and treating livestock effluent.*
- *Develop a system, similar to that for point sources, of regulating rural waste discharge where it directly or indirectly enters waterways.*

- *Regulate rural wastes that are not suitable for discharge to ensure that they are dealt with in an environmentally acceptable manner.*

4.3.6 Horticulture and tree crops

Fruit growing is established in the hills east of Perth and Lennard Brook catchments and grape growing in Swan Shire. Nutrient losses from vineyards and orchards are relatively minor due to the heavier clay soils and efficient application of fertilisers.

Market gardens, turf farms and nurseries have been heavy users of fertilisers and water. Where large amounts of poultry manure are applied, nutrient losses can be heavy.

Deep-rooted forage tree crops, such as tagasaste, have the potential to provide good grazing while lowering groundwater and reducing nutrient export. Nutrient and Irrigation Management Plans can be useful tools to manage both water use and nutrient export, particularly when incorporated into Best Management Practices.

Pesticide use is relatively heavy in orchards, market gardens and turf farms, and is a possible source of contamination of groundwater and runoff. Even when degraded, insecticides contribute phosphates and some fungicides contribute heavy metals to groundwater.

Integrated weed and pest management systems reduce the need to use herbicides and pesticides in orchards, vineyards and other intensive horticultural enterprises. Many of the features for managing horticulture and tree crops so that they do not pollute the environment are also being addressed in the development of a Code of Practice for horticulture by the same agencies that are considering dairies and piggeries.

Actions needed

- *Develop and implement Best Management Practices for irrigated horticulture (including market gardens) and turf farming.*
- *Encourage the wider adoption of Nutrient and Irrigation Management Plans and Integrated Pest Management in orchards, market gardens, turf farms and nurseries.*
- *Encourage the planting of perennials and forage trees on cleared sandy soils to stabilise erosion, lower watertables and provide summer fodder.*

4.3.7 Rural housing

Old septic tanks contribute to pollution from rural housing, particularly when situated in low-lying areas and close to waterways. Liquid wastes tend to rise to the surface and overflow into waterways following heavy rainfall and waterlogging. Current town planning scheme provisions and regulations preclude development in unsuitable areas and establish appropriate setbacks for approved developments.

Better planning will do much to eliminate this problem in future developments. Retrofitting and relocation of activities can be conditions for renewal permits under town planning controls and objectives for new town planning schemes.

Action needed

- *Review redevelopment of established rural housing areas to minimise nutrient sources.*

4.3.8 Fire management

Fires are necessary for the regeneration of many native plants, but they also help mobilise nutrients stored in plant matter and make land vulnerable to erosion when it is temporarily denuded. Nutrient uptake from soil is reduced due to plant death immediately after fires.

Excessive unnatural fire regimes exacerbate environmental impacts, including increased weed growth.

Changes in the fire regime following clearing for agriculture or forest management affect the amount and timing of nutrient exports. Frequent fires damage the vegetation buffer around streams and encourage the growth of weedy plant species with higher fire resistance.

Actions needed

- *Include management of potential loss of soil, nutrients, weeds and plant diversity in Bush Fires Board and local government fire management plans.*
- *Develop methods of fuel reduction in foreshore areas to minimise fire risk and nutrient loss.*

4.3.9 Loss of native vegetation

Clearing of native vegetation has been a major contributor to poor water quality, and the issue needs to be directly confronted and managed. Clearing increases runoff and decreases evapotranspiration. Dead and burnt native vegetation decomposes, mobilising nutrients previously locked in plant biomass. In addition to reducing biodiversity and flora and fauna habitats, clearing leads to raised watertables, salinisation and increased export of nutrients from catchments. Soil is lost from cleared land about four times as fast as from areas of native vegetation. Native vegetation is also regarded as one of the lowest nutrient loss "land-uses".

Clearing restrictions and remnant vegetation protection schemes administered by the Commissioner for Soil and Land Conservation have reduced wholesale clearing in agricultural areas. Extension of these clearing restrictions to smaller parcels of land (< 1 ha) might be a useful management tool in coastal areas.

Some local governments (e.g. Kalamunda) have identified important areas of native vegetation within their shires and are implementing measures to protect them on both public and private land. Such schemes also assist local governments in meeting their environmental requirements under *Local Agenda 21*, a program to improve sustainable practices and policies of local government. Natural Heritage Trust Bushcare initiatives, particularly those being coordinated by CALM and Greening Australia, are also addressing loss of native vegetation, which will result in benefits to the catchment.

Extensively cleared paddock in the Swan Coastal Plain

A Memorandum of Understanding for the Protection of Remnant Vegetation on Private Land in the Agricultural Region of Western Australia (1997) has been jointly developed and endorsed by the Department of Environmental Protection, the Environmental Protection Authority, the Commissioner for Soil and Land Conservation, Agriculture Western Australia, the Department of Conservation and Land Management and the Water and Rivers Commission. This memorandum provides a basis on which to address clearing on both a small and large scale in rural areas of the Swan-Canning system.

There is also a need to revegetate and restore natural functions originally provided by bushland in coastal catchments that have already been cleared. Strategic replanting along fencelines and streamlines, vegetated buffer areas, windbreaks and revegetated foreshores and floodplains would help reverse this loss.

Planning controls that encourage development on existing cleared land, instead of clearing remnant vegetation such as banksia woodlands on sandy soils, should also be instituted. Such controls would be very important in the Ellen Brook catchment, with its history of large nutrient exports to the Swan River. The use of planning controls is discussed later in this document.

Action needed

- *Improve existing clearing controls on small parcels of land in semi-rural areas.*
- *Implement the Perth Bush Plan and explore options to develop Memorandums of Understanding with relevant government agencies to regulate clearing controls on parcels of land less than one hectare in semi-rural and rural areas.*

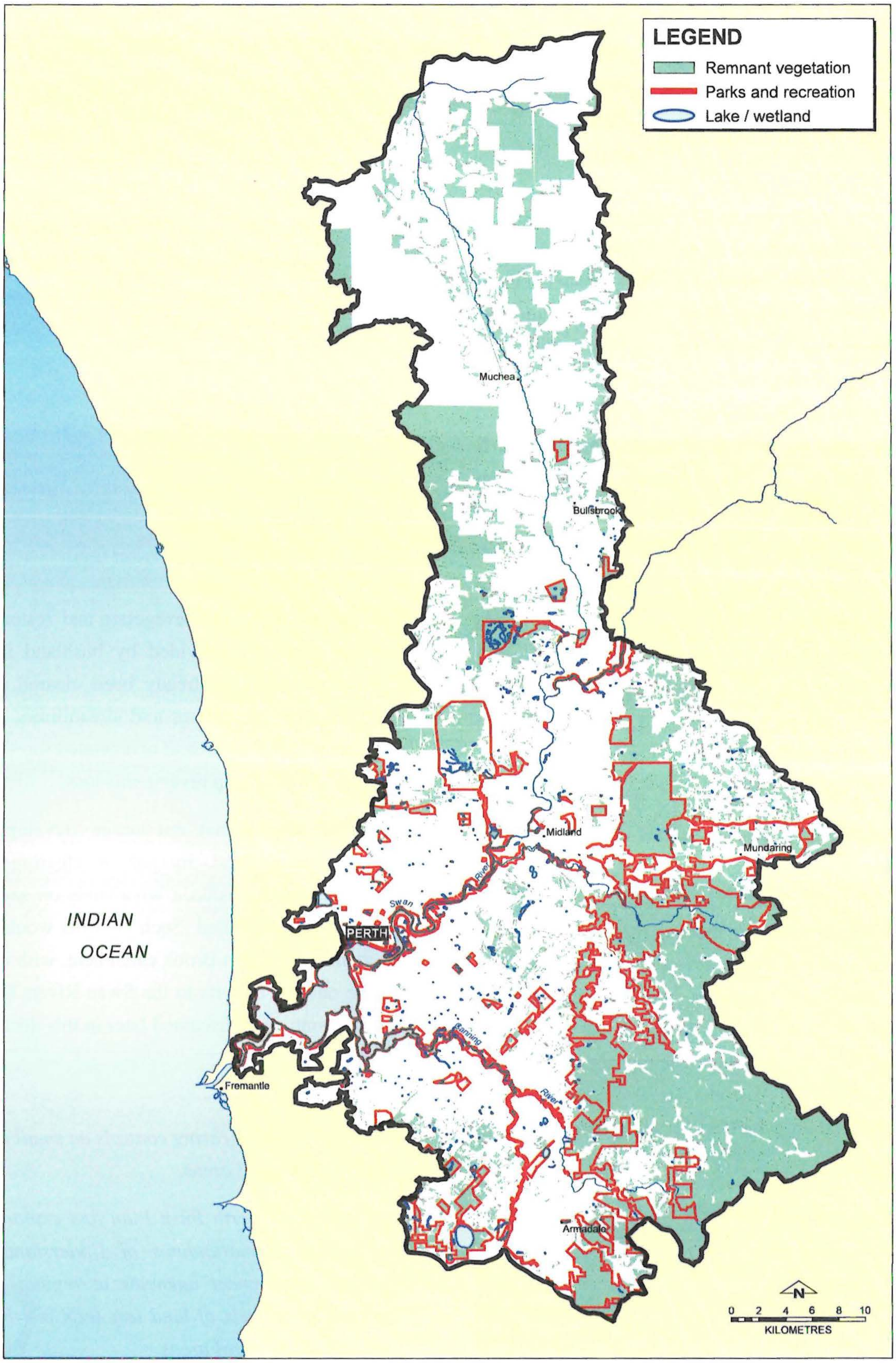


Figure 12: Parks, recreation areas and remnant vegetation of the Swan-Canning system

Large parks and recreation areas in the Swan-Canning system often require irrigation and the use of fertilisers. In those situations Water-Sensitive Management is required, including nutrient and irrigation management plans. The overlap between remnant vegetation and current parks and recreation areas indicates considerable potential to create plant and animal corridors linking parks and large reserves by providing adequate foreshore vegetation areas. Many of the remnant vegetation areas contain regionally significant vegetation types, and a better process for managing the clearing of these areas and protection of watercourses is required. Data courtesy Ministry for Planning, 1998, and Agriculture Western Australia, 1998.

4.3.10 Salinity

More than 70 per cent of Australia's dry-land salt-affected area occurs in Western Australia, and much of this land is found in the Swan-Avon catchment inland of the Swan coastal scarp. Salinity developed following widespread clearing of deep-rooted native vegetation and its replacement with annual crops and pastures. The watertable has risen as a result, bringing with it salt stored in the deeper soil. Eventually the saline groundwater reaches the soil surface, affecting agricultural productivity, existing native vegetation, biological diversity and the environmental health of wetlands and rivers. It has the serious potential to impact surface drinking water supplies; it also affects soil structure and damages buildings and roads.

In general, the sandy, well-drained soils of the Swan Coastal Plain, which receive relatively high rainfall, are less likely to become saline than others found inland of the scarp. Nevertheless, there are a few areas within the coastal plain catchments draining into the Swan-Canning system where salinisation is increasing and will need preventive management to reduce any long-term threats (e.g. north of Muchea). It is also recognised that some of the scarp-hill catchments are becoming salty (e.g. Brockman).

The State Government Salinity Action Plan (1996) is addressing this issue. The plan advocates strategic replanting and revegetation on the coastal plain to increase water usage in line with Catchment Management Plans. This would control rising watertables, particularly along lower elevation watercourses where salinisation is likely to occur. The Salinity Action Plan is dealing with this matter.

4.3.11 Soil erosion

Erosion leads to loss of soil nutrients and organic matter. Eroded soil contributes to river turbidity and sedimentation, and nutrients and pesticides bound with soil particles are carried into the river systems. Minimising soil erosion is a key strategy for reducing both nutrient and organic loads.

There is a clear need to study and manage the sources and causes of soil erosion and to make accurate estimates of the bound nutrient load entering the Swan-Canning system.

Most of the nutrients reaching the system from the Avon are believed to be bound to soil particles. Phosphate bound with soil or organic matter contributes to the pool of phosphate in river sediments. Continual input of soil-bound phosphate can contribute to raised levels of phosphate-in-solution in the river.

Improvements to catchment management and land care will help to reduce erosion. Foreshore Management Plans can identify and define the extent of erosion along areas of foreshore and provide strategies for minimising the damage.

Actions needed

- *Target catchment management and land care practices in the rural areas of the catchment to minimise erosion in the catchment and on the foreshores.*
- *Incorporate into catchment management and farm plans Foreshore Management Plans to control and manage erosion.*
- *Undertake research to identify the sources and causes of soil erosion in the catchment.*

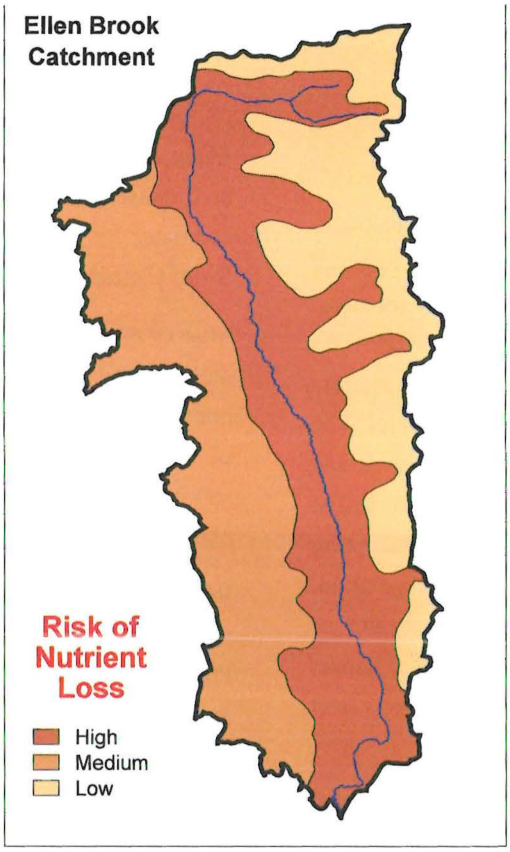
4.3.12 Nutrient and fertiliser management

Application of fertilisers can increase nutrient loads in streams, drains and rivers under certain conditions.

In reasonably flat catchments such as Ellen Brook, heavy rainfall may result in sheet-flow of water. This occurs when the surface soil becomes saturated with water, leading to runoff carrying particles of fertiliser and organic matter directly into streams.

In sandy soils, leaching of fertilisers and manures increases concentrations of nutrients in the groundwater, which often reaches nearby watercourses.

Rapid nutrient mobilisation is difficult to manage.



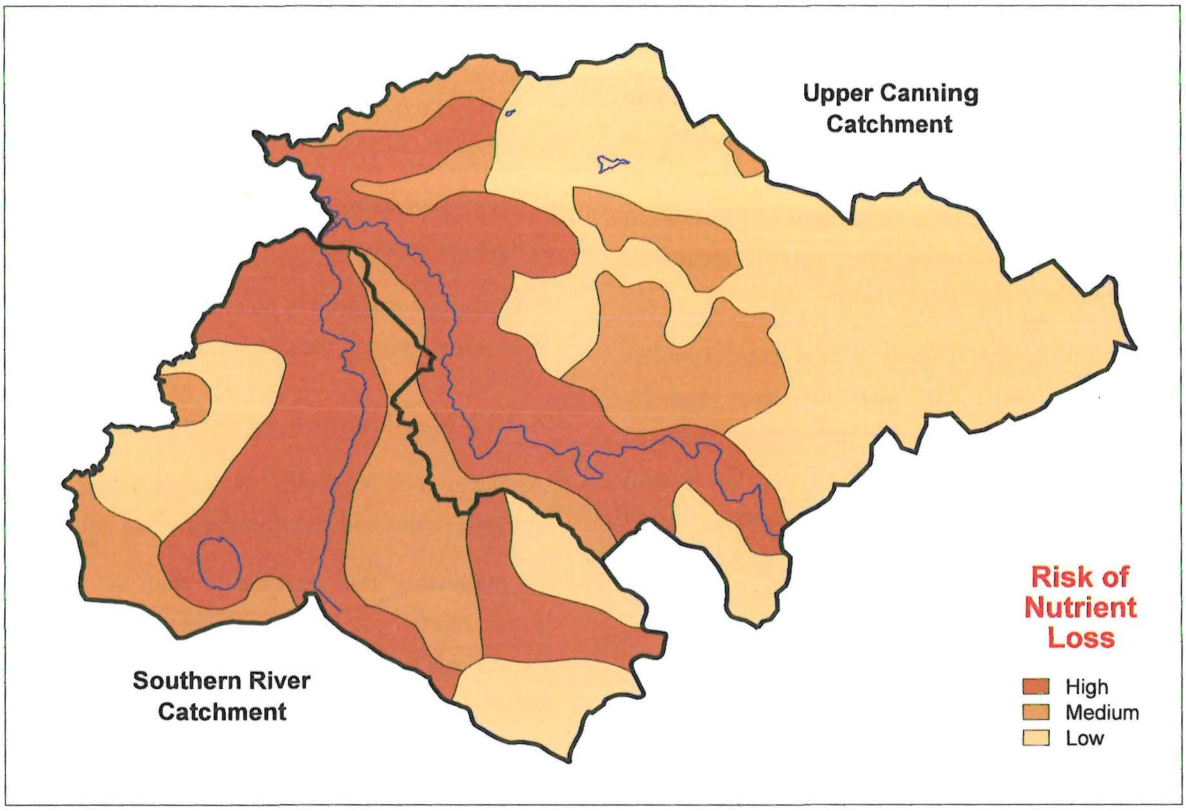


Figure 13: Land susceptible to nutrient loss and erosion due to current land-use practices in Ellen Brook and Southern-Wungong - Canning catchments.

The risk categories outlined in these maps indicate the general areas requiring caution and nutrient and erosion management due to current land practices and extent of hardstand surfaces associated with urbanisation and development.

Implementation of water management and conservation techniques on site, improved fertiliser regimes and stream restoration would partly rectify the problem. Establishing setbacks beyond or within which no fertilisers are applied, and vegetated buffer areas which break up and reduce the severity of sheet flows, are also critical tools in managing this problem.

Nutrient reduction depends on good farm management.

Actions needed

- *Provide guidelines for best practice fertiliser use through local government, manufacturers and retailers.*
- *Encourage all land-users to adopt Best Management Practices in fertiliser use.*
- *Include in Farm and Catchment Management Plans land management practices to reduce nutrient loss.*

4.3.13 Drainage in rural areas

It has been estimated that there are well over 500 kilometres of privately owned large drains on the rural catchments of the Swan-Canning system. In contrast, the estimate for publicly owned rural drains is less than 100 kilometres. Many natural streams have been modified for drainage purposes to direct water away from flood-prone land used for agriculture and townships.

On a smaller scale, drains protect homesteads and paddocks from flooding and improve production by maintaining desirable flooding regimes for plant growth. Drains can be designed to increase grass production by extending growth further into summer.

Unfortunately, many small drains collect fertilisers and sediments, especially when the first winter rains occur or following major rainfall events. These nutrient-enriched and sediment-laden waters enter the larger arterial rural drains that flow into the tributaries of the Swan-Canning system, affecting its water quality.

Large drains should be redesigned to slow down water flows and allow vegetation to become established to take up nutrients. Restricting access of livestock and maintaining buffers and setbacks can reduce the likelihood of nutrients entering drains that eventually flow downstream, and also help to reduce erosion. In many cases, stream restoration can return natural functions to larger drains and still provide flood control.

Actions needed

- *Rehabilitate drains and streams to reduce the nutrient and sediment loads carried into the Swan-Canning system.*
- *Incorporate stream and drain restoration provisions in catchment management and farm plans, and where appropriate, in town planning schemes.*

4.3.14 River and stream management

River and stream management includes flow management, foreshore management and maintenance of banks, beds and ecological functions.

Stream restoration consists of the rehabilitation and establishment of vegetation on drainage lines, restriction of stock access and establishing buffers and setbacks from drains to reduce nutrient and sediment loads. It also includes restoration of natural meanders (bends and turns) in the watercourse as well as employing natural and soft engineering solutions like placing rocks or woody debris to create riffle and pool sequences. Where possible flood conveyance should be accounted for within a "stream corridor" rather than in a trapezoidal drain without natural features and functions. The best streams are living streams.

Dams and weirs in the Canning and Helena catchments (e.g. Mundaring Weir) reduce flooding and downstream flushing in winter. They diminish the cleansing and scouring effects of flowing water in some streams, and modify variations in river flows. This may result in increased retention of nutrient-rich sediments in the river system, predisposing it to poor water quality.

Minimum flow requirements for the Canning and Southern-Wungong rivers are based primarily on those required to maintain "riparian" and irrigation rights. Monitoring is now being undertaken to determine minimal flows to maintain environmental health. Increased water movement may reduce the likelihood and intensity of algal and cyanobacterial blooms, particularly blue-greens in the Canning River. The Council of Australian Governments has identified the need to establish minimum environmental flow requirements for regulated river systems.

Provision of environmental flows or manipulation of weirs is one option to improve water quality and to help reduce the frequency of algal blooms. This comes at a cost, however. Alternative water resources would need to be developed or water-saving practices and technologies adopted.

It is also necessary to improve the health and extent of foreshores that buffer sediment losses due to erosion and help reduce nutrient inputs from the surrounding land. River flows and foreshore management are intimately linked. Foreshore Management Plans can be used on both private and public foreshores to manage stream foreshores and floodplains so that a number of uses can be sustained without damaging the ecological integrity. Foreshore Management Plans are a critical tool for balancing multiple rural uses.

4

Actions needed

- *Establish environmental flow requirements for all the impounded rivers in the Swan-Canning system.*
- *Provide economic incentives and support to encourage land-holders to manage, protect and rehabilitate foreshores to enhance natural functions.*

4.3.15 Natural and constructed wetlands in rural areas

Natural wetlands can contribute significantly to the cleanup of the Swan-Canning system. As well as providing valuable habitat for wildlife and sources of forage for livestock in droughts and during late summer and autumn, wetlands fulfil the natural function of filtering and processing nutrients and stabilising hydrology, particularly shallow groundwater levels. A natural chain of wetlands slows down and filters water flows before they enter defined watercourses.

Wetlands receive nutrient and sediment runoff from rural activities and are often cleared or overgrazed, thus reducing their natural functions.

Protection of natural wetlands in the State is now guided by the Wetlands Conservation Policy (1997). Permanent lakes are protected by the Swan Coastal Plain Lakes Environmental Protection Policy (1992), and those wetlands placed on a register in the Southwest Agricultural Zone Wetlands Environmental Protection Policy (EPP) 1997 are protected by it.

Constructed wetlands can augment or help to replace former natural wetlands and play a critical role in filtering nutrients from contaminated drains and waterways. For example, the downstream end of Ellen Brook would be an excellent location to filter and process nutrients before water enters the Swan River. The trialing of river intervention and agroforestry woodlot techniques could also be carried out in constructed wetlands.

There are few constructed wetlands in rural areas at present. Those that exist include manure lagoons and large aeration and holding ponds with some fringing vegetation. They are used in intensive agricultural enterprises to receive the effluent from dairies, piggeries and other animal-intensive activities.

Proper planning and design of constructed wetlands must take into account the size necessary to handle the amount and timing of water they will receive. It is vital to establish clear targets and to monitor wetlands that are being used to reduce nutrients.

Conserving and managing natural wetlands and establishing functional constructed wetlands are important aspects of farm and catchment management planning and essential components of Water-Sensitive Design.

Actions needed

- *Incorporate natural and constructed wetlands in catchment and farm plans where appropriate.*
- *Investigate use of constructed wetlands to improve water quality in tributary streams.*
- *Provide economic incentives and support to encourage land-holders to protect and rehabilitate natural wetlands.*

- *Protect and enhance natural wetlands and constructed wetlands through statutory planning.*
- *Construct and test the use of a constructed wetland of up to 100 hectares in the Ellen Brook catchment.*
- *Trial sediment remediation and oxygenation techniques in wetlands (see Section 4.5).*
- *Trial the use of floodplain agroforestry woodlots to help restore floodplain function and foreshore vegetation and to help cleanse nutrient- and sediment-laden floodwaters to supplement the use of downstream constructed wetlands.*

4.4 Urban land use and catchment management

4.4.1 Urban issues

Most major sources of pollutants from residential, commercial and industrial areas have now been removed or controlled.

Smaller, often diffuse, nutrient and other contaminant sources remain. They are difficult to manage. They can be better managed by encouraging changes to urban landscaping and more efficient water and fertiliser use, and by designing and maintaining urban areas, commercial and public properties and houses on Water-Sensitive Urban Design principles. The business community can improve the way it stores goods and cleans commercial premises. Ultimately the residents of the metropolitan area need to change their land-use practices.

The management of diffuse nutrient and pollution sources has received some statutory support through the licensing of light industrial grease traps by the Department of Environmental Protection. The Swan River Trust-SCCP, the Water and Rivers Commission and some local governments have conducted a preliminary survey of light industrial premises to determine levels of awareness, washdown and drainage practices and emergency cleanup procedures in the metropolitan area. When finished, the survey will also recommend steps that can be taken to improve practices and reduce water pollution. Planning authorities are implementing model town planning scheme amendments that situate light industrial premises in more appropriate areas and control practices so that there is a reduction in their potential to pollute.
The dissemination of practical information and guidelines for residential occupants, industry and commerce is being supported by government and industry groups, but it needs to be done more effectively.

Actions needed

- *Incorporate and enforce Water-Sensitive Urban Design principles in all new urban developments.*
- *Support and provide public information and guidelines to residents, industry associations and commercial users on Water-Sensitive Urban Design and best practices.*

4.4.2 Pollution from residential areas

Nutrient runoff from urban areas increases in proportion to the area of impervious surfaces such as roads and roofs. This pollution comes from vehicles, domestic animals, atmospheric fallout, garden fertiliser runoff and accidental spills from materials stored in sheds and garages. These sources are difficult both to pinpoint and to control. Some research in fertiliser runoff suggests there is an optimum lot size that balances roof and hardstand areas with yard areas such that there is minimal nutrient export. This is because smaller gardens often require less fertiliser application and are able to efficiently absorb water runoff from hardstand areas and so prevent flow off the property. Local government street sweeping has also been found to be effective in reducing nutrient inputs particularly for particulates and sediment associated contaminants. Street sweeping removes nutrients and contaminants before they enter urban drainage systems.

Recent studies have suggested that the main sources are:

- domestic pet faeces (mainly from dogs), which contributes up to 10 per cent of nitrogen and phosphorus inputs to urban drains;

4

- lawn fertiliser and excessive watering;
- nutrient-rich groundwater from septic tank leaching.

This pollution is transferred to the Swan-Canning system through groundwater and urban drains that discharge as point sources.

Constructing detention basins, vegetated swales and artificial wetlands for nutrient-stripping is an important component of Integrated Drainage Management. Better stormwater drain design and treatment trains for runoff are integral to alleviating this problem.

At present most advice on use of garden fertilisers is provided by manufacturers and retailers. Householders need impartial advice on the correct amounts of water and nutrients required to maintain attractive lawns and gardens. Use of water on domestic lawns is already being addressed by the Water Corporation; however, interaction between fertiliser leaching and water application rates needs to be studied further and information made available to guide domestic and local government activities. Guidelines to minimise nutrient leaching from lawns, native and exotic ornamental plants, and vegetables are not readily available to householders.

Actions needed

- *Incorporate Water-Sensitive Urban Design principles in the design of stormwater and other drainage systems.*
- *Provide impartial advice, information and support to householders to minimise nutrient use and loss and to conserve water through initiatives like the Waterwise program.*

4.4.3 Pollution from commercial areas

Commercial premises include retail establishments, car yards, nurseries, medical and business offices, churches, government offices and museums. They differ from light industry in their requirements for transport, public access and paved areas rather than the industrial processes that are undertaken.

Most commercial properties have hardstand surfaces which generate surface drainage directly to watercourses. Activities such as fresh food retailing and vehicle repair generate nutrients, organic matter, heavy metals and other contaminants which cumulatively impact on water quality. Many premises experience accidental spillages. During washdown procedures water runoff mobilises nutrients and contaminants, which then enter waterways. Where commercial areas are built on environmentally sensitive lands, special controls should be imposed on practices and planning.

Polluting runoff can be managed by better design of operations yards and parking lots, by constructing filter beds and trash racks, by applying Best Management Practices and by instituting planning procedures that incorporate Water-Sensitive Urban Design. Approval for and control of such premises is best managed through the provision of adequate clauses in town planning schemes.

Actions needed

- *Require, where applicable, that all commercial premises have contingency plans to contain spillages and utilise best practices for washdown procedures and pollution trapping.*
- *Incorporate Water-Sensitive Urban Design principles in new commercial areas.*
- *Retrofit existing commercial areas to take account of Water-Sensitive Urban Design principles.*
- *Establish accreditation procedures to identify and demonstrate environmental responsibilities of commercial and industrial premises and companies.*

4.4.4 Pollution from industrial areas

Point sources of pollution in urban and industrial areas include former landfills, especially those adjacent to the Swan-Canning river system, trade and industrial sites, stockyards, boat-slipping facilities, sewage spills from pump station overflows and metropolitan drains containing pollutants. These are all technically easy to identify but are often hard to manage if found to be polluting. Sewage spills are relatively rare in the Perth Metropolitan Area and usually have very limited short-term impacts.

Light industry and non-prescribed premises include a wide variety of typically small businesses and shops including motor vehicle repairers, panel and paint shops, printers, food processors, service stations and radiator repairers. These industries are generally not regulated by the Department of Environmental Protection and, as small businesses, also often lack the resources and skills to develop appropriate environmental management systems. The DEP licenses and registers premises that produce more than 205 litres a year of grease, petrol and oil and ensures that these wastes are delivered to proper waste-processing facilities. Facilities producing less than this are not regulated and can cumulatively contribute significant quantities of nutrients and other contaminants to waterways. Large and heavy industrial premises, if they produce pollution, are licensed and managed by the DEP.

More than 500 light industrial premises have been surveyed to determine what current practices are in place for washdown, surface runoff and waste disposal, and to assess emergency plans to deal with chemical spills. The survey also assessed the potential of current practices to pollute, the hazards they pose to waterways, and the overall environmental risks involved.

Light industries may be point sources of pollutants such as nutrients, hydrocarbons, solvents and organic and inorganic chemicals entering the Swan-Canning system. Typical pollutant loads from industrial and commercial land-use areas include higher levels of phosphorus, nitrogen, oxygen-demanding material, nitrate, zinc and cadmium than those from residential zones. An inventory of chemicals used by light industries is currently being developed by the Swan River Trust. The record of pollution incidents from the Swan River Trust and local government over the past few years demonstrates the inadequacy of current management practices (highlighted by the 1997 Belmont fish kill, brought about by accidental release of pesticides).

Management practices that can determine the level of risk that a premises poses as a source of pollutants to surface- and groundwater resources may be summarised as follows:

- emergency management practices in response to such events as accidental spills;
- illicit practices or poor housekeeping, resulting in discharge to surface or groundwater;
- storage practices, i.e. where there is no bunding of chemical storage areas;
- waste management, i.e. the extent to which there is waste contamination of runoff;
- stormwater management, i.e. the extent to which there is contamination of runoff and groundwater.

Depending on how satisfactory practices in these areas are, water pollution risk is revised downwards or increased according to the type and quantity of chemicals and their proximity to the river or wetland.

Expanded identification and monitoring of pollutant sources are required to manage and eliminate the sources within a strict time frame. All point sources need to be assessed, licensed and regulated for effective management.

The development and gazetting of a light industry Environmental Protection Policy under the *Environmental Protection Act* 1986 by the Environmental Protection Authority may be a strategic way of providing for control and management of pollution generated by light industry.

Local governments, under delegated authority and through guidance and support given by the Water and Rivers Commission, the Swan River Trust, the Department of Environmental Protection and the Water Corporation, should take more responsibility for promoting pollution prevention in light industrial premises by encouraging the use of Best Management Practices methodology, by auditing and by education.

Local governments should be allowed to recover the cost of overseeing and controlling light industry according to the principle of polluter pays (i.e. the proponent should be encouraged to develop appropriate management practices with information from local governments).

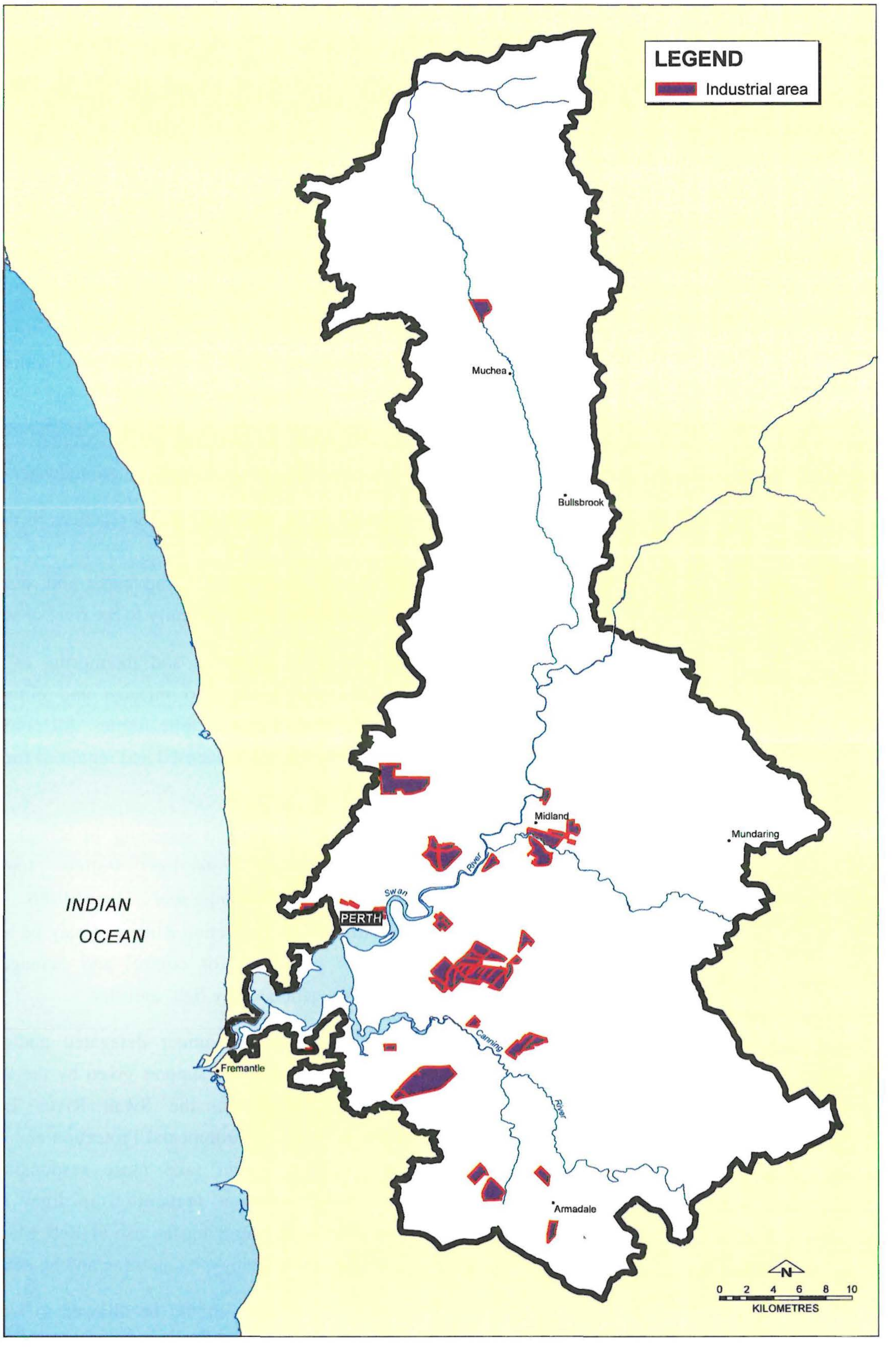


Figure 14: Industrial areas of the Swan-Canning system

The industrial precincts outlined indicate areas where heavy and light industrial practices occur and where nutrients and pollution can enter watercourses, including drains, and eventually the Swan-Canning system. Data courtesy Ministry for Planning, 1998.

The skills of local government staff and industry personnel could be improved through training in waste management and industry processes and in cost-effective solutions for on-site pollution prevention and spill cleanup.

Training should cover light industry auditing and methodology to standardise risk assessment and follow-up. It may be possible to have an accreditation of "good housekeeping" as part of the training courses. Some of this work could be done with the assistance of the Chamber of Commerce and Industry.

Actions needed

- *Develop and implement a strategy to prevent and reduce pollution from light industrial premises, including consideration of an Environmental Protection Policy to provide for better coordination between State and local government.*
- *Implement and extend the preliminary survey of light industry to all local governments and establish an ongoing management strategy.*

4.4.5 Waste disposal sites

Leachate from waste disposal sites can be an important source of nutrients and other contaminants. Many of the newer disposal sites within easy reach of metropolitan local governments have disposal pits which are lined to prevent leaching and other features to minimise impacts on the environment. Cradle-to-grave recycling and regional coordination, consolidation and management of solid waste disposal sites help to reduce environmental pollution from current and future waste disposal sites.

Older waste disposal sites, including landfills and rubbish tips, particularly those older than 10 to 15 years, pose a greater potential environmental threat than newer facilities. Many of these older sites were located on sandy or riverine soils, which have little ability to retain pollutants or prevent nutrients leaching into the groundwater. If left undisturbed they may pose little environmental threat. Over time their putrescible wastes will have been decomposed by bacteria, many nutrients and other contaminants will have leached away and those remaining are probably now bound to soil. However, new development on these sites may mobilise nutrients or in some other way create a new set of environmental and health risks.

The risks that older waste and landfill sites pose is often related to the flow of groundwater through them. Former waste disposal sites bordering the rivers should be monitored with bores to determine the potential or actual threat of contaminants, including nutrients, leaching directly into the rivers or via groundwater. Management plans should then be developed to intercept and manage all identified leachate sources before pollutants enter the river.

An inventory of these sites, based on current information, should be carried out and the data supplied to the National Land and Water Audit and National Pollutant Inventory programs.

Action needed

- *Evaluate the potential of old waste disposal sites close to the Swan-Canning system's waterways to contribute nutrients and other contaminants to the system by leaching.*

4.4.6 Drainage in urban areas

Drains are essential for creating a suitable environment for housing and for commercial and industrial activities. It has been estimated that 200-300 kilometres of mainly urban drains are managed by the Water Corporation and that over 2500 kilometres of surface and subsurface drains are under metropolitan local government control.

Most drains manage normal surface water runoff events (including storm events of up to 1-in-10-year intensity) and help manage some flooding. They capture runoff and redirect it to lakes, ponds and watercourses. At the same time they collect and concentrate pollutants, in some cases effectively converting non-point sources into point sources as they discharge into large water resources. Many older drains also intercept and drain high watertables and can flow all year round, continuously transporting nutrients and contaminants into the watercourses of the Swan-Canning system.

Many old drains were designed before our current understanding of Water-Sensitive Design principles. These principles are easier to incorporate in the development of new stormwater systems than in existing ones, but retrofitting may be justified where an existing stormwater discharge is adversely affecting the receiving water body.

Many stormwater drains discharge into compensation basins and detention ponds to allow temporary storage of runoff and reduce the need for large-capacity storm drains. Some of these could be redesigned and expanded to allow sediment to settle and vegetation to grow, take up nutrients and immobilise them as plant biomass. Denitrification and other nutrient processes may also occur under some soil conditions in drainage systems.

Stormwater drains could be redesigned to increase aeration and therefore the rate of nitrification and organic matter degradation. Other simple structural measures that should be investigated to reduce the impact of nutrient-rich runoff water on the river system are trash racks, splash boards, grassed swales, first-flush detention systems, wetland settling areas, riparian buffers and any other measures that can filter and slow down runoff.

The Middle Canning Catchment Study has demonstrated Water-Sensitive Urban Design principles and the improved environmental consequences of stormwater drainage systems that incorporate these principles. The information from lessons learnt in such studies needs to be communicated to local government.

A review of local government drainage systems is required to identify the need for treatment trains and their construction. It is also essential that local government drains be mapped to complement the map of Water Corporation drains so that they can be managed to meet the objectives and goals of this plan as well as to improve emergency responses to accidental spills.

Actions needed

- *Develop and implement Water-Sensitive Design principles for urban drains to reduce nutrients and contamination where levels are highest (see Table 7).*
- *Map local government drains to identify those that most urgently require management.*
- *Investigate licensing of main drains as a means of controlling nutrient concentrations entering Swan-Canning watercourses.*
- *Trial and install structures including trash racks to trap rubbish before it enters drains.*

4.4.6.1 Retrofitting and maintenance of existing drainage systems

Nutrients deposited in drains and compensation basins are often taken up and immobilised by vegetation and sediment. If they are to deal with runoff following storms, drains must be maintained so that they are free-flowing. However, removal of vegetation and sediment from drains and compensation basins may remobilise nutrients that were unavailable for biological activity when they were undisturbed. Residue from herbicides may also enter the system through drain cleaning.

The existing drainage system (see Figure 16) was designed without our present knowledge of river ecology and when there was much less public concern for river health. Redesign and replacement of outdated systems is one option that would reduce the risk of pollutants reaching the river.

Retrofitting systems now, without regard to age, may be an expensive option. However, as sections of the drainage system reach the end of their practical life or require major maintenance, retrofitted systems should be designed on Water-Sensitive Design principles. For example, structural measures discussed above could be applied to existing drains. Importantly, trash racks and sediment-stilling structures may be added to older drains without a large increase in costs or resources.

Drainage management plans that address these issues need to be in place for all drainage areas, particularly for drains identified as being the worst in terms of having high nutrient concentrations or in transporting pollution.

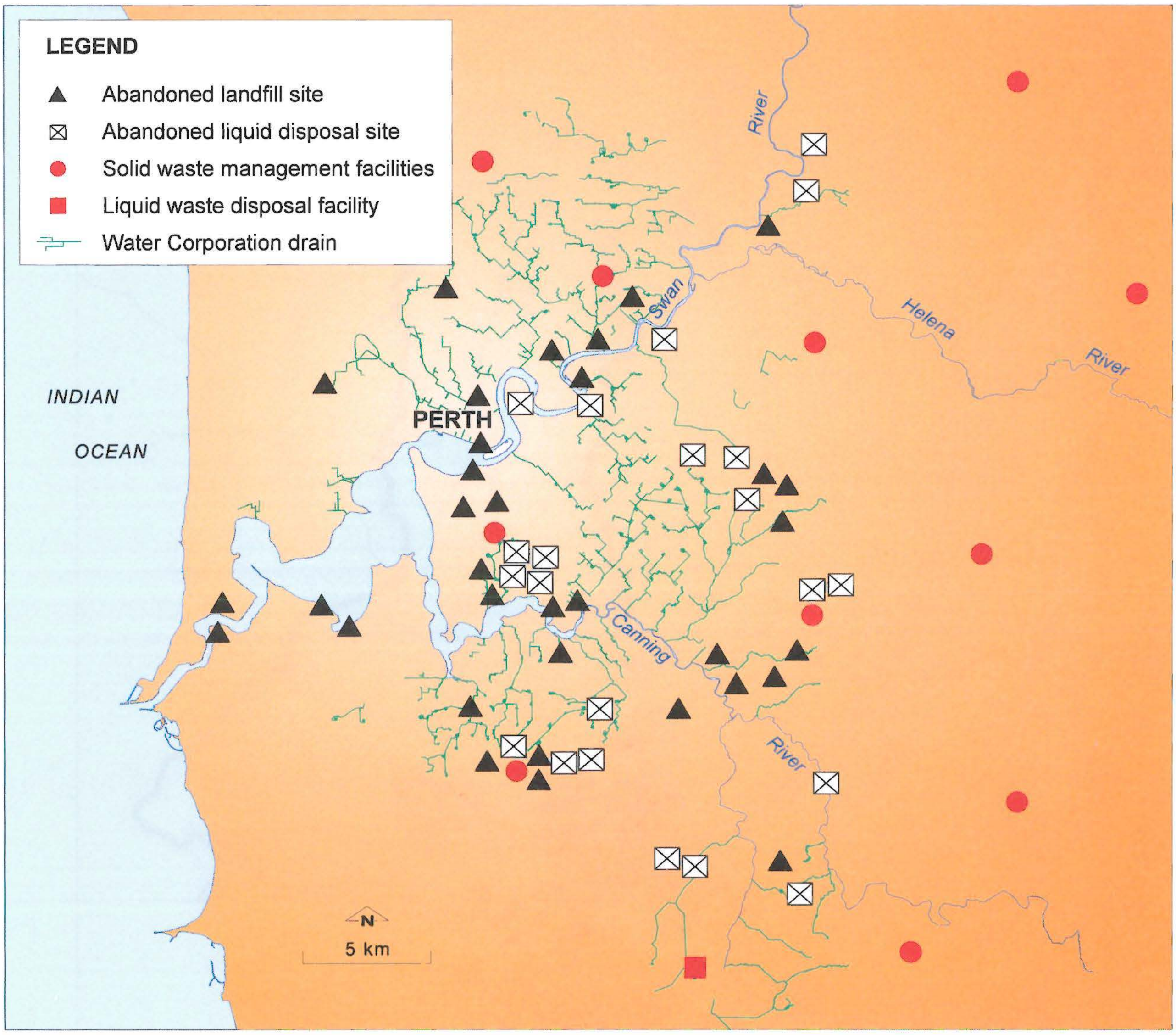


Figure 15: Landfill waste disposal sites

Many abandoned landfill and liquid waste disposal sites lie close to existing Water Corporation drains. Note the large number adjacent to the Swan-Canning system foreshores. Many of the sites need to be assessed to determine their pollution potential and their present effects on the nearby waterways. Data courtesy Department of Environmental Protection, 1999 and Herschberg (1989).

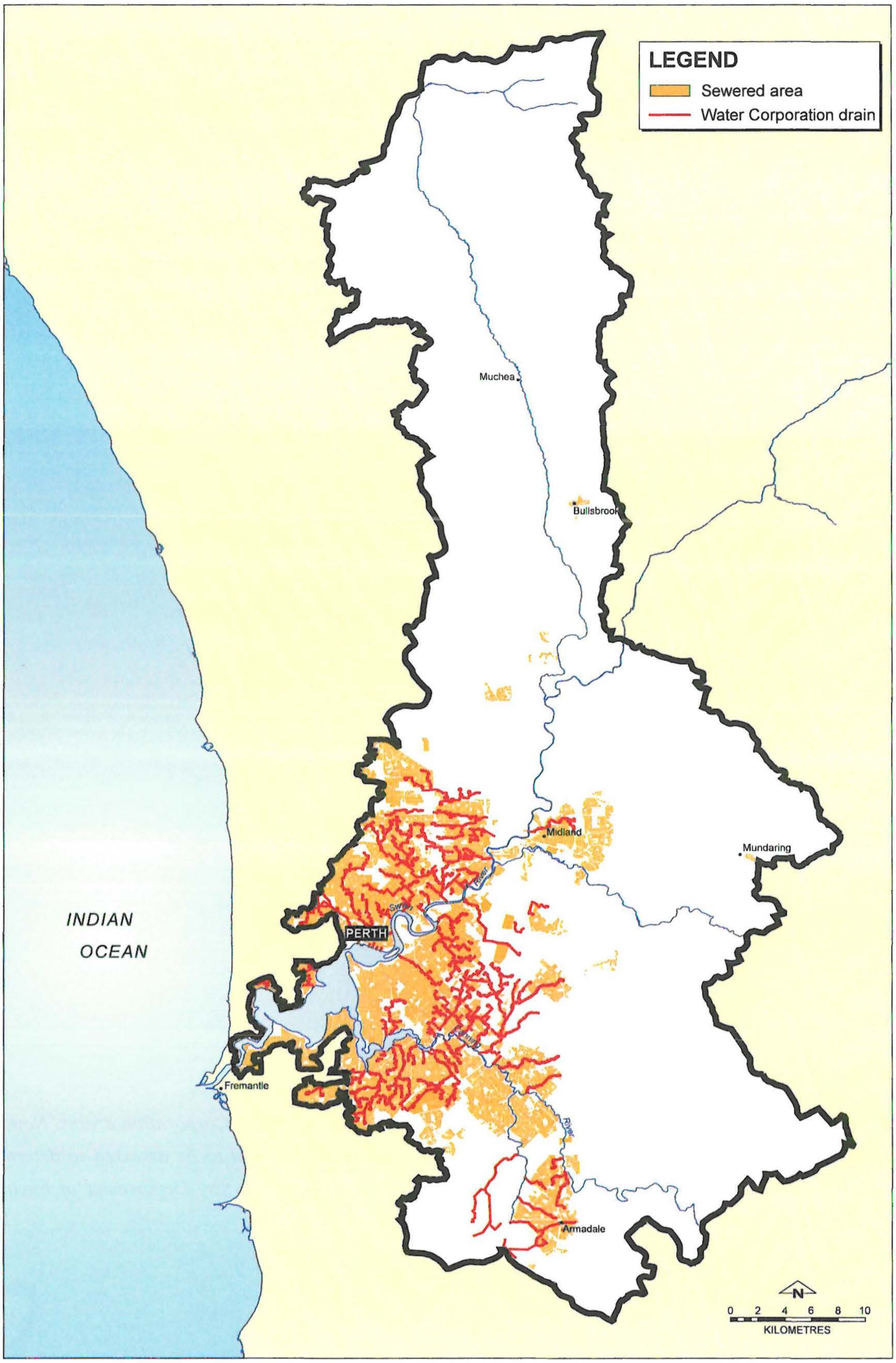


Figure 16: Sewered areas and Water Corporation drains within the Swan-Canning system

Many areas currently and previously serviced by septic systems have major Water Corporation drains running through them. If the drain is deep enough it intercepts groundwater contaminated by septic nutrients, leading to all-year-round contaminated flows that enter the Swan-Canning system and may cause localised algal blooms. These drains also capture and transport nutrients, trash and pollutants from their catchment as a result of excessive use of fertilisers, over-watering and dumping of rubbish. Many of these drains can be modified to minimise or remove nutrients and other pollution before they enter the Swan-Canning system. Data courtesy Water Corporation, 1999

Actions needed

- *Develop drain management plans for all metropolitan drainage districts.*
- *Modify existing drainage systems to incorporate measures to improve water quality, and to reduce nutrients and other contaminants.*
- *Develop and implement drain management and maintenance practices that minimise nutrient and other pollution levels.*

4.4.6.2 Road drainage

Sealed road surfaces deflect water runoff to drains and verges. In the process the runoff carries accumulations of tyre debris, exhaust fallout, nutrients and spillage from road traffic to the drains and verges. In times of heavy rainfall these pollutants will reach rivers and wetlands.

Road drainage can be most effectively managed by directing runoff in a water-sensitive manner. Water-Sensitive Design maximises the time for water and runoff from roads to percolate back into the ground and it directs water runoff into treatment trains in the form of water-detention and nutrient-stripping basins before allowing it to reach the larger drains that flow into rivers and wetlands.

Action needed

- *Ensure that Water-Sensitive Design principles are incorporated into new and existing road drainage systems.*

4.4.7 Natural and constructed wetlands in urban areas

In urban areas the few remaining natural wetlands often help reduce the velocity of water flowing off the urban catchment, allowing sediments to settle. In many cases water in surface flows from the catchments moves downward, gently "cascading" from wetland to wetland in flood conditions before coalescing into a defined watercourse. Much of the Ellen Brook catchment would have been like this prior to clearing. Wetlands also support plants that extract nutrients from water and sediment. Micro-organisms in the root zone play a critical role in nutrient cycling, such as denitrification, and the breakdown of organic matter and pollutants. There is a need to increase the area of existing wetlands and to protect them in order to help reduce nutrient flow from urban catchments into the river.

Constructed wetlands have a role to play in urban as well as rural drains (see Section 4.3.15).

In urban settings, Australian and international experience indicates that constructed wetlands can be effective in treating road runoff and commercial and light industrial drainage, and for final removal of nutrients and other contaminants in sewage and waste waters (grey waters). Constructed wetlands require areas of adequate size, proper landscape and design features and regular maintenance to meet most nutrient-stripping requirements. This is often a problem in developed urban areas and other situations where planning has not taken these requirements into account. Nevertheless they can be very effective in eliminating contaminated runoff before surface drainage enters waterways, and they can be utilised in Water-Sensitive Design treatment trains for this purpose. There is also the potential to use environmental remediation techniques to enhance the ability of constructed wetlands to strip nutrients and other contaminants out of the water (e.g. applying modified clays and oxygenation).

Actions needed

- *Incorporate provisions protecting natural wetlands and encouraging the use of constructed wetlands in town planning schemes and encourage their use in new urban developments.*
- *Use constructed and modified wetlands to improve water quality in urban drainage systems and monitor their effectiveness.*
- *Protect natural wetlands in urban areas according to existing wetland policies and legislation.*

4.4.8 Fertiliser and water use

According to research conducted in the 1980s, fertiliser use in gardens often reaches 40 kilograms of total phosphorus per hectare annually. This is more than double the application rate in agricultural areas. Over

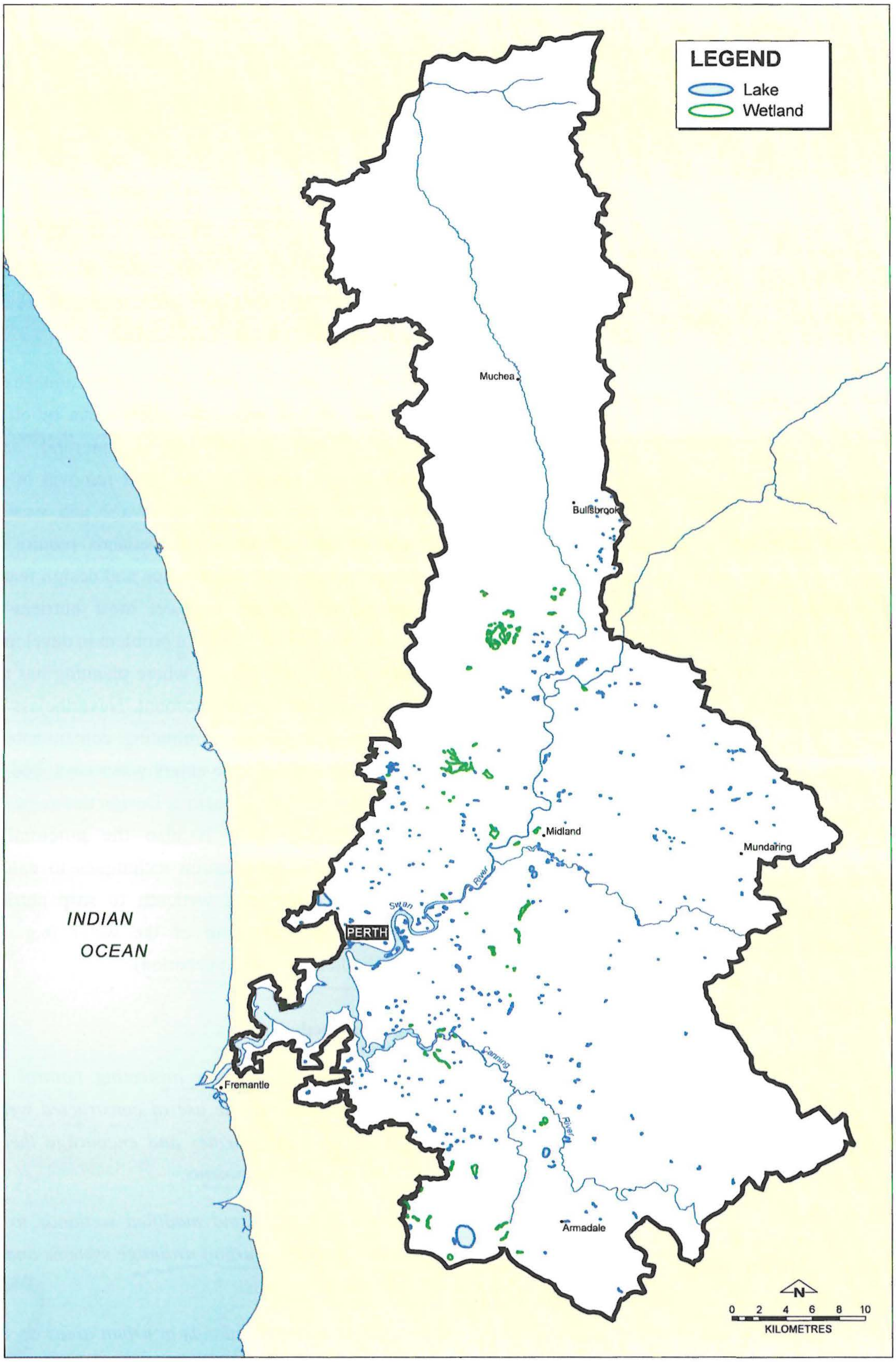


Figure 17: Lakes and wetlands within the Swan-Canning system

The Swan-Canning system contains a very large number of both natural and constructed wetlands and lakes. These water features are often the recipients of excessive nutrient inputs and so can have poor water quality. However, if properly managed they offer an opportunity to provide large-scale treatment of poor quality water and habitat for conservation purposes.

5000 tonnes of fertiliser is used in the Perth Metropolitan Area every year. As the city grows, blocks have become smaller than the traditional 1000 square metres, with multiplex dwellings and units replacing many single dwellings. Although the area of cultivated soil decreases, fertiliser application tends to increase as housing density increases, potentially leading to heavy leaching losses to the groundwater and surface runoff to drains. This is particularly true if high-fertiliser and water requiring ornamental gardens are grown. Further research is needed to determine the impact of fertiliser practices in such urban settings.

A five-year Turf, Irrigation and Nutrient Study has been undertaken to identify best practices in the management of irrigation and fertiliser application to parks and turf-based recreational areas. The findings need to be made available to local government, lawn and garden contractors and the general public. Support also needs to be given to the training of local government officers on best practices. An Environmental Code of Practice for management of recreational grass areas and turf farms that will help address the lack of information is currently being developed by the Department of Environmental Protection and the Water and Rivers Commission. If Codes of Practice fail to achieve positive changes then further regulatory action may be required.

Encouraging reduced fertiliser use in gardens and changing to slow-release products in both garden and turf is one management option. Another is to switch to planting native species with low nutrient and water requirements.

Irrigation of parks and recreational areas accounts for up to 75 per cent of urban water use for non-domestic purposes in summer, and overall water use for irrigation in urban areas is often excessive. In some cases about 70 per cent of the water passes below the root zone, often taking nutrients into the groundwater.

Nutrient and irrigation management plans should be part of all local government and school horticultural management practices.

Actions needed

- *Apply best fertiliser and water use practices (e.g. Nutrient and Irrigation Management Plans) to large urban parks and reticulated areas.*
- *Develop a system of monitoring fertiliser and water use in parks, public gardens and education establishments with the aim of reducing application and use.*
- *Provide advice and support to urban residents on the best use of fertilisers and water.*
- *Work with nurseries and the lawncare industry to develop best practice guidelines for fertiliser and water use and slow-release fertilsers for turf production.*
- *Review fertiliser and water use on large urban areas to determine whether further research is required.*

4.4.9 Clearing and erosion

Clearing remnant vegetation in urban areas makes the land more susceptible to erosion and can contribute directly to poor water quality by loss of the filtering and nutrient uptake capacity of natural vegetation. According to one estimate, over 6000 hectares of bush were cleared in the Perth Metropolitan Area over a two-year period in the mid-1990s. More than 23 per cent of this land was considered to contain regionally significant vegetation. It is important to emphasise that much of it was cleared for approved urban development. Approved clearing of large land-holdings for urban development has been through a rezoning process, subjected to submissions by the public and tabled in Parliament. A formal process, however, may be justified for small land-holdings to protect regionally significant vegetation before clearing land for development.

Retention of adequate vegetated buffers and riparian zones around waterways in the Swan-Canning system's catchment is essential to control erosion and nutrient export to waterways, and to reduce downstream water quality problems.

A greater recognition of the need to reserve land around waterways for Parks and Recreation Reserves in regional and town planning schemes will assist in the

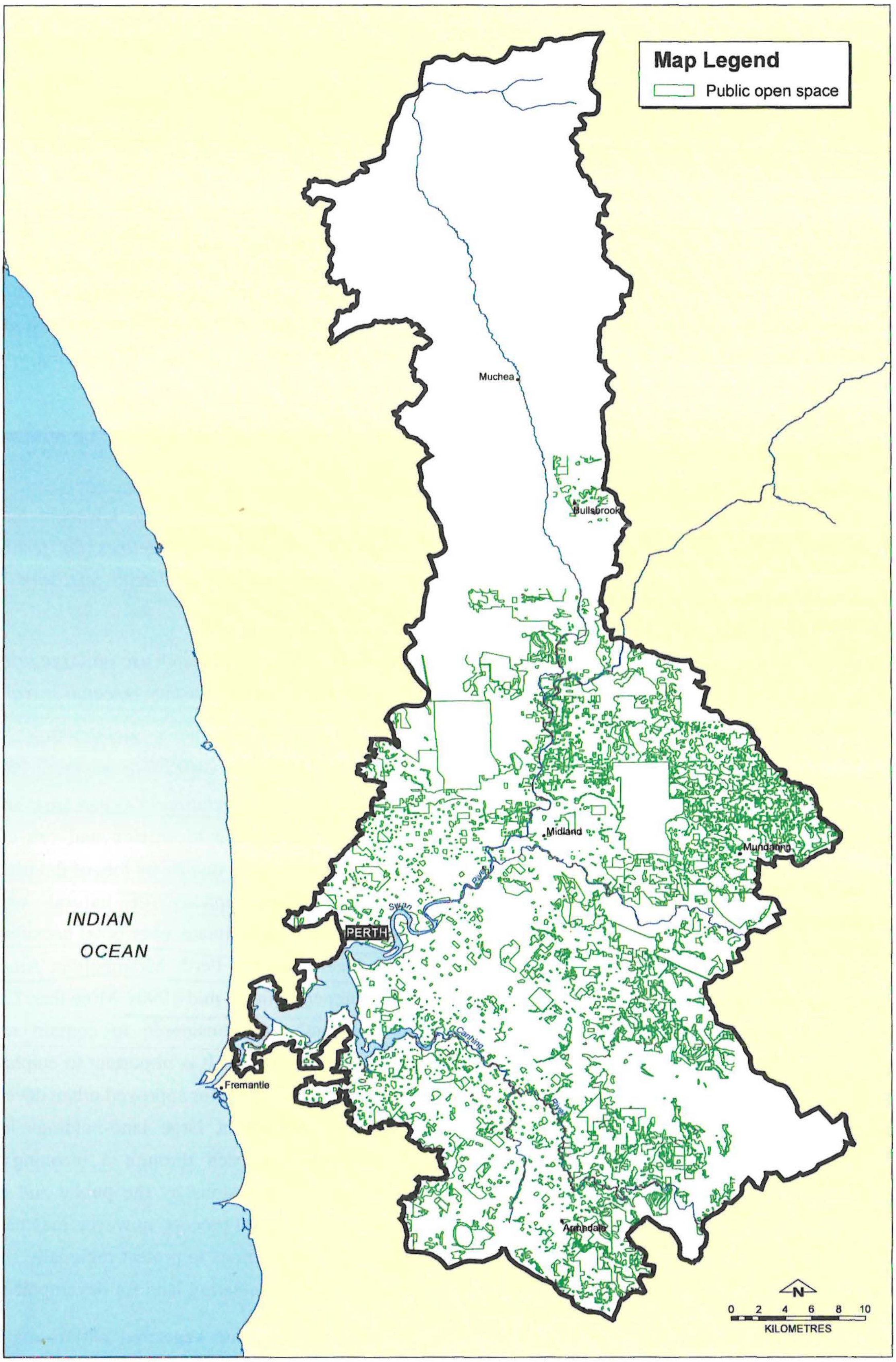


Figure 18: Large public open spaces in the Swan-Canning system

The Perth Metropolitan Region contains large areas of public open space used as park and recreation areas and for stormwater overflow. Many of these areas are irrigated and use substantial amounts of fertilisers. The use of Nutrient and Irrigation Management Plans may be appropriate to eliminate nutrient contamination of any receiving drains and watercourses. Public open spaces are essential to help meet Water-Sensitive Design principles. Data courtesy Department of Land Administration, 1998.

future control of nutrient export. This will help prevent further clearing of bushland and eventually result in the land being purchased by the WA Planning Commission. There may be a role for the Metropolitan Regional Improvement Scheme to further support the acquisition and management of parks, and the development of park management plans, contributing to this purpose. Town and regional planning schemes should also consider setting net increases in vegetation cover particularly for deep-rooted vegetation as annual and five-yearly goals. This would contribute to improved catchment health, reduce the pressure for extensive stormwater drainage systems and also help stabilise groundwater levels.

Current park management plans for the Swan-Canning system should be supported and implemented. An example is the Milyu and Canning Regional Park system. New parks and reserves that maintain and rehabilitate foreshores and floodplains should be designated.

Soil erosion in urban areas is often caused by the clearing of land for the development of buildings and infrastructure and the clearing of steeply sloping land for houses, roads and gardens. Such urban erosion contributes to sediments found in waterways in the same way as erosion from rural catchments. The greatest potential for such erosion is in catchments with steeper slopes and less permeable soils such as those found in the hill catchments.

Generally, larger developments are well controlled but smaller developments can have a cumulative effect and cause additional sediment loads in streams and drains that enter the Swan-Canning system.

There is a need for Water-Sensitive Design requirements to be taken into account when applications for town planning approvals are being considered.

Actions needed

- *Support plans and procedures that manage clearing and loss of vegetation in urban areas as a means of maintaining areas of remnant and waterway vegetation in the Perth region.*
- *Recognise the need to reserve land around waterways for Parks and Recreation Reserves in regional and town planning schemes.*
- *Support and fund park management plans for the Swan-Canning system.*
- *Take account of Water-Sensitive Design requirements when issuing town planning approvals for urban developments.*

4.4.10 Sewage and septage management

Septic tanks are still widely used for disposing of domestic sewage in residential areas.

Septic tank functioning depends on a network of leach drains to remove surplus water. They are potential sources of pollution in low-lying areas, especially for nitrates. Sulphate is also frequently high in the groundwaters of unsewered areas.

Illegal disposal of septage has been an ongoing problem, but it is now being addressed by the Department of Environmental Protection and the Health Department.

Reticulating unsewered areas is already a government priority. It will eliminate problems associated with these locations over the longer term. The Water Corporation are currently completing the Infill Sewerage Program, which is helping to stabilise existing contaminated groundwater plumes caused by residential septic systems and will eventually lead to a run down of nutrients in these plumes. No further action is warranted at present on the issue of sewage and septage management.

4.4.10.1 Sewered areas

Power failure, pump breakdowns and blockages sometimes result in spillages of untreated sewage. Pumping stations are generally located in low-lying areas, and sewage spills occasionally reach waterways. Completion of the Water Corporation Contingency Plan for sewer overflows will virtually eliminate this problem. No further action is warranted at present on the issue of sewered areas.

4.4.11 Dewatering

Dewatering, as part of building and development operations, may discharge into stormwater drains discoloured water with high levels of iron, acidic water, water carrying suspended solids and organic matter and/or water with low levels of oxygen. This may lead to contamination of the river, depending on the history and features of the site being dewatered.

In New South Wales this issue is considered to be so serious that developers and contractors are required to submit soil and water management plans to authorities before conducting operations.

In Western Australia guidelines for dewatering have been developed by the Swan River Trust and the Water and Rivers Commission. Any dewatering operation that would result in a significant flow to the Swan-Canning system needs the approval of the Trust or the Commission. To improve the use and effectiveness of these guidelines, industry groups that utilise dewatering need to be educated on its effects on the environment and how to minimise them.

4

Actions needed

- *All dewatering discharge entering the Swan-Canning system within the Swan River Trust management boundary should be approved by the Swan River Trust and comply with its guidelines. Dewatering activities in other locations must be approved by local government following referral to the Water and Rivers Commission.*
- *Industry groups engaged in dewatering should be educated on how to minimise its impact on the environment.*

4.4.12 Foreshore management

Foreshore management includes provision of natural and engineering structures and vegetation management to reduce erosion, control weeds, stabilise banks and maintain vegetation corridors. Particularly in urban settings, foreshore management is best done under Foreshore Management Plans, which balance natural riparian and floodplain features with human requirements for recreation and boating access. Well-managed foreshore reserves are essential to healthy waterways.

Bushland, which acts as a buffer to foreshore areas, should also be retained wherever possible. Retaining nodal areas of natural bush large enough to maintain self-propagation in the foreshore and floodplain zones is important for river health and essential to successful foreshore management.

It is essential that integrated foreshore, wetland and bushland policies are in place and implemented through proper decision-making. Economic incentives to foster better foreshore management in privately held foreshores would also help to improve waterways management. This mechanism is discussed in more detail in Section 5.2.3.

Actions needed

- *Provide economic incentives and support to encourage land-holders to protect and rehabilitate river and stream foreshores.*
- *Develop and implement Foreshore Management Plans for all rivers and streams in the Swan-Canning system.*
- *Use foreshore management agreements to protect and manage private foreshores.*

4.4.13 Weeds

Introduced weeds reduce the diversity of native animal and plant species and diminish the ecological value of both disturbed and undisturbed habitats by competition. Weeds often have soft and deciduous leaves which decay quickly in water, contributing to excessive organic loads entering waterways. Weed-dominated floodplain and riparian zones may be less effective in reducing the energy in stream flows and shore erosion processes.

Weed-infested foreshores often become monocultures, with reduced soil microbial and invertebrate fauna, severely compromising ecosystem function.

Weed infestations are a particular problem in the Canning River. The *Hydrocotyle* infestation that choked it in the early 1990s is a clear example of their serious threat to healthy waterways. Large areas of watsonia also infest foreshores along Ellen Brook and the Swan River, where they reduce habitat and vegetation diversity.

Many weeds are garden escapees. Endeavours should be made to ensure that garden waste such as lawn clippings and prunings are not discarded into waterways or along their foreshores.

Actions needed

- *Map levels of weed infestation along the foreshores of the Swan-Canning system and identify priority areas for rehabilitation.*
- *Coordinate the weed control activities of local government, State and Commonwealth agencies, land-holders and community groups.*
- *Develop best management guidelines for the control and elimination of weeds on foreshores.*

4.5 River and estuarine intervention

Intervention in the rivers and estuarine basins of the Swan-Canning system may be necessary to lessen the symptoms of eutrophication until changes in catchment management practices result in reduced inputs of nutrients. A certain amount of river intervention has already occurred, such as the removal of the Fremantle sill, dredging for navigation, damming tributaries and the removal and infill of shallow wetlands for highway and building construction and foreshore development. These interventions have contributed to increased seawater exchange (and hence salinity levels) in the Swan-Canning system, helped control downstream flooding and contributed to loss of riparian zone habitat.

The object of any in-estuary intervention targeted at algal blooms is to reduce the supply and availability of nutrients to the surface waters for the growth of phytoplankton. Australian and international experience teaches us that nitrogen and phosphorus should be reduced together rather than separately and that loadings of organic matter should also be reduced.

A range of potential techniques has been evaluated by the SCCP Task Force for their applicability to the Swan-Canning system. Intervention techniques with the capacity to enhance natural estuarine processes that reduce the availability of nitrogen, phosphorus and organic carbon, and that do not further impair the ecological integrity of the system, were determined to be the most effective. Three of the most promising techniques were selected for in-depth study and trial during 1997-98. These are:

- destratification of the water column to enhance removal of nitrogen, phosphorus and organic carbon;
- oxygenation of bottom waters for removal of nitrogen, phosphorus and organic carbon;
- sediment remediation with modified clays for phosphorus removal.

The objective of current SCCP river intervention trials is to develop a number of options for use in the Swan-Canning system and to establish the criteria for their use. The Swan River Trust and the Water and Rivers Commission are working with the Environmental Protection Authority to ensure that the trials and any large-scale applications of these techniques are environmentally acceptable.

The techniques selected for trial in 1997-98 are innovative approaches to nitrogen and phosphorus removal. Ultimately, however, all river intervention techniques depend on the elimination and control of the sources of nutrients entering the system. Both oxygenation and sediment remediation using modified clays can be applied in the catchment tributaries close to nutrient sources, and they are compatible for use together. Successful river intervention techniques (e.g. oxygenation) can provide short-term relief to the system while in the long term they may provide cost-effective benefits to waterway health and complement necessary catchment changes.

River and estuary intervention in this Action Plan is not intended to clean up blooms as they occur or when they collapse. If necessary and possible, cleaning up the debris and material left by blooms is currently done by the field staff of the Swan River Trust or local governments. Intervention techniques advocated in this plan are targeted at preventing the conditions that lead to blooms or reducing their frequency, not stopping them as they occur. However, some techniques, for example sediment remediation, may help reduce bloom intensities or stop them as they are occurring.

Algal bloom bubble curtain experiment

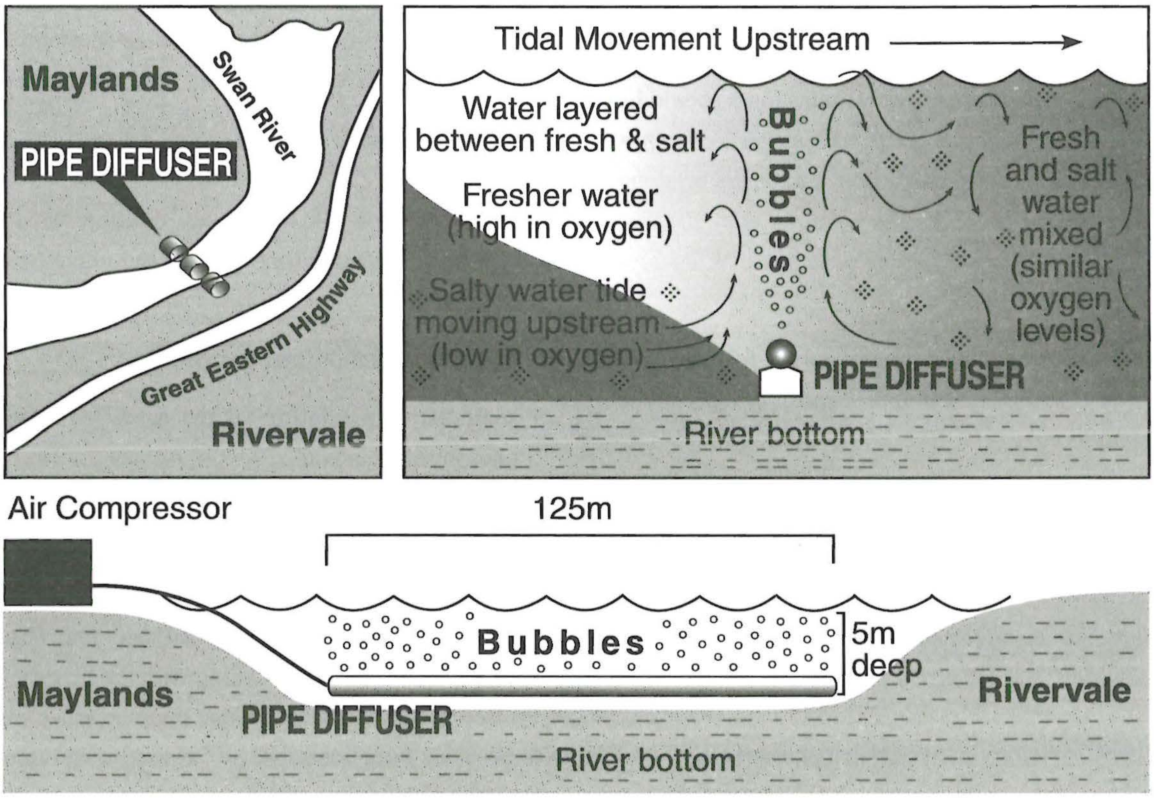


Figure 19: Location and mechanics of a bubble curtain trial held on the upper Swan River

The purpose of operating a bubble curtain in the Swan-Canning system would be to break down salinity and thermal layering of the water where good oxygen diffusion between top and bottom waters is prevented. When oxygen diffusion is poor, bad water quality usually follows. Results of the experiment did not warrant further investigation of this approach at this time.

Actions needed

- *Continue development and trial of remediation techniques using modified clays and oxygenation for phosphorus and nitrogen removal in such a way that the technologies can be used both in the estuaries and in the catchment.*

- *Continue evaluation of intervention techniques other than those selected for trial in 1997-98 in order to keep on building a "toolbox" of intervention options.*

4.5.1 Destratification

The use of a bubble curtain to mix water in the salt wedge moving upstream from the sea with fresh water flowing on the surface was proposed by the Centre for Water Research at the University of Western Australia to increase the oxygen concentration of the water in the upper Swan. Breakdown of the summer stratification would allow wind mixing of atmospheric oxygen to the bottom waters. A well-oxygenated water column would reduce the amount of phosphorus leaving the sediment, improve loss of nitrogen to the atmosphere through nitrification and denitrification, and reduce organic matter in the sediment.

Destratification techniques have been developed in lakes and reservoirs to break down temperature stratification of the water in order to increase oxygenation and to move blue-green cyanobacteria below the surface and out of the light. To the Task Force's knowledge, these techniques have not previously been applied to an estuary. Based on the results of a laboratory trial, a field trial at Maylands was carried out in spring 1997 using a bubble curtain to mix water from the incoming salt wedge with overlying fresh river water. The technique was effective in destratifying the two layers for

50 metres upstream of the curtain, with secondary effects apparent up to 400 metres away. However, stratification quickly re-formed upstream of the trial site. A final report assessing the method is now available.

It was concluded that the bubble curtain technique was not effective in breaking down the highly stable salinity stratification associated with the advance of the salt wedge in the Swan-Canning estuary. No further investigations of this technique are planned.

4.5.2 Aeration and oxygenation

Aeration is the use of various techniques to mix water with air and introduce oxygen into the water. This is achieved by bubbling compressed air through water, splashing it or passing it through a fountain, as can be seen in small lakes and ponds. Using aeration for large water bodies such as the Swan and Canning rivers is considered less efficient than using pure oxygen as a source of oxygen.

Oxygenation techniques developed for lakes and reservoirs involve direct oxygen injection using pure oxygen or compressed air scrubbed of nitrogen. Oxygenation has been in use for over 100 years as a technique for treating sewage effluent. The technique has been used quite successfully in the Thames estuary, where it counters stormwater inputs of organic matter. Oxygenation has also been used to advantage in water bodies in North America and Norway, and it has been assessed as very promising for the Swan-Canning system's waterway conditions. Oxygen is relatively cheap and readily available as a by-product of industrial processes, and it can be produced on site if required.

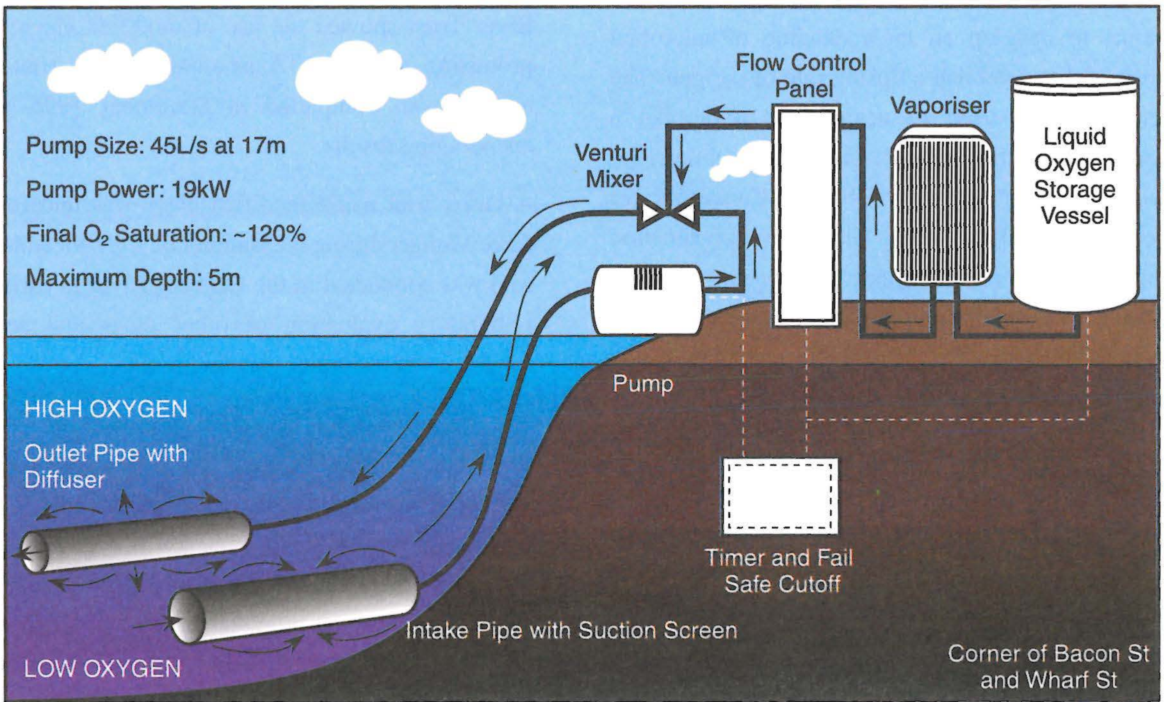


Figure 20: Schematics of the oxygenation trial conducted on the Canning River

The purpose of oxygenation is to pump low-oxygen water from the bottom of the river to a mixing plant to increase oxygen content and then return the treated water. Oxygenation thus specifically targets the low-oxygen layer of the river and does not interrupt natural layering caused by salinity and temperature differences. BOC Gases donated material and expertise for a trial conducted on the Canning River in 1997-98. In the Thames River, authorities utilise a barge that injects oxygen directly to the bottom of the river to solve the problem of poor water quality following storm and pollution events.

Water low in oxygen is drawn from the bottom of the water body and injected with oxygen through a diffusion device to produce oxygen-saturated water, which is then returned to the bottom. This technique differs from destratification in that breakdown of the saltwater/freshwater interface or of temperature stratification is not required. In fact, a stratified water body may allow better transport of the freshly oxygenated water along the bottom.

The aim of the technique is to increase the rate of nitrification and denitrification (i.e. nitrogen loss), and breakdown of organic matter in sediments. Well-oxygenated bottom water will also help reduce the flow of nutrients from the sediment.

Based on a review of available oxygenation technologies, a field trial was developed for the Canning River using a fixed installation on the river bank to dissolve pure oxygen into bottom water drawn from the river. The intent of the trial was to demonstrate the technique, to develop an understanding of microbial response, and to establish a dosing rate of oxygen. The results are being used to design and undertake a large-scale trial on the Swan River using a mobile barge delivery system, and a larger trial on the Canning River adapted to the shallow water. Ultimately, oxygenation may be complementary to other treatment systems used upstream before waters enter the tidal rivers and estuary. A report on the successful trial of this technique in the Canning River during 1998 is now available.

Actions needed

- *Develop an extended oxygenation trial on the Canning River for implementation in 1999.*
- *Evaluate barge-mounted delivery of oxygen in the Swan River, based on the results of the Canning River trials.*
- *Use oxygenation as an intervention tool in the Swan and/or Canning rivers if initial evaluation is positive.*

4.5.3 Sediment remediation

4.5.3.1 Sediment modification

The natural processes for phosphorus removal are export to the ocean (in water or in biota) and burial in sediments. As sediments accumulate, phosphorus becomes mineralised and therefore unavailable for algal growth. Until that occurs, sediment phosphorus may be released under low-oxygen conditions or, in the case of the Swan River, through groundwater flow. Immobilisation of nutrients, particularly phosphorus, through some form of sediment modification is therefore an attractive intervention technique.

Following an exhaustive review of sediment remediation techniques it was concluded that current methods were unsuitable for the binding of phosphorus or nitrogen in sediments. Extensive laboratory studies carried out by the CSIRO Land and Water in partnership with the Water and Rivers Commission and the Swan River Trust showed the use of modified clays to be a promising technique. A small-scale river trial in the upper Swan completed in December 1996 showed encouraging results.

A larger trial using modified clays was undertaken at Lake Monger during the summer of 1997-98 and a small trial was conducted in the Canning River in early 1998. Laboratory evaluation of other clays and sediment modification techniques is continuing.

The modified clay has great promise for upstream treatment of water before it enters the Swan-Canning system. However, using materials that are easy to obtain, it appears practical to bind only phosphorus, not nitrogen, in sediments under brackish or saline conditions. Nitrogen removal may be possible only in fresh water. The technique is applicable to constructed wetlands, compensation and nutrient-stripping basins, drains and rivers, and can be applied to the sediment and to the water column. The method could be incorporated into catchment management and Water-Sensitive Design strategies.

Actions needed

- *Finalise development of sediment remediation techniques through laboratory and field trials and apply them in the Swan-Canning system.*
- *Develop techniques for combining sediment remediation with oxygenation for nutrient reduction in water bodies and sediments.*
- *Scale up technology for sediment remediation to allow river-wide trials.*

4.5.3.2 Physical capping

Sediments may be isolated from water bodies by capping them with a layer of sand or other material to prevent release of nutrients. This approach has been used in Japanese coastal seas and US harbours for containment of a range of contaminants. The technique is not a feasible option for the Swan-Canning system for the following reasons:

- Capping is unlikely to be effective because strong groundwater flow carries nutrients through the sediment into the water.
- Nutrient-enriched sediments will continue to be imported from the catchments, and organic matter from decay of algae would repeatedly cover sediment caps were they applied. New evidence indicates that even small amounts of nutrient-enriched sediments lying as a thin layer on the bottom of the river can provide enough nutrients to trigger algal blooms.
- The cost of applying sediment caps has to be weighed against the large surface area of the sediment to be covered, the difficulty of accurately targeting the sediments that need capping and the possibility that the sediment cap may have a short life - perhaps less than five years.
- Capping would have a short-term environmental impact on bottom-dwelling organisms, as smothering would lead to mortality until recolonisation occurred, and it would alter bottom habitat.

4.5.3.3 Sediment removal

Removal of nutrient-enriched sediments by dredging has been proposed for the Swan-Canning system. Controlled dredging to remove contaminants in bottom sediments of rivers, estuaries and bays has successfully occurred in Canada, the Great Lakes and East Anglia in England. National and international experience indicates however that dredging is not a suitable option in the Swan-Canning system for the following reasons:

- Nutrient-rich sediments are spread thinly over a large area, and are difficult to target accurately as their location changes from year to year.
- The cost and difficulty of the operation (removing a thin lens of fine, easily suspended sediment) makes it unlikely to provide a cost-effective option, especially given that suitable dredging equipment and methods are not available in Australia.
- The environmental impact is potentially high. The dredged sediment must be settled out in ponds, dried and disposed of without leaching nutrient-rich waters back into the river, an operation that requires a large well-managed area. Disposal of the spoil is also a problem given the high sulphur content and the large volumes expected.
- It is very likely that, with the next winter flow, new sediments would replace those dredged.

Removal of sediment in smaller areas such as nutrient-stripping basins before water enters the waterways is likely to be more appropriate (see Sections 4.3.13, 4.3.15, 4.4.6 and 4.4.7). However, there may be a need to review strategic estuarine and riverine dredging in the next three to five years.

4.5.4 Riverbed modification

4.5.4.1 Channel modification

Removal of nutrient-rich estuarine waters by increasing exchange and flushing with marine waters is a process that has been used before in Western Australia, most notably in the Peel-Harvey with the construction of the Dawesville Channel and, in the 1950s, with the "cut" at the Leschenault Inlet. A similar connection is not feasible for the Swan-Canning estuary. Apart from the fact that it does not have estuarine basins parallel to the coast, the algal bloom problems of the Swan-Canning system are located in the upper regions. In fact substantial increases in seawater exchange into the

Swan-Canning estuary came about last century with the removal of the Fremantle sill and subsequent port dredging.

Opportunities are limited for increasing seawater mixing in the upper Swan, as 80 per cent of the ocean tidal range already reaches Barrack Street Jetty. Thus, only 20 per cent of the ocean tidal range would be potentially made available by any additional modification. Barometric tides due to the passage of low pressure systems over the area have a large effect on the movement of marine water (e.g. the salt wedge) and would be similarly affected.

If maximum seawater exchange was the aim, removal of sandbars at Point Walter and extensive dredging of Perth Water would be required. These are large engineering undertakings with significant environmental impacts. It is not known whether the resulting increase in marine water inflow and flushing would be significant enough to warrant such intervention. The dredged material produced by channel modifications would require proper disposal.

Although evaluation of the technique indicates that the costs and impacts would be high for little benefit, the potential to increase seawater exchange through channel modification will be further evaluated through use of a hydrodynamic model being developed by the Western Australian Estuarine Research Foundation and funded through the SCCP Program.

Action needed

- *Evaluate channel modification, particularly the cost-benefit aspects, using the two-dimensional hydrodynamic models developed for the Swan-Canning Cleanup Program.*

4.5.4.2 Bathymetric smoothing

It has often been postulated that depressions or holes were created in the bed of the Swan River from dredging for navigation, silica sand extraction, raising foreshores and other purposes, and that over time these holes have become filled with nutrient- and organic-rich sediment. In turn, these holes were believed to be sources of nutrients for algal blooms in the river. The solution proposed was either to fill them with some inert material or to remove the intervening ridges between them so that sediment would not accumulate and the river bottom would be smoothed out.

A detailed evaluation was made of the size and extent of holes in the bed of the upper Swan from the Causeway to Success Hill using shallow-water seismic techniques and detailed bathymetry at 20-metre spacing. This survey and other analyses revealed that:

- Less than 10 per cent of the estuary bottom has holes, and these are general depressions less than one metre deep spread over 100 metres - not steep, deep holes.
- Observations of river sediment processes suggest that high winter flows and river currents remove accumulated sediment in existing depressions and would rapidly create new depressions.
- It is also now believed that the sediment nutrients available to support algal blooms occur in the upper few centimetres of sediment spread over most of the bottom of the upper Swan rather than in accumulations in a few "problem" areas.

"Deep holes" are now considered to be much less significant than previously thought and, due to the complexity of bottom hydrodynamics, neither infilling of the depressions nor removal of restrictions between depressions is considered a viable option for the upper Swan.

4.5.5 Canning River options

Because of the impoundment, solutions for the Canning River upstream of the Kent Street Weir will be very different from those applied to the Swan River. Little or no summer flow, stretches of still water, plentiful sun, fresh water and high levels of nutrients, especially phosphorus, make the Canning River prone to blue-green cyanobacterial blooms. Toxic blue-green blooms occurred in 1994 and 1997-98.

There have been proposals to remove the weir and allow the river to revert to an estuarine condition such as existed before its construction. The SCCP Task Force has determined that this option would require very careful evaluation due to the historic status of the weir itself and the desire of most residents to maintain a freshwater environment during the summer, which makes it very popular with recreational users. It is, however, an option that has been evaluated from a technical aspect.

When river flows are low and high levels of nutrients enter the system, returning the river to an estuarine condition during the summer would not be preferred. This is because tidal intrusion may not result in tidal flushing but rather in a stratified, slow-moving water body that would still be susceptible to algal blooms, probably of the brackish-water-tolerant species such as the blue-green *Nodularia* spp. Although introduction of saline water would inhibit infestations of freshwater weeds (e.g. *Hydrocotyle*), it would also completely change the nature of the riparian vegetation. Vegetation would probably revert back to brackish-tolerant species, with the loss of melaleucas and other fringing freshwater plant communities.

Increase in groundwater salinisation, loss of amenity and reductions in the amount of fresh water that can be extracted from the river would also be of concern. Water levels would be lower than at present and much of the foreshore would be reduced to mud flats for part of the year.

Major studies of blue-green blooms in weir pool situations have shown that the most effective way to reduce or prevent them is to increase river flow at critical times to break up bloom formation. The options for increasing flow are limited by the amount of water impounded in the upper Canning and Wungong reservoirs, and the allocations in place mean that, at normal levels, it is already committed. A substantial part of the flow released from the dams is extracted for irrigation or commercial use. If extra water could be found, or downstream users were prepared to share

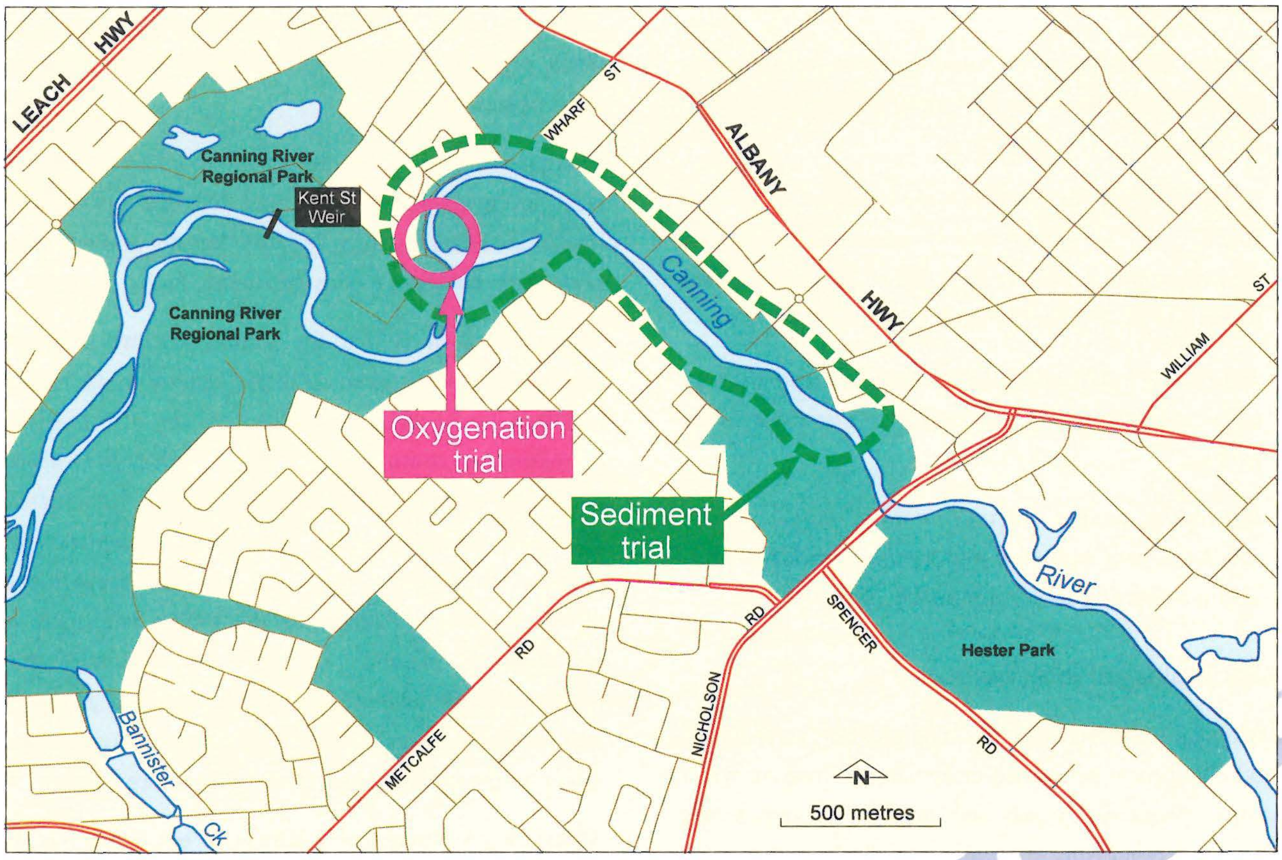


Figure 21: Location of river intervention trials on the Canning River upstream of the Kent Street Weir

Key features of the upper Canning River near the Kent Street Weir are shown along with the locations of oxygenation and sediment remediation trials to improve water quality and reduce algal blooms.

extraction rights, water releases at critical times in the spring and summer, possibly combined with temporary lowering of the weir, might help to improve water quality in the upper Canning. Examination of the use of reservoir water for bloom control is critical (see Section 4.3.14).

Adjusting the height of the weir could also provide flexibility in balancing fresh and brackish conditions. For example, late replacement of the weir boards in the spring would allow small amounts of salt water upstream, which would discourage exotic weeds. Increasing salinity above the weir has potential also to contribute to the management of algal growth.

The release of river water and allowances for incursion of estuarine water flows could be more effectively handled with a redesigned weir system.

Actions needed

- *Assess management of algal blooms by securing experimental environmental flows through the lower portions of the Canning River.*
- *If the assessment confirms the usefulness of this strategy, review allocation of water rights so that environmental flows are set at a level that will address water quality and algal bloom issues.*
- *Assess manipulation of the weir boards as a strategy (a) to increase river flow and (b) to introduce saline water.*
- *Depending on the outcome of this study, evaluate whether a new structure next to the Kent Street Weir would be preferable for controlling flows.*

4

4.5.6 Biological intervention

Biological techniques such as manipulating an estuary's food chain have been used elsewhere to improve water quality. These techniques introduce or encourage the growth of organisms such as zooplankton, other algal grazers, plankton-eating fish and molluscs. The main aim is to control the growth of algae, though successful use of this technique would contribute to improved water quality in other ways.

Biological intervention has been used successfully overseas in estuarine and river environments, but generally only in locations where salinity remains fairly consistent, as opposed to the extreme fluctuating regime in the tidal portions of the Swan-Canning system. The seasonal salinity changes and lack of substantial hard surface areas make the establishment of a permanent resident biological community difficult, particularly for large populations of filtering organisms (e.g. mussels), which would be required to improve water quality. Initial assessment indicates that there is little potential for currently available biological techniques to be effective here.

No significant research on biological intervention approaches has so far been conducted in Australia. Studies undertaken as part of the SCCP program show that zooplankton in the upper Swan, which is the part of the Swan-Canning system where techniques of this kind are most likely to be successful, are dominated by small organisms which are unable to graze on large phytoplankton cells.

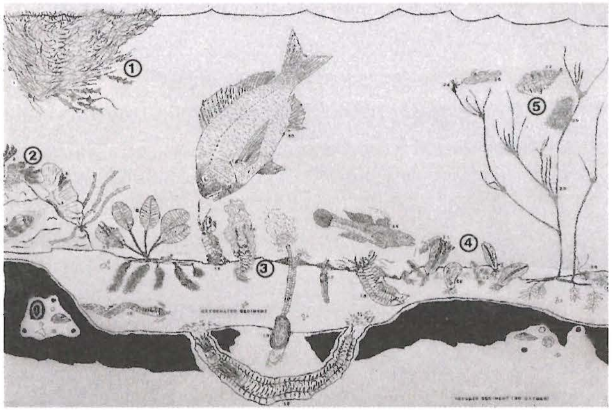
There is strong evidence that larger zooplankton grazers were more abundant in the past but that inter-annual hydrological and salinity variation has not allowed their population numbers to stay constantly high.

What is known is that the salinity regime was less extreme before the opening of the estuary to the ocean, and that could be an important factor affecting the zooplankton community. Current work in Europe also suggests that even low levels of some contaminants, especially pesticides and other toxic and persistent organic compounds (e.g. oil, grease, herbicides), adversely affect elements of the food chain such as zooplankton grazers. It must be assumed that pollution levels in the Perth system, albeit at generally low levels based on existing data, are also having some effect on the numbers and types of these organisms.

Monitoring contaminant loadings in the estuary is an essential step in the ultimate restoration of a fully viable biological system, and reducing their levels must be a continuing aim.

Actions needed

- *Establish a watching brief on biological intervention trials elsewhere.*
- *Support research that improves understanding of food web dynamics in the Swan-Canning system so that advantage can be taken of promising biological techniques when they become available.*
- *Review levels of contaminants entering the Swan-Canning system, especially pesticide residues and other persistent organic compounds including hydrocarbons, and seek ways for reducing those inputs.*



A stylised food chain. Drawing courtesy T. Rose

1. *Hardyheads feeding and laying eggs on floating algae.*
2. *Snails grazing on rocky outcrops.*
3. *Polychaete worms filtering water for feeding using fine mucus nets.*
4. *River mussel bed.*
5. *Small grazing amphipods and fish feeding on seagrass and seaweeds.*

4.6 Modelling to help decision-making, monitoring and investigations

Modelling environmental systems and linking model output to monitoring can be very useful tools and approaches for management and to assist in decision-making.

In the past, water quality models have been used mostly in scientific research. They are now playing an increasingly important role in improving monitoring and management of catchments and estuaries.

Computer programs developed from mathematical representations of processes, such as runoff from catchments, phytoplankton growth, river flow, groundwater interaction and estuarine flushing, provide a means of predicting the likely effects of various management options before they are implemented at full scale in the field.

The models achieve this by comparing a simulation of a real case against a series of simulations that represent different management options. The feasibility of each option can then be examined in terms of other factors such as cost and policy aims.

Another advantage of modelling is that it can be used to test the sensitivity of the modelled system to changes in the input data. In this way, the type, methodology for collection, quantity and quality of the data can be reassessed and rationalised relative to the costs of data collection.

Water and land resource agencies like the WRC, WC and AGWEST use catchment and groundwater flow models to improve water resource allocation and monitoring methods, and to understand flow patterns and pollution effects. Many of these models have recently been applied to WA catchments. Successful application requires some understanding of strengths and limitations of the various models. They include catchment process models such as Large Scale Catchment Model (LASCAM), Agriculture Non-Point Source (AGNPS), spatial Geographic Information Systems (GIS), Catchment Management Support System (CMSS) and groundwater simulation models such as AQUIFEM-N, FEFLOW and the Perth Urban Water Balance Study Model (PUWBSM)

The WAERF has also been developing a hydrological and ecological estuarine model to improve scientific understanding and management of the Swan River and the estuary. It accepts output data from catchment and groundwater models and uses it to assist in modelling estuarine processes in the Swan.

The SCCP Task Force has recommended a number of catchment and groundwater models for further use and development. They include LASCAM, AGNPS and GIS models for catchment input to the "downstream" WAERF estuarine model, and AQUIFEM-N, FEFLOW

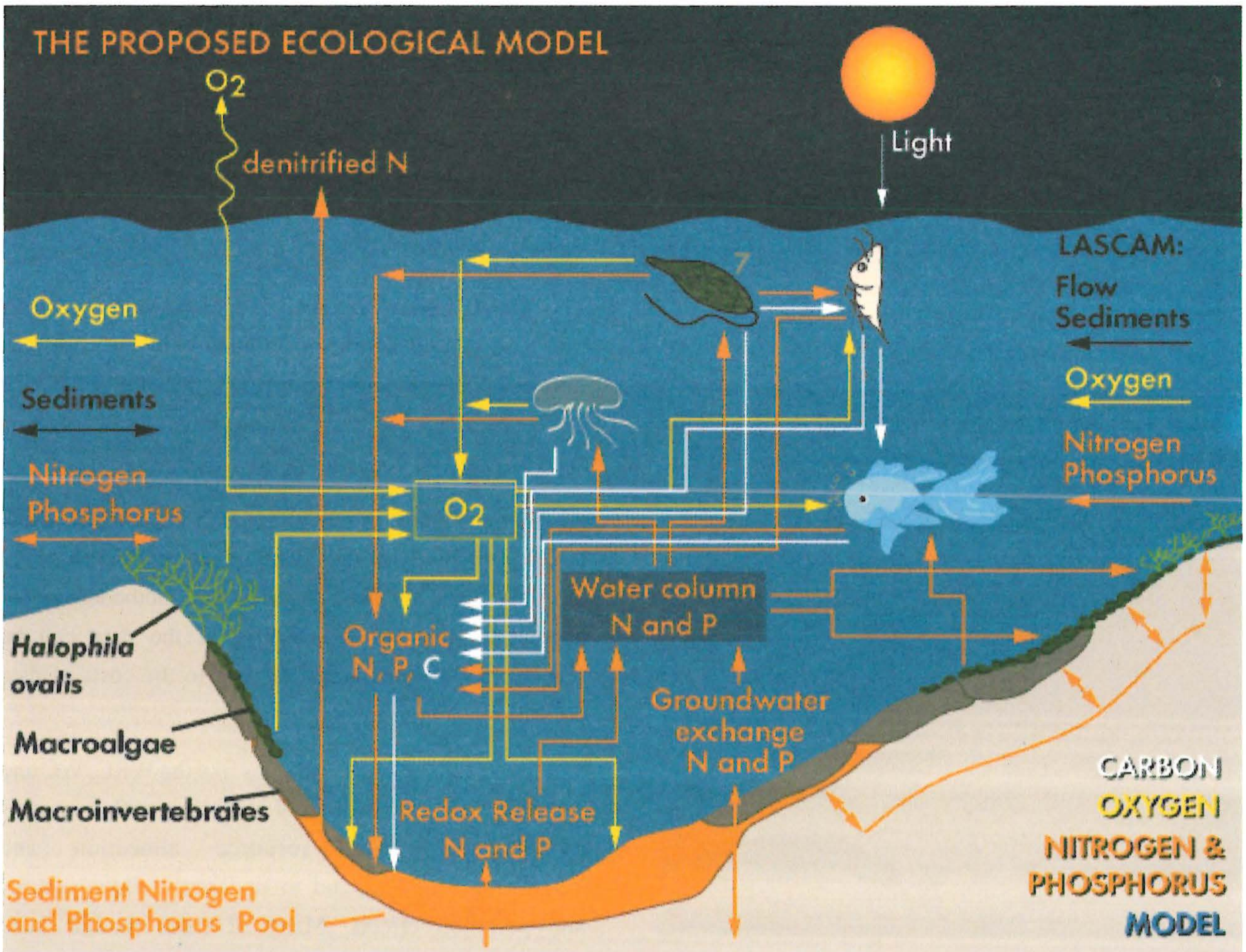


Figure 22: Processes and links in the WA Estuarine Research Foundation estuarine model

The SCCP has funded WA Estuarine Research Foundation to develop a process-based ecological model for the Swan-Canning estuary. This model is state-of-the-art, and takes account of a large number of links and cycles between physical and chemical features and biological components of the estuary. The aim is to improve water quality management. Note the large number of complicated relationships that are a feature of the model. Illustration courtesy Centre for Water Research, University of WA.

and PUWBM for groundwater interaction with the river. The Task Force has also recommended that urban catchment and riparian models be utilised to strengthen information on the processes driving estuarine dynamics and the predictive and management power of the estuarine model.

At present there is no accepted framework for the use of catchment and estuarine models by State agencies responsible for water quality management, particularly in the WRC. To capitalise on the results and the powerful utility of the WAERF catchment and estuary water quality models, management agencies and modelling specialists need to further develop their close liaison to ensure that model simulations are focused on key management issues and are translated into practical management decisions and practices.

Actions needed

- *Develop the use of LASCAM, AGNPS and spatial GIS catchment models to provide input to the estuary model currently being developed and to improve knowledge of catchment processes and management options.*
- *Develop the use of PUWBSM, AQUIFEM-N, and FEFLOW groundwater models to provide inputs to the estuary model and improve knowledge of groundwater management options.*

- *Allocate resources to ensure that modelling specialists and management agencies liaise closely to define modelling objectives, and ensure that modelled scenarios are focused on and applicable to management issues at agreed levels of complexity.*

4.7 Filling gaps in our knowledge: future investigations

During the course of the SCCP, a better understanding of basic estuarine and catchment processes has been developed from existing data and information, from original research conducted through WAERF projects and from specific investigations and monitoring programs commissioned by the SRT and the WRC. An estuarine model being developed by the WAERF encapsulates much of this understanding and will help to identify additional information gaps crucial to development of effective management solutions.

As a result of this effort, significant advances have been made in our knowledge of the Swan-Canning system. Several knowledge gaps have been identified however. They fall broadly into three categories: processes within the water body itself, processes within the sediments and processes within catchments.

4.7.1 Processes within the water body

Food web dynamics. The relationships between phytoplankton, the animals that graze on them and the animals (including fish) that in turn consume the grazers are poorly understood. A better understanding of these relationships (particularly energy, carbon and nutrient exchange) will help in predicting the consequences of remedial solutions and may allow the development of biological control methods for improving water quality in the future.

Nutrient limitation of phytoplankton growth in the Canning River. It is not yet known whether nitrogen or phosphorus is the limiting nutrient in the Canning River nor if some other factor such as light or flow dynamics is limiting algal growth. To apply the most effective cleanup strategy it is imperative that factors limiting algal growth are better understood.

4.7.2 Processes within the sediments

Role of organisms within sediments in the cycling of nutrients. Algae (especially diatoms), bacteria and other micro-organisms play an important role in the way nutrients are stored and released from sediments. Understanding the contribution of these organisms to nitrification, denitrification and other nutrient processes, as well as the rate at which they process nutrients, is critical in the Swan-Canning system.

Nutrient cycles within the sediments. There is broad recognition that the nutrients nitrogen, phosphorus and carbon are stored in significant quantities within the river and estuarine sediments. However there is poor understanding of how the nutrients transform from one chemical form to another and how they are recycled and mobilised into the water column where they become available for phytoplankton growth.

4.7.3 Processes within catchments

Source of nutrients in the catchment. Although the main source of phosphorus in rural catchments is most probably fertiliser, the relative contribution of fertiliser-derived phosphorus compared to soil-derived phosphorus (i.e. natural phosphorus bound to soil) has not yet been shown. The relative contributions of water and nutrients in surface water flows and groundwater are also not clearly understood in a number of catchments. There is a need for better understanding of nutrient loss processes and their rates from catchment soils.

Groundwater flows and their role in nutrient supply. Groundwater has been shown to discharge nutrients into the bottom water at selected sites in the Swan. However, little is known about the importance of groundwater sources of nutrients in the remainder of the Swan and nothing at all about this process in the Canning. Knowing the magnitude and timing of the contributions of groundwater sources is crucial to effective management.

Urban catchment modelling of flows. The relatively new and informative catchment model LASCAM was developed primarily for rural catchments and is only applicable with substantial developmental work to the mainly urban Canning catchment or the urban sub-catchments of the Swan such as Bayswater and Mills Street. There is a strong need for the development of urban catchment models to support decision-making for management.

Catchment processes affecting erosion and hydrology. There is a dearth of information about a number of catchment processes, the understanding of which would contribute to the improvement of catchment management and upstream water quality. For example, it is not known where most of the soil being washed into the Swan-Canning is coming from or where in the sub-catchments of the Avon and Swan-Canning is erosion of soils most serious. On the sub-catchment level, it is not known where most of the eroded soils originate, of what kind they are and under what conditions erosion takes place.

These knowledge gaps can be addressed by designing and implementing a research plan and program that targets them. Research in these areas should be linked to specific applied waterways management methods and result in field guidelines.

Action needed

- *A comprehensive research plan should be developed to fill critical knowledge gaps in several areas: in-river and waterway processes that contribute to algal blooms, processes in sediments and processes in catchments.*

5. Implementation recommendations

Management of waterways requires particular attention to maintain the health of the river body, and address factors that can degrade its integrity. This Action Plan has made it clear that excessive nutrient input to the waterways of the Swan-Canning system is the most significant influence degrading the quality and health of the waterways, and it addresses nutrient reduction in both rural and urban settings. Nutrient reduction is needed at the source, along watercourses and in the river to reduce the severity and frequency of nuisance algal blooms and, in the Canning River, toxic cyanobacterial blooms. The "actions needed" described in Section 4 include:

- Change existing urban, industrial and rural land-use practices to reduce nutrient losses from the catchments.
- Ensure that new developments, and changes to land-use, minimise nutrient losses.
- Restore catchments, foreshores, wetlands, streams and drains to maximise nutrient retention.
- Manipulate conditions in the river to reduce algal blooms.
- Report on reductions to nutrient inputs and algal blooms.

The recommendations in Section 5 describe the procedures needed to implement these actions.

Changes in existing land-use practices, and catchment and wetland restoration, are addressed through supporting Integrated Catchment Management.

Improving planning procedures and land-use management practices will ensure that new developments and changes in land-use reduce, or at least do not increase, nutrient inputs.

A variety of in-river techniques to modify river conditions will reduce the incidence and severity of algal blooms.

A program to measure and report on reductions in nutrient inputs and algal blooms will monitor river health and report progress to the community. A well-directed and applied research program will complement this.

The Task Force recognises that it will take at least 20 years to materially influence the overall water quality in the system. Consequently, recommendations are arranged with the first (catchment) requiring immediate implementation as they require a number of years to become effective. Recommendations listed towards the end (targets, monitoring, reporting) can be implemented within one to two years. As decision-support systems and models are developed for the Swan-Canning system they will prioritise future actions and recommendations. Realistically this will occur after the first five-year period of this Action Plan.

5.1 Support Integrated Catchment Management to reduce nutrient inputs

5.1.1 Strengthening Integrated Catchment Management in the Swan-Canning catchment and supporting ICM groups

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

ICM is one process for integrating catchment management. Others include Integrated Local Area Planning (ILAP), Whole Catchment Management and Total Catchment Management.

The aim of integrated natural resource management is sustainable use, protection and management of natural resources now and in the future. ICM is a process for coordinating the many activities involved in achieving this.

Managing the natural resources in a catchment involves dealing with a multitude of environmental, social and economic issues. There is no simple solution to the problem of eutrophication built up over many years as a result of a variety of land-uses.

The solution will require a range of actions to improve land-use planning and management and to address specific issues such as pollution. They include setting targets (for example for water quality), introducing statutory regulation, using economic and other incentives to encourage land-use reform, constructing on-the-ground works and providing engineering solutions. Success depends on coordinating the efforts of all land and water managers, land-holders, government, business, industry and the community.

ICM provides a mechanism for the necessary coordination.

Integrated Catchment Management has become established in the Swan-Canning catchment in the past five years. The Swan-Avon catchment was the site of Western Australia's first regional Natural Heritage Trust initiative, designed to demonstrate the effectiveness of a whole-catchment approach. The Swan-Avon ICM Program began in 1995. ICM groups in the Swan region were initiated and supported on the basis of community interest.

In 1994-95 the only active ICM group in the Swan-Canning system was the Bayswater Main Drain ICM Group but by mid 1998, 13 integrated catchment management groups and four Land Conservation District Committees (LCDCs) with catchment-wide ICM membership and interests had been established. The success of groups such as the Canning and Bayswater ICM Coordinating Groups is encouraging others to take a coordinated approach to local environmental issues. The Action Plan recognises that there are now over 85 community and environmental groups working towards improving the catchment,

Table 5: Catchment groups within the Swan-Canning system

Catchment groups within the Swan-Canning system	Date established
Bayswater Integrated Catchment Management (BICM)	February 1991
Swan Catchment Council (formerly Swan Working Group) (coordinating group for the Swan-Avon ICM Program in the Swan-Canning catchment)	April 1995
Canning Catchment Coordinating Group	May 1995
Litoria Catchment Care Group	1995
Bennett Brook Catchment Group	December 1995
Ellen Brook Integrated Catchment Group	January 1996
Upper Canning / Southern-Wungong Catchment Team	April 1996
Bannister Creek Catchment Group	May 1996
Blackadder Woodbridge Catchment Group	June 1997
Jane Brook Catchment Group	September 1997
Claise Brook Catchment Group	November 1997
Belmont-Victoria Park Catchment Management Group	April 1998
Helena River Catchment Group	May 1998
Gingin LCDC	1984
Wooroloo LCDC	1989
Chittering LCDC	1991
North Swan LCDC	1997

bushland and waterways environments. These groups are sustained by thousands of volunteers throughout the greater metropolitan region. The Action Plan also recognises that improvements to environmental problems like salinisation, sediment and nutrient loss in the greater Avon catchment are essential to the long-term health of the smaller downstream Swan-Canning system.

The role of ICM groups is to bring together all stakeholders in planning and decision-making for a defined catchment. These ICM groups will identify issues, set goals and encourage better informed planning and development decisions, with a focus on meeting these goals.

Strengthening and expanding ICM in the Swan-Canning catchments, and supporting catchment groups to specifically include strategies for reducing nutrient losses from the catchments, will play a large part in meeting the goals of the Swan-Canning Cleanup Program. While focus catchments that are currently the "hot spots" for nutrients are a priority, supporting community-based ICM across the catchment will be necessary to prevent problems arising as Perth expands, or to address them if they do arise.

The Swan Catchment Centre (SCC) was established in 1995 in response to community requests to provide support to ICM groups. Continuation of funding to the Catchment Centre is crucial. To ensure effective and consistent participation of community group and executive members, financial support will need to be provided - for example, for attendance and travel fees and administrative support.

In this section of the Action Plan, recommendations are followed by identification of responsible parties, with the lead agencies and parties in bold italics. There is a key to the abbreviations in the appendix of this document.

5.1.2 Developing and implementing catchment management and farm plans and managing drain inputs to reduce nutrients

Catchment Management Plans (CMPs) guide management of natural resources in a river or groundwater catchment, taking account of social and economic factors. They are a tool to help catchment management groups to agree on the issues, goals and strategies to be used, and to review their success. They can also be used to underpin aspects of town planning schemes and their land-use tables. CMPs define the management boundaries, describe environmental resources and identify issues of concern in the catchment such as the rehabilitation of degraded areas and the identification and monitoring of areas at risk. More extensive CMPs also review other relevant studies and may embody land ownership details, parties responsible for action and funding options. They need to include a review date to measure progress and make any revisions. In essence, the best CMPs are dynamic and change over time to reflect new information and issues.Catchment Management Plans are based on cooperative action by community groups, individuals and government agencies at all levels.

CMPs are being developed with the assistance of SRT, WRC, AGWEST and some local governments for several important catchments in the Swan-Canning system. These catchments are deemed "critical", either because they have been identified as large contributors of nutrients (e.g. Ellen Brook, Bayswater Main Drain, Southern-Wungong River and Canning River catchments) or because community concern has created an impetus for action.

CMPs based on Water-Sensitive Design principles and focused on reducing nutrient loss must be developed for the rural and urban catchments of the Swan-Canning system. The plans need to include stream and drain restoration measures, erosion control, use of natural and constructed wetlands and coordinated weed control. The SCCP program is helping to develop Catchment Management Plans for the Ellen Brook, Canning River and Southern-Wungong River catchments. The latter was completed in 1998 and the Ellen Brook Catchment Management Plan will be completed by mid 1999. The Bayswater Integrated Catchment Management Group has recently completed a management plan but needs adequate support for its implementation.

The Department of Environmental Protection is in the process of developing guidelines to help community groups and farmers prepare Catchment Management Plans.

Several drains in the Perth Metropolitan Area (e.g. Mills Street, Bayswater and South Belmont main drains) could be targeted for intensive intervention to improve water quality before any flows reach the Swan-Canning system. These targeted drains would need to incorporate a number of design features including trash racks, splash boards (to increase oxygen content), nutrient-stripping and sediment-trapping basins, and areas for the application of sediment remediation material. Targeting drains using these strategies can be an important part of urban Catchment Management Plans.

Farm Management Plans (FMPs) are a strategic approach developed by the farmer to balance economic, social and environmental factors that need to be taken into consideration when managing a farm business. They are individualistic and heavily influenced by the farmer's own personal values. FMPs contain a number of operational elements such as:

- stocking rates;
- planting of perennial and forage trees for summer pasture;
- streamline fencing and restoration;
- erosion control (catchment and foreshore);
- fertiliser use;
- use of natural and constructed wetlands;
- earthworks (e.g. grassed waterways to manage surface water).

Farm Management Plans are effective tools to ensure source management of nutrients and sustainable farming practices. They complement CMPs and can be extremely helpful in leading farming operations so that they are sustainable and profitable.

A section of the *Tax Act* allows the costs of preparing a Farm Management Plan to be tax deductable providing the plan is approved by the local regional office of Agriculture Western Australia or the local Land Conservation District Committee.

Recommendation 1

Strengthen Integrated Catchment Management in the Swan-Canning catchment and support ICM groups.

1.1. Provide executive and administrative support for Integrated Catchment Management groups in the Swan-Canning system. **(*WRC*, SRT)**

1.2. Appoint Catchment Coordinators to support completion and implementation of Catchment Management Plans in the four focus catchments (Ellen Brook, Southern-Wungong River, Canning River and Bayswater Main Drain) to reduce nutrient input. **(*WRC*, AGWEST, LGs, MfP, WC, SRT,** LCGs)

1.3. Support and establish additional ICM groups and appoint Catchment Coordinators to further ICM processes and to develop and implement Catchment Management Plans in the other catchments that have high nutrient concentrations entering the rivers and estuary (South Belmont Main Drain, Bennett Brook, Bannister Creek, Mills Street Main Drain, Blackadder Creek, Yule Brook, Susannah Brook and Bickley Brook). **(*WRC*, AGWEST, LGs, MfP, WC, SRT,** SCC, LCGs)

1.4. Complete the development and implementation of the Swan-Avon regional strategy ("Working Together" document prepared by SAICM and the Swan Catchment Centre) which develops partnerships with key stakeholder groups involved in planning and management of the river and catchment. **(*WRC*, SCC, SRT, WAPC, AGWEST,** LGs, LCGs)

1.5. Prepare catchment management guidelines for the reduction of nutrient losses from rural and urban catchments. **(*WRC*, AGWEST, MfP,** LGs, DEP, LCGs)

1.6. Provide support for development and implementation of farm management plans that ensure sustainable farm practices while reducing nutrient loss from farm activities, including part-time farm activities. **(*AGWEST*, LGs)**

1.7. Provide seed funding to determine feasibility and cost effectiveness to design and construct artificial wetlands as demonstration sites for stripping nutrients in the Mills Street and South Belmont main drains. **(*WRC*, WC, LGs,** SRT, DEP)

1.8. Provide funds to fence, stabilise and revegetate watercourses in the catchments as part of developing and implementing Catchment Management Plans. **(*WRC*, AGWEST,** SCC, LGs)

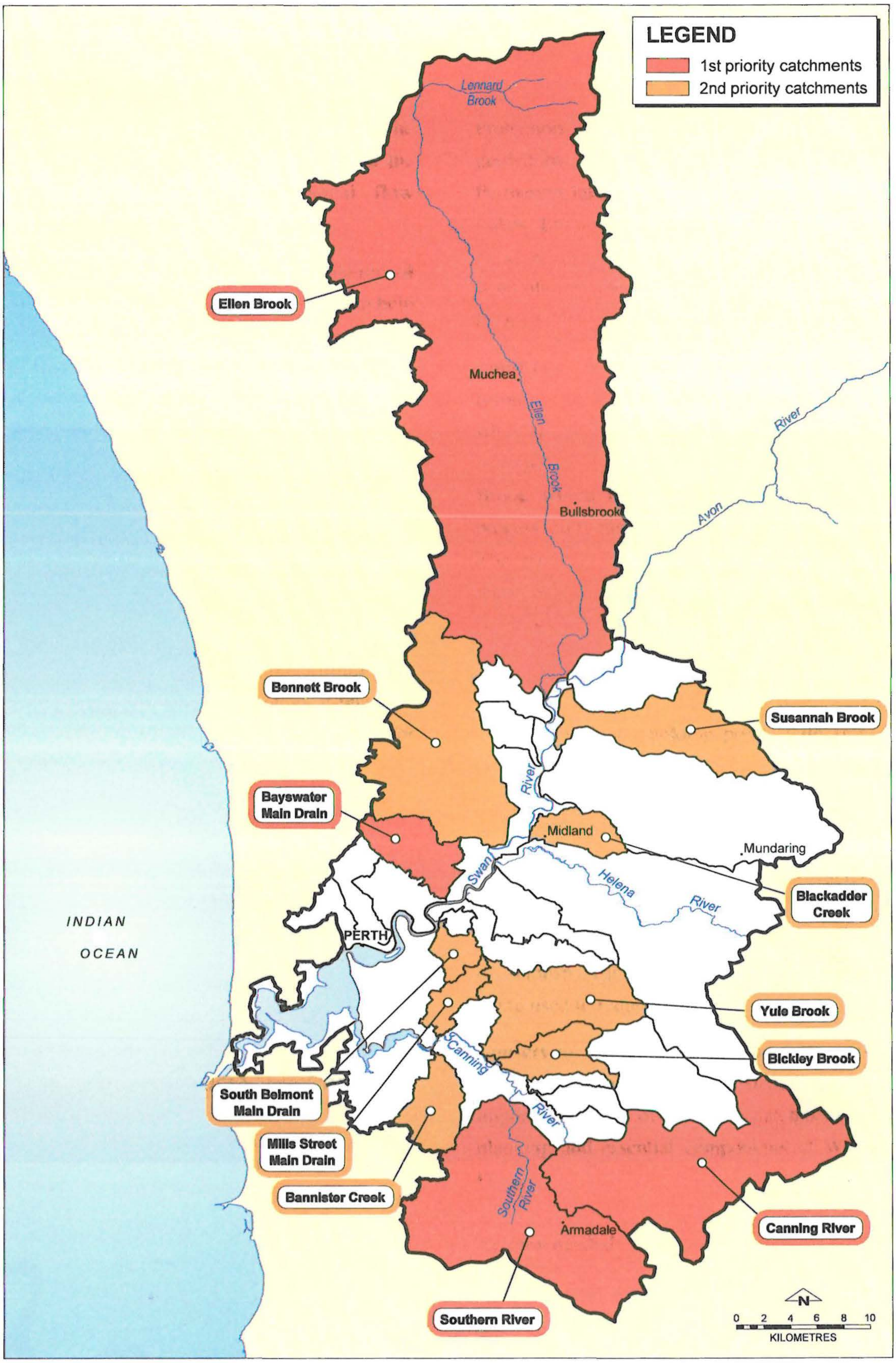
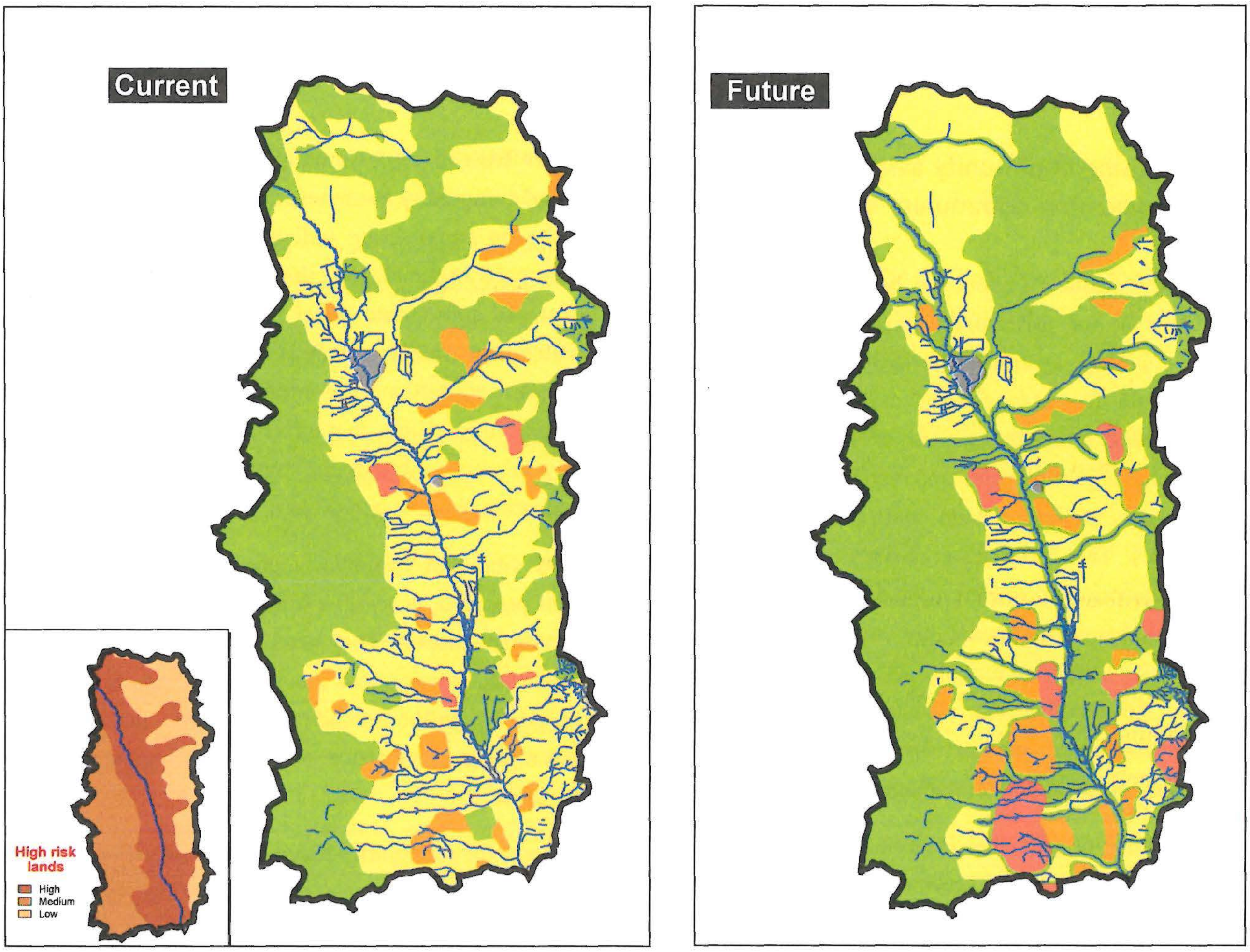


Figure 23: Focus catchments of the Swan-Canning system

There are both first and second priority catchments requiring development, completion or implementation of Catchment Management Plans (CMPs). The Action Plan recommends the appointment of Catchment Coordinators to expedite development and implementation of CMPs in conjunction with community groups and local governments.



Land use	Management
Urban / services	- Water Sensitive Design (WSD) - Nutrient stripping - Vegetated parks and reserves
Grazing	- Farm plans - Fertiliser management - Stocking densities - Re-vegetation -- stream lining (50-100 m buffers) -- windbreaks and flora and fauna corridors - wind and water management (erosion management)
Industry	- Waste Management Plans (WMP) - Vegetation buffers - Licence controls
Vegetation	- Notice of Intent (NOI) clearing controls - Fencing - Stock management plans - Fire management plans - Reserve management plans
Intensive land use	- Nutrient Irrigation Management Plans (NIMP) - Nutrient stripping - Buffers with vegetation (50-100 m) - Integrated Pest Management (IPM)

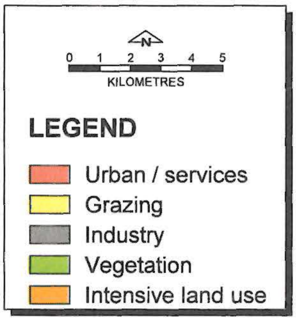


Figure 24: Hypothetical Catchment Management Plan

Catchment Management Plans (CMPs) help guide land-use and planning and development to meet water quality and other management goals. Five general land-uses and some of the management features associated with a hypothetical CMP have been depicted. Note the relocations and the vegetated buffers around many of the land-use locations which would be realised over the long term. To be effective, CMPs involve the whole community, particularly land-users and local government, to realise long-term goals. These long-term goals must consider water quality issues and provide specific guidance for management such as fencing large rural watercourses to prevent or restrict animal access. CMPs must also be adaptive and change with the times.

5.1.3 Raising community awareness and supporting community involvement

Community concern about the health of the river was the catalyst for government action to clean up the Swan-Canning system. The Swan River Trust is responsible for management and protection of its management area (the waters of the Swan-Canning system and adjoining parks and recreation reserves), and its activities include erosion control and restoration of foreshores. The Swan River Trust is an agency with limited powers and resources, and it does not have the capacity to comprehensively manage all of the waterways and catchments of the Swan-Canning system. An effective river cleanup plan will depend on strong continued support by way of community involvement in catchment management.

Considerable progress has been made in recent years in developing Integrated Catchment Management in the Swan-Canning system. In many areas, the community is leading the way through various environmental and catchment groups. Some groups have projects aimed directly at restoration of the Swan River and its tributaries; others have different objectives, such as bushland restoration, but with spinoffs for river water quality. Some of the community-based initiatives have led the way in catchment restoration with Men of the Trees, Greening Western Australia, Weeds Action Group, Urban Bushland Council, Wetlands Conservation Society and the Wildflower Society playing leading roles. There are over 50 other local river-care and bushland groups.

Because of their long association with and intimate knowledge of the waterways of the Swan-Canning system, Aboriginal people could provide valuable assistance in activities to clean up the river.

Community awareness of environmental issues is generally high, but awareness is not necessarily supported by understanding. There is a need to explain to the public what is happening to the river's water quality and ecology, the management issues, the possible roles of community groups and individuals, and where people can find more information or opportunities to participate. Community consultation by the Swan River Trust in 1995 substantiated the strong need for a broad community awareness campaign. The focus needs to be on empowering individuals and groups to play their parts in the cleanup through their own actions, for example appropriate water and fertiliser use in their 'catchment-friendly' gardens. This would enhance and support activities of community groups and other organisations. Signs that inform the public of the names of watercourses and drains can help raise awareness and education about watercourses.

It is vital that community groups are provided with well prepared, accessible information, technical advice and direct support. They need to have an opportunity to influence government decision-making as well as support for on-the-ground projects. They also need to be given government officer support to minimise volunteer burn-out.

Support for community-based catchment management is provided by the Swan Catchment Centre (part of the Swan-Avon ICM Program). The centre is a focal point for networking, supporting catchment groups, information exchange, publicising activities and accessing training and resources.

Although technical reports and publications are available, they are often not readily accessible, and information is presented in a form that is not 'user-friendly'. The Swan Catchment Centre can provide 'one-stop-shop' access to information and technical advice, and can distribute material from government agencies. The need for information by local government, catchment and community groups will increase when recommendations in the Action Plan are implemented. Therefore, the centre requires more resources to enable it to respond to community needs, and future funding is uncertain.

Targeted, accessible information should be provided on the key issues of nutrient source management and drain and stream restoration, for example:

- adoption and development of Best Management Practices;
- community involvement in river-care and catchment management;

- fertiliser use;
- drain and stream restoration, including revegetation and engineering intervention;
- Water-Sensitive Design;
- waste disposal practices;
- dewatering;
- soil testing;
- catchment and foreshore erosion control;
- foreshore weed control.

The community should also be familiar with State policies, relevant legislation and regulatory mechanisms and the environmental goals of this Action Plan through the availability of targeted information.

To increase the knowledge and skills of community participants, there should be training and workshops covering the broad issues of catchment management, nutrient enrichment and land degradation, as well as the practical skills required for bushland and streamline restoration.

Recognition needs to be given to the critical role played by volunteer members of community catchment groups and the volunteers that help project activities. Education and direct government support are vital to maintaining volunteer enthusiasm and to the development of demonstration sites and successful completion of on-the-ground works.

Ribbons of Blue, a program supported by the State, the Federal *Waterwatch* program and private sponsors, provides an educational model that encourages learning and involvement. The program's focus is on monitoring water quality, understanding the results and converting this into action for the environment. Students develop the necessary knowledge, skills and values to be environmentally responsible citizens through practical involvement in field activities. The program also influences parents, teachers and other organisations, especially local government bodies, which become involved in projects. Ribbons of Blue coordinators play an important role in linking school education, community projects, Landcare and local government activities, but they are few and their involvement is part-time. The program should be extended to provide greater support for school and community programs including technical support for water monitoring.

Recommendation 2

Raise awareness and provide support to enable the participation of land-holders, catchment and river management groups, local government and the broad community in catchment and river management.

2.1. Implement a cross-media public awareness campaign involving a variety of information sources for the general public to encourage changes in individual behaviour and involvement in river-care and catchment management. (***SRT***, SCC, DEP, AGWEST)

2.2. Through the Swan Catchment Centre, provide locally applicable technical and administrative support, information, advice and training to those involved in or affected by catchment management to enable their effective involvement in catchment management decision-making and practical activities. (***WRC***, **SCC, SRT, AGWEST,** DEP)

2.3. Extend the Ribbons of Blue program to ensure better support of school and community education programs linked to practical action for the Swan-Canning river environment. (***WRC***, **SRT**, SCC, LGs)

5.1.4 Improving government coordination and support

The long-term success of the Action Plan depends on effective government coordination and support. Strategic mechanisms include development of Partnership Agreements, Memorandums of Understanding and Senior Officer Steering Committees between key State agencies and local governments. These mechanisms would work more effectively if all parties were aware of and support a common language which defines permissible and priority land and water uses in the catchment.

The Action Plan subscribes to the philosophy of applying the principles of natural resource management in all planning decisions in the Swan-Canning catchments.

Local governments need trained environmental officers to help implement improved council practices, raise local community awareness and meet the goals of nutrient reduction and better land-use. Trained environmental officers also help councils assess developments, review and improve statutory mechanisms, and improve environmental management performance.

Effective communication with, and support for, community and ICM groups is required to establish ICM, integrate decision-making and rank support needs.

Recommendation 3

Improve government coordination and support.

3.1. Establish formal and financial agreements involving State government agencies and local governments defining responsibilities for implementation of the Action Plan and ICM and audit progress after five years. (***SRT*, WRC, LGs, MfP,** AGWEST, DEP, WC)

3.2. Establish a Senior Officers Group to audit and manage agreements defining responsibilities for implementation of the Action Plan. **(*SRT*, WRC, WAMA, AGWEST, DEP, WC, MfP, CALM, SAICM)**

3.3. Establish a Project Managers Group that reports to the Senior Officer Group to coordinate projects and activites to implement the Action Plan and an Interdepartmental Catchment Management Liaison Unit to review land-use controls and define agency responsibilities. **(*WRC*, SRT, WAMA, AGWEST, DEP, WC, MfP, CALM, SAICM, LGs)**

3.4. Financially support the appointment of environmental officers to formulate and prepare local government natural resource management strategies and policies. **(*WRC*, LGs)**

5.2 Improve planning and land-use management to reduce nutrient inputs

5.2.1 Statutory mechanisms, town planning and policy

The Action Plan advocates a partnership between the State and local governments, the public and the business community. The State and local governments will need to look at statutory tools such as regulations, town planning schemes and State policies to meet the goals of the Action Plan. In turn, the community will need to look at and participate in town planning scheme reviews and amendments and catchment management processes and be involved in other public statutory processes such as environmental assessments.

Statutory enforcement of management plans for the Swan-Canning catchment areas is possible through the pollution control provisions of the Environmental Protection Act and town planning schemes prepared under the Town Planning and Development Act. Regulations prepared under legislation for the Swan River Trust and those dealing with water and sewage contribute to coordinated catchment and river management. Local government by-laws also contribute. Proposals for development and changes to land-use and zoning trigger a hierarchy of regulatory mechanisms that require the proponent, the public, local government and State government agencies to make decisions. These decisions must comply with town planning schemes and State policies (see Table 6 for legislation affecting land-use and waterways management).

5.2.1.1 Regulations

More effective regulation and enforcement can contribute to better catchment and river management. Practices and land-uses that generate wastes unsuitable for the sewerage system and that are unacceptable for the drainage network must be identified and regulated to minimise illegal disposal and impact on the environment.

Enterprises that produce large quantities of nutrients, such as piggeries, stock-holding paddocks and intensively used recreation areas, should be located on land that does not threaten watercourses and wetlands. Improved regulation of activities such as dewatering of construction and development sites will reduce erosion, sediment inputs and high nutrient discharges. Non-conforming land-uses that generate nutrient and sediment exports must be carefully regulated. Coordination between the regulatory agencies and local government is essential.

5.2.1.2 Town planning

The Metropolitan Region Scheme is a broad-based regional planning scheme for the Perth Metropolitan Area within which local governments prepare town planning schemes for their districts. The majority of local governments in the Swan-Canning coastal catchment are influenced by it. Town planning schemes can be structured to support and complement Government policies and legislation affecting the environment and its management.

It is important that future regional planning and town planning schemes incorporate the principles and goals of the Swan-Canning Cleanup Program and ensure that land-uses are not detrimental to the future of the Swan-Canning system. Local government town planning schemes, which are more detailed than regional planning schemes, should incorporate Water-Sensitive Design principles. Land-use tables in these schemes should specifically eliminate uses that can contribute nutrients and sediments to watercourses and wetlands. Issues that the schemes can cover include:

- protection and enhancement of wetlands and use of constructed wetlands;
- development of controls to minimise soil erosion and maintain adequate vegetated buffers;
- stream and drain restoration.

The Action Plan recommends that all parties incorporate the principles and goals of the Swan-Canning Cleanup Program in regional planning and town planning schemes and scheme amendments.

	Agriculture Western Australia	Bush Fires Board	Dept of Conservation & Land Management	Department of Environmental Protection	Department of Land Administration	Environmental Protection Authority	Fisheries Western Australia	Health Department	Local Governments	Ministry for Planning	Office of Water Regulation	Swan River Trust	Western Australian Planning Commission	Water Corporation	Water and Rivers Commission
Soil and Land Conservation Act	■														
Fire Brigades Act		■							■						
Conservation and Land Management Act			■												
Environmental Protection Act				■		■									
Land Act					■										
Fisheries Act							■								
Health Act								■	■						
Local Government Act									■						
Town Planning and Development Act									■	■			■		
Metropolitan Region Town Planning Scheme Act										■			■		
Planning Legislation Act										■			■		
Western Australian Planning Commission Act										■			■		
Water Services Coordination Act											■				
Water Agencies Powers Act											■			■	■
Swan River Trust Act												■			
Country Towns Sewerage Act														■	
Land Drainage Act														■	
Metropolitan Water Authority Act														■	
Water Corporation Act														■	
Metropolitan Water Supply, Sewerage and Drainage Act														■	■
Rights in Water and Irrigation Act															■
Water & Rivers Commission Act															■
Waterways Conservation Act															■

Table 6: Acts of Parliament that affect land-use practices and management of water quality in the Swan-Canning system, and the bodies involved in their administration

5

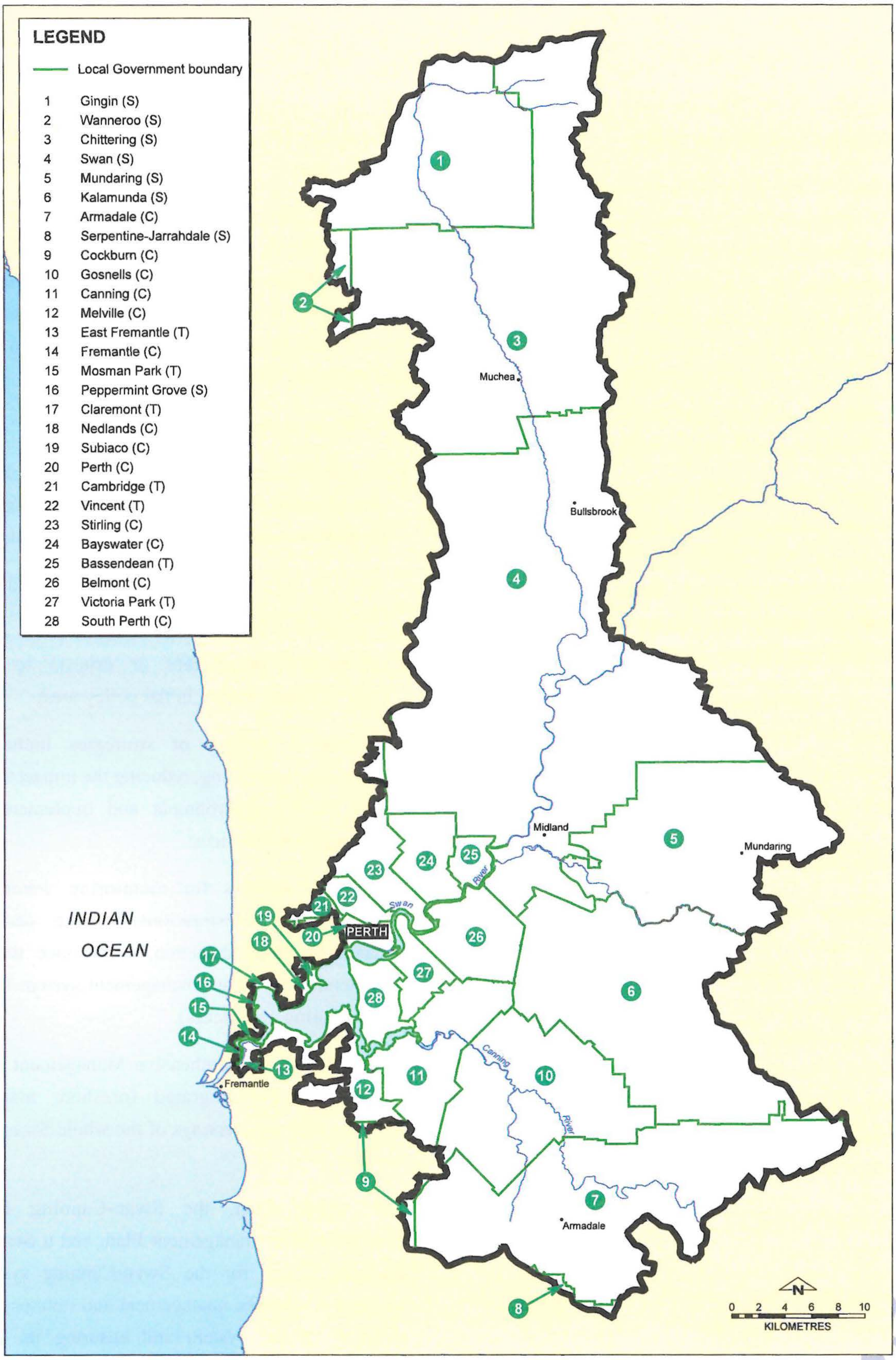


Figure 25: Local government boundaries in the Swan-Canning system

Twenty-eight local governments exist in the Swan-Canning system and many have significant areas of watercourses and foreshores. Local governments will be responsible for implementing and overseeing many aspects of the Action Plan. Many of these authorities are currently involved in catchment, conservation, planning and development projects that directly affect the success of the plan.

5.2.1.3 Statements of planning policy

Section 5AA of the *Town Planning and Development Act* 1928 allows the WA Planning Commission, with approval of the Minister for Planning and the Governor in Executive Council, to prepare statements of planning policy. These policies may make provision for any matter that may be the subject of a town planning scheme but are directed primarily towards broad general planning and facilitating the coordination of planning throughout the State by local governments.

All local governments and the Town Planning Appeals Tribunal must pay due regard to these policies. They are therefore ideal tools for establishing the principles of the Action Plan, drafting standard clauses for inclusion in town planning schemes, and influencing the decisions of the Town Planning Appeals Tribunal.

Revision of town planning schemes is an effective mechanism for phasing out high-nutrient land-use activities if they are unable to meet nutrient reduction objectives.

5.2.1.4 Environmental Protection Policies

Environmental Protection Policies (EPPs) are formulated under the *Environmental Protection Act* 1986 to provide protection to any portion of the environment or to prevent, control or abate pollution in the environment. Once gazetted they have the power of being a part of the Environmental Protection Authority Act. They define environmental objectives such as the draft water quality targets that are proposed in this Action Plan. EPPs can also provide for:

- control and management of activities that can degrade waterways;
- encouragement and support for protecting the beneficial uses of waterways;
- development of a framework and processes for evaluating foreshore and catchment clearing in urban and semi-rural areas;
- preparation of Best Management Practices for the range of activities that can impact the Swan-Canning system;
- the outline of a program to protect beneficial uses of a policy area.

Parliament has gazetted an EPP for the Swan-Canning system (SCEPP). The Task Force has made the Action Plan complementary to the SCEPP and recognises the requirement for a Comprehensive Management Plan to be developed by the Environmental Protection Authority and the Swan River Trust.

The Comprehensive Management Plan will:

- provide a framework and schedule for coordinate management of designated catchments and identify the parties responsible for that management;
- identify areas requiring protection and needing remedial action;
- recommend parameters or criteria to measure environmental quality in the policy area;
- develop a number of strategies including the prevention of littering, reducing the impact that drains have on the environment and implementing Best Management Practices;
- define a process for monitoring water quality, undertaking investigations, setting performance standards, trend detection, compliance testing and implementing a data management system (including data sharing and access).

Ultimately the Comprehensive Management Plan will provide for an integrated foreshore management program for the waterways of the whole Swan-Canning system.

The Action Plan, the Swan-Canning EPP and Comprehensive Management Plan, and a Statement of Planning Policy for the Swan-Canning system will together provide the management and statutory basis for cleaning up the system and ensuring its long-term health.

Recommendation 4

Use statutory mechanisms including regulations, by-laws, town planning schemes and statements of planning policy to modify land-use practices and prevent or relocate polluting activities.

4.1. Incorporate Water-Sensitive Design and nutrient source reduction principles and goals of the Swan-Canning Cleanup Program and the Swan-Canning Environmental Protection Policy, in regional planning and town planning schemes and scheme amendments to ensure that proposed developments are consistent with these principles and goals. (***MfP*, WAPC, LGs, DEP,** WRC)

4.2. Prepare a statement of planning policy for the Swan-Canning coastal catchment that incorporates the principles and goals of the Action Plan and that is also complementary to the Swan-Canning Environmental Protection Policy; and establish a group to review land-use tables in town planning schemes to identify and phase out high-nutrient land-use activities that are unable to meet nutrient reduction objectives and determine what steps are required to eliminate or manage them. (***MfP*, WAPC, LGs,** WRC, SRT, AGWEST, DEP)

4.3. Improve land-use controls for intensive agriculture such as horticulture that are not adequately addressed by present legislation or planning policy to identify and phase out high-nutrient land-use activities that are unable to meet nutrient reduction objectives and determine what steps are required to eliminate or manage them. (***MfP*, LGs,** AGWEST, DEP)

5.2.2 Developing and implementing Best Management Practices

Improving current land management practices and restoring degraded land and foreshores can significantly reduce nutrient inputs. Improvements can be achieved through implementing Best Management Practices (BMPs), introducing regulatory mechanisms and providing information, support and incentives. A review of current practices in farming and intensive agriculture, development and construction, light industry, fire and flood management and clearing of native vegetation would identify where changes are necessary.

BMPs complement industry standards and objectives, taking account of the state of technology, local conditions, practicalities and financial implications. They can be applied to the design of industrial processes and structures, and to business, industry and land-use practices. BMPs will set out the steps necessary to achieve more sustainable methods of operation and to implement measures to prevent pollution of waters. Companies and agencies can often develop their own methods to meet the defined standards, leading to innovation as well as improved practices. The approach is flexible and allows for continual improvement as research and technology progress. Furthermore, the process of developing BMPs will be a statutory requirement in the Swan-Canning Environmental Protection Policy.

Practitioners whose activities contribute nutrients to the river system and land managers and regulators who are responsible for land and water resource planning and management should be trained in Best Management Practices.

Nutrient and pollutant loss from land is a function of the concentration of the nutrients or pollutants in water, air or transported sediment (i.e. the carriers) and the quantity of these (i.e. their mass). Consequently, these losses can be reduced by decreasing either their concentration or the carrier mass. In selecting a BMP it is useful to determine how nutrients and pollutants are being transported to receiving waters. A BMP that modifies this manner of transport may then be identified.

BMPs can be classified as to how they reduce carrier mass and nutrient and pollutant concentrations on their delivery from the source area to the receiving waters.

- **BMPs that reduce carrier mass**

  Examples of BMPs that reduce carrier mass include street sweeping, conservation tillage, contouring, terracing, vegetative filter strips, grassed swales and protective vegetative cover. Many of these BMPs are erosion control practices and consequently are effective in reducing sediment-bound nutrients and pollutants.

- **BMPs that reduce nutrients and pollutant concentration**

  BMPs intended to reduce nutrient and pollutant concentrations usually involve modifying the method, rate, timing and formulation of chemical applications. The concentration of a chemical at the land surface may be reduced by removing the chemical altogether, reducing application rates or applying the chemical when it is less susceptible to loss. This is true for BMPs that include Integrated Pest Management, improved manure and fertiliser management, street sweeping and waste oil collection and recycling.

- **Structural BMPs**

  Structural BMPs that reduce nutrient and pollutant delivery include landscaping and physical structures and can sometimes be considered "end-of-the-pipe". They use terracing, filter strips, wetland filters, sedimentation detention ponds and basins, porous pavement and infiltration trenches.

Whatever the BMP, it is imperative to remember that BMP effectiveness is extremely site specific. Effectiveness is controlled by characteristics of the site's soil, topography, hydrology and a number of other factors.

Estimates of BMP effectiveness are essential for:

- selecting the most appropriate BMP for a particular problem and site;
- estimating the benefits of BMP implementation;
- ranking BMP alternatives in terms of cost-effectiveness;
- determining an optimum BMP program based upon program objectives.

Consequently, BMPs may be broadly categorised into three groups - those that:

- have known effectiveness, cost and management regimes;
- are suspected of being useful, but have not been tested locally;
- have yet to be defined in terms of their design, effectiveness or cost of implementation.

BMPs that reduce nutrient and pollutant concentrations at their source are considered to be the most cost-effective options for improving water quality. In contrast, structural BMPs are generally more expensive, particularly in established residential areas, because of their initial high capital cost (associated with acquiring lands for such installations) and maintenance costs.

Monitoring of new and untried BMPs will be required to establish their performance and effectiveness. This will allow us to build up an information base on those BMPs that are appropriate to Western Australian conditions. It will also allow us to recommend and require those BMPs that will be necessary for compliance with a regulatory requirement such as for discharge licences.

Key areas that would benefit from BMPs are:

- Water-Sensitive Design;
- stormwater drainage design and management (including WSD, trash racks and integrated drain management plans);
- drain and stream restoration techniques;
- fire management and fuel reduction in riparian areas;
- dewatering construction and development sites;
- foreshore weed control;
- erosion control and repair;
- Integrated Pest Management;
- aquaculture management;
- fertiliser and irrigation practices (including soil-testing and integrated water and fertiliser management for horticulture, market gardens, nurseries, turf farms, ovals and urban landscaped areas);

- treatment and disposal of livestock effluent;
- industrial waste management;
- street and hardstand pavement sweeping.

Water-Sensitive Urban Design (WSUD) guidelines are one example of an existing and available 'toolbox' of BMPs which may be employed to manage the effects of stormwater discharge and other aspects of water management. Further definition of the costs, effectiveness, design and management of these practices will be required for urban, rural and industrial land uses.

5.2.2.1 Sharing the risks of BMPs

It is likely that, upon implementation, some BMPs may be found to be not as effective as initially intended. However, should provision for BMPs (particularly structural ones) not be made at the time of planning and development approval, the likelihood of retrofitting these practices to established urban areas is likely to be small. It is important that industry, decision-makers and the community recognise and share the risks and uncertainty of establishing and maintaining BMPs in the rural and urban landscape. Monitoring and reporting will help planners and managers quickly assess the value and effectiveness and further use of BMPs.

Recommendation 5

Develop and adopt Best Management Practices for nutrient reduction in current land management practices and in all future developments, redevelopments and stormwater drainage schemes.

5.1. Establish a Best Management Practice (BMP) working group to evaluate existing BMPs and prepare a program to develop and implement BMPs to achieve SCCP objectives. (***WRC*, SRT, AGWEST, DEP, WC, LGs,** LCGs)

5.2. Establish an extension program to facilitate development and implementation of Best Management Practices (e.g. Water-Sensitive Design, Integrated Pest Management, Nutrient Irrigation Management Plans, industrial waste disposal, spill and washdown practices) by training practitioners whose practices contribute nutrients to the river system and land managers who are responsible for land and water resource planning and management. (***WRC*, AGWEST, DEP, MfP, WC, SRT, SCC, LGs**)

5.2.3 Economic and other regulatory mechanisms

Economic instruments include rebates, levies, incentives, disincentives, penalties, concessions and differential rating to promote sustainable land-use and water management in the catchment. These instruments should encompass all rural, urban and industrial land-uses. A package of economic incentives is also required to encourage catchment restoration.

Economic incentives can include:

- introducing "tax breaks" that reward changes in land-use and land restoration;
- setting differential rates that reward land-holders and land-users for improved land practices and restoration efforts, and encourage catchment land-use reform;
- buying back land;
- obtaining partial acquisition of land development rights of the landowner;
- paying land-users to change land practices on designated lands.

Economic incentives can be incorporated into the Comprehensive Management Plan required under the Swan-Canning Environmental Protection Policy. The feasibility and structure for economic mechanisms can be investigated and outlined in the Comprehensive Management Plan.

Refer to Appendix 2 for a brief discussion of tax credits associated with economic instruments used for restoring catchments and foreshores.

Another worthwhile approach could be to develop servitude, foreshore management agreements and/or other formal agreements (caveats and memorials) with landowners, for example to improve land-management practices on floodplains, foreshores and high-risk lands along watercourses. Agreements could define the support to be provided from agencies, including materials, labour and technical advice. In turn, landowners would maintain foreshores to minimise export of nutrients and sediments to the river, fence to restrict livestock access and rehabilitate degraded foreshores. Voluntary and required agreements as a condition for development or land-use change are examples of a combination of voluntary and statutory controls.

Licensing is another useful regulatory mechanism. For example, drains acting as point sources of pollution could be licensed and controlled.

Recommendation 6

Use economic and regulatory mechanisms to encourage catchment, wetland and river foreshore management for nutrient reduction.

6.1. Evaluate the establishment of and mechanism for financing a land acquisition fund to buy back sensitive or degraded land and change current land-uses. (***MfP*****, AGWEST, LGs,** WRC, CALM, Treasury)

6.2. Develop foreshore management agreements with landowners to reduce nutrient losses to watercourses, through fencing and rehabilitation of foreshores and erosion control with initial priority given to Ellen Brook and Southern-Wungong River. (***WRC*****, LGs, LCGs**)

6.3. Provide State and local government incentives to encourage catchment rehabilitation by rewarding landowners for adopting practices that reduce nutrient inputs to the river. (**WRC, AGWEST, LGs, C&T**)

6.4. Investigate licensing for drains discharging into the Swan-Canning rivers, as a tool for controlling nutrient inputs. (***DEP*****, WC, WRC,** LGs)

5.3 Modify river conditions to reduce algal blooms

River management is intended to maintain natural riverine and biological processes, and bank and streambed stability. Management options include foreshore management, streamline protection and revegetation, ensuring adequate environmental flows in regulated streams, engineering intervention in riverine and estuarine processes and controlling human access. Restoration and protection of buffer zones of vegetation along watercourses will secure a biological filter for nutrients and prevent erosion. Balancing the harvesting of water needs for drinking purposes while providing adequate environmental flows is extremely difficult. Consideration will need to be given to compensating agencies for "essential water" that needs to be released to improve stream quality.

The SCCP has undertaken research and trials to develop a 'toolbox' of intervention techniques to reduce the occurrence of algal blooms (see Section 4.5). Promising techniques that require further development include oxygenation and sediment remediation, separately and in combination.

The Water and Rivers Commission and the Swan River Trust need to continue to investigate and test any promising techniques that could be added to this toolbox.

Recommendation 7

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

7.1. Develop river oxygenation methods to an operational scale, undertake oxygenation trial in the Swan River to reduce nutrient availability and implement if successful. (***SRT,*** **WRC)**

7.2 Operate oxygenation plant in the Canning River to reduce nutrient availability. (***SRT,*** **WRC)**

7.3 Develop sediment remediation methods to an operational scale and apply the technique in the Swan and Canning rivers to reduce nutrient availability. (***SRT,*** **WRC)**

7.4. Develop and evaluate new river intervention techniques to reduce algal blooms. (***SRT,*** **WRC)**

7.5. Construct an artificial wetland to strip nutrients from Ellen Brook using oxygenation, sediment remediation and other techniques. (***WRC,*** **SRT,** DEP)

7.6. Evaluate nutrient and pollution risk from former landfill sites bordering the rivers and drains. (***SRT,*** **WRC, DEP, LGs)**

7.7. If risk is unacceptable undertake appropriate management action to reduce nutrient and pollutant leaching from former landfill sites bordering the rivers and drains. (***SRT,*** **WRC, DEP, LGs)**

7.8. Develop and implement a management plan for the Canning River based on environmental flow allocations and controlled discharges from the Kent Street Weir. (***WRC,*** **SRT, WC)**

7.9. Restore the ecological function of the Swan-Canning foreshores and secure erosion protection. (***SRT,*** **WRC, LGs,** DEP, LCGs, AGWEST)

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

5.4.1 Water quality targets

The prime purpose of the Action Plan is to improve and maintain water quality and reduce the frequency and duration of algal blooms. An important part of river management is to monitor water quality in the tributary inflows to the estuary and in the estuary itself. Measuring performance or progress is referred to as environmental auditing. It has three main components:

- identifying sources of contaminants and the timing of their contribution to rivers and estuaries (spatial and temporal information);
- testing compliance with water quality targets (compliance monitoring);
- measuring progress towards meeting water quality targets (trend detection).

The main sources of nutrient input to the Swan-Canning system have largely been identified (see Sections 4.2.1 and Appendix 3). The next phase of the water quality monitoring program is to confirm water quality targets that can be used as goals for the SCCP. Compliance testing against water quality targets will be carried out and reported on annually. Detailed analysis for trends in water quality will be done at regular but longer intervals, no less frequently than five-yearly. An analysis of trends in phosphorus and nitrogen levels in tributary inflow to the Swan-Canning system will become available in 1999.

Targets should help management to assess progress and maintain a momentum of success. Unachievable water quality targets in the short term can actually be counterproductive, acting only to demoralise the management effort, whereas in fact there may be real progress.

In the revision of the national ANZECC water quality guidelines currently under way, four types of target are recognised: ecosystem-based, management-based, issue-based and risk-based targets. The proposed targets for the SCCP fall into the categories of management-based and issue-based, and the issue addressed by the targets is enrichment of the estuary with nutrients and consequent algal bloom activity.

It is difficult to predict the changes to algal bloom activity that will result from the achievement of estuarine nutrient concentration targets because there is not a direct relationship between algal abundance and nutrient concentrations. The ecological model developed by the WAERF will endeavour to provide predictive capacity for the Swan-Canning system.

A target for reduction in algal bloom activity is also being developed by the Water and Rivers Commission as a measure of improvement in the quality of estuarine waters.

The targets for catchment streams are computed to meet management objectives in the estuaries; they are not meant to be a measure of water quality in the wider catchment. There is confidence that compliance with the targets for incoming waters will result in reductions of phytoplankton activity in the Swan-Canning system. However, because of the internal supply of nutrients from the sediments of the estuaries, the catchment targets will need to be met for some time before there can be confidence about seeing a measurable change in phytoplankton activity.

Nutrient loads (flow multiplied by concentration) are difficult and expensive to measure accurately and are very different between wet and dry years. Experience with nutrient loads is now leading authorities to change from measurement of nutrient *loads* to measuring the *number of times nutrient concentrations exceed a set target*. The SCCP recommends compliance testing based on the latter strategy, taking note of 'exceedances'. The measuring of variation from a set target is known as an **excursion method**. Load estimates still have a place in research and in determining nutrient budgets, but the Task Force believes that an excursion method for reporting on nutrient levels and monitoring progress of the Action Plan is a better, more practical and more reliable system. **Nutrient yields** (kilograms per hectare) are also helpful to management because they are calculated independently of flows but indicate how much is leaving the catchments.

The Action Plan therefore recognises two targets - one for the short term, over five years, and one for the long term, within 20 years. To provide cost-effective measures of progress to the SCCP management, and to satisfy the Action Plan's short- and long-term goals, the Plan recommends five and 20-year nutrient performance targets. These targets are based on the number of times nutrient concentrations exceed set levels. They may be refined if monitoring data over longer periods indicates the need for change in both numbers and methodology.

The Action Plan proposes that maximum acceptable concentrations be established as set out in Table 7. These concentrations apply to all streams.

Table 7: Maximum concentrations for short- and long-term catchment water quality targets

Variable	5 years	20 years (ANZECC guideline)
Total phosphorus	0.2 mg/L	0.1 mg/L
Total nitrogen	2.0 mg/L	1.0 mg/L

Extensive analysis of the nutrient data for freshwater tributaries indicates that streams fail the compliance test when more than 53 out of 90 samples have greater than the nominated target levels (based on a statistically defensible approach). Detailed tables outlining concentration trends for nutrients are contained in Appendix 3.

Waterway	Phosphorus target in mg/L	Nitrogen target in mg/L
Swan River		
Avon River	0.1	1.0
Helena River	0.1	1.0
Jane Brook	0.1	1.0
Susannah Brook	0.1	1.0
Bennett Brook	0.1	2.0
Blackadder Creek	0.1	2.0
Bayswater Main Drain	0.2	2.0
Ellen Brook	0.2	2.0
South Belmont Main Drain	0.2	2.0
Canning River		
Bannister Creek	0.1	2.0
Bickley Brook	0.1	2.0
Upper Canning River	0.1	1.0
Yule Brook	0.1	1.0
Mills Street Main Drain	0.2	2.0
Southern-Wungong River	0.2	2.0

Table 8: Recommended total phosphorus and nitrogen concentration targets for each of the monitored inflows for the year 2005. Targets reflect the condition of tributaries as measured between 1995 and 1997.

The targets are applied to the tributaries based on the current catchment classification as described in Section 4.2.1. For example, with reference to total phosphorus concentrations, the tributaries on the Swan River from the Avon River through to Blackadder Creek are already classified as low, which means the concentrations fall below 0.1 mg/L. The 20-year target is therefore applied to show that the management priority is to keep these streams in the low category. Similarly South Belmont Main Drain is in the moderate category (between 0.1 and 0.2 mg/L) for phosphorus, and the five-year target is therefore applied. Refer to Appendix 3 for classifications of nutrient concentrations of tributary inflows to the Swan-Canning system from 1987 to 1997.

Although these targets are not intended for the allocation of expenditure among catchments or estuarine areas, the shift from load-based to concentration-based targets will increase attention to low-flow (i.e. low volume), high-concentration inflows such as urban drains. From work so far completed it is known that inputs of relatively small amounts of phosphorus and especially nitrogen during the summer months can trigger bloom activity, whereas large amounts of nutrients delivered during the winter may have a lesser effect when there is flushing to the sea. Improvements on small streams and drains are technically more straightforward and the improvements are more easily measured. Identification and control of the low-flow/high-concentration sources are essential to the reduction of algal bloom activity.

Targets for the estuarine portions of the system are being developed using the same excursion-based philosophy for parameters such as dissolved oxygen, phytoplankton cell counts and nitrogen and phosphorus concentrations. Environmental objectives for the Swan-Canning system have been outlined in the Swan-Canning Environmental Protection Policy developed by the Environmental Protection Authority. These objectives provide the context for the water quality targets for the estuarine and tidal portions of the Swan-Canning system outlined in the Action Plan.

5

Recommendation 8

Adopt recommended water quality targets for the freshwater tributaries and estuarine portions of the Swan-Canning system for the year 2005 and use this to assess performance of the Action Plan.

8.1 Adopt recommended water quality targets for the freshwater tributaries (Table 8) of the Swan-Canning system for the year 2005 and use this to assess performance of the Action Plan. (***SRT*, WRC, DEP**)

8.2. Prepare water quality targets and a compliance table for the estuarine and tidal portions of the Swan-Canning system for nutrients, dissolved oxygen, chlorophyll and phytoplankton cell counts. (***SRT*, WRC, DEP**)

5.4.2 Monitoring, developing models and investigating critical gaps in knowledge

A catchment and estuarine monitoring program is necessary in order to measure compliance against the targets and to track trends in concentrations. It is very important to measure performance of a range of actions associated with the plan, so additional programs will be developed to allow evaluation of specific catchment or estuary management solutions.

The use of catchment and estuary models can help improve the quality of information gathered to monitor water quality and catchment data. For example, they can help improve monitoring by identifying the most effective times and locations to collect samples.

Research is also needed to fill gaps in existing information as a basis for waterway management as outlined in Section 4.7. This research should include and address gaps:

Within the waterways and riparian zones

- improved understanding of food web dynamics to allow evaluation of biological management techniques;
- nutrient limitation of phytoplankton growth in the Canning River;
- understanding shifts in phytoplankton species composition due to nutrient reductions;
- leaching of nutrients and contaminants from former landfills and waste disposal sites;
- foreshore weed infestation;
- trials of sediment remediation and oxygenation techniques in wetlands;

Within sediments

- role of microphytobenthos (microscopic plants on the estuary floor), meiofauna (animals slightly larger than microscopic organisms on the estuary floor or in the water column) and other organisms in nutrient cycling;
- rates of nitrification-denitrification and other nutrient cycling processes;

Within catchments

- sources of nutrients in urban and rural catchment areas;
- sources and causes of catchment soil erosion;
- role of groundwater in nutrient supply (groundwater flow modelling);
- environmental flow requirements of impounded rivers in the Swan-Canning system;
- fertiliser use on parks and reserves;
- use of constructed wetlands, including a trial in the Ellen Brook catchment, and monitoring their effectiveness in improving urban water quality; trials of floodplain management techniques (e.g. agroforestry woodlots, which capture and filter nutrients and sediments on floodplains);
- soil amendments to reduce nutrient movement from land;
- prioritisation of drains for management.

Effective management of waterways can still occur despite some gaps in knowledge. Managing natural resources requires an understanding of the level of variability or uncertainty associated with natural systems. Filling gaps in knowledge is still important to improve and ensure more effective waterways management and reduce the risk of poor decision-making. The development of decision-support and forecast modelling systems will help ensure future actions are cost and environmentally effective.

Progress can only be measured if regular reporting on the state of the waterways in the Swan-Canning system is undertaken and results are communicated to management bodies. Reporting is a central requirement of accountability and performance monitoring, and a process for reporting must be a central feature of the Action Plan.

Recommendation 9

Undertake investigations to fill critical knowledge gaps, monitor the river conditions and produce a "State of the Swan-Canning River System" report every five years.

9.1. Implement a monitoring program and report on
- all water quality data and compliance against targets annually;
- water quality trends at intervals of three years;
- success of catchment management actions after five years;
- data against goals and objective targets established by the Action Plan every five years;
- success of catchment management actions.

(***SRT*****, WRC, AGWEST, LGs**, LCGs)

9.2. Investigate nitrification-denitrification and carbon cycles in relation to estuarine sediment nutrient cycling. (***SRT*****, WRC**)

9.3. Complete development and validation of estuary and catchment models and use them to model system fluxes of nutrients including carbon. (***SRT*****, WRC, WAERF**)

9.4. Develop decision-support systems to predict and demonstrate the consequences of changes to the catchment or the estuarine system, to optimise management practices. (***SRT*****, WRC**)

9.5. Develop expertise within the Water and Rivers Commission in the application of WAERF estuarine process and decision-support models. (***WRC*****, SRT**)

9.6. Evaluate the relationship between zooplankton and low levels of contaminants other than nutrients in the Swan-Canning system. (***SRT*****, WRC, WC**)

9.7. Investigate sediments in areas for potential dredging in the Swan River. (***SRT*****, WRC**)

9.8. Investigate sediments in relation to groundwater flows and nutrient fluxes in the Canning River. (***SRT*****, WRC**)

5.4.3 Reporting to the community

Because of the importance of community involvement, as well as for funding accountability, the public must be kept informed of progress in implementing the Action Plan, achievements in improving river health and the projects in which they can participate. Community extension is required in a variety of situations.

Examples include:

- *In-river engineering solutions* require explanation, consultation and mechanisms for community debate and understanding.
- *Regulation and policies* require consultation, publication, distribution and promotion of explanatory documents, and education and training of those responsible for implementation.
- *Catchment management and community action* require awareness of the issues, education and information, technical advice and practical support.

It is therefore essential that a properly resourced community extension program be part of the Action Plan. The program would coordinate information and awareness campaigns for the Action Plan and provide direction for activities.

The focus should be on linking with and building on current programs - Ribbons of Blue, Living Streams, Swan Catchment Centre and other community catchment projects. Attention should also be paid to ensuring that there is consistent opportunity for community feedback and involvement in the adoption and implementation of the plan. This includes land-users, local government, State government agencies, catchment and community groups and the wider community.

The community extension program would be part of the implementation of the Action Plan.

Recommendation 10

Report progress regularly to the community and ensure that there are opportunities for feedback and for involvement in the adoption and implementation of the Action Plan.

10.1. Coordinate reporting to the community and ensure that there are opportunities for community feedback on implementation of the Action Plan. (***SRT*, WRC, SCC,** AGWEST, LGs, DEP)

5.5 Implementation

5.5.1 Management and accountability structure and process

In order to coordinate and monitor implementation of the Action Plan, allocate resources and ensure that an agreed process is followed, an Implementation Plan was prepared that outlines actions necessary to implement the specific recommendations and allocate responsibility to particular agencies. The Implementation Plan also covers coordination of community awareness and involvement programs and sets standards for accountability (see Section 5.1.3 and 5.1.4).

5.5.2 Accountability

Government initiatives must be formally accountable to Treasury, Cabinet and the public. Open accountability will allow all parties to monitor progress of the plan and provide the opportunity to influence changes in direction when necessary. Most reporting methods involve annual reporting against Performance Indicators; i.e. success is measured in terms of objectives and outcomes.

Accountability also requires clear identification of the responsible parties - for example, who manages local drains and who licenses small-scale polluting activities?

It will be necessary to define and allocate responsibility for implementing the Action Plan and developing Partnership Agreements and Memorandums of Understanding. They should include drainage management (major and minor), licensing of point-source pollution and discharges to the river system to rationalise control of nutrient inputs and ensure the long-term success of the Action Plan. This would be a task for the Senior Officers Group (see Recommendation 3.2).

5.5.3 Cost sharing

Nutrients have accumulated in the estuary sediments because of the ways in which urban and rural land has been used and the river has been changed. Land-use decisions were appropriate at the time and necessary to support development of the region. But the cumulative result is a legacy of nutrient-rich sediments and waterways that need to be managed to reduce the incidence of algal blooms and poor water quality.

Current activities in urban and rural catchments also contribute to the problem and need to be modified to reduce the levels of nutrients entering the estuary.

There are three main options for meeting the financial and social costs of achieving this:

- The costs are borne by those undertaking activities that contribute nutrients to the estuary (polluter pays).
- The costs are borne by those who use the estuary or benefit from its amenity (beneficiaries and users pay).
- The costs are borne by the community as a whole (everyone pays).

The first option has a number of problems.

Many of the activities that contributed to the problem have ceased. These activities were acceptable and may even have been best practice with the knowledge and technology then available. It is also impossible to identify or quantify the contribution made by individual activities, or the extent to which the problem is caused by current as distinct from past activities.

A significant portion of catchment nutrients come from diffuse sources that are difficult to isolate and quantify. The Action Plan accepts the principle that polluters should pay where their activities are clearly identified as being significant point sources, particularly for larger discrete premises or industries. However, it is impossible to determine nutrient losses from smaller, individual diffuse-source activities.

It is therefore impractical and unreasonable to allocate costs in this way.

The second option, based on the concept of user pays, is also fraught with difficulties.

Those using the rivers for activities such as boating, swimming and fishing are seldom responsible for causing the problem and therefore should not bear the cost of solving it. Moreover, most commercial activities that support recreational use of the rivers are not located near them, making the psychological and political connection to the user pays concept difficult.

The amenity value of the rivers supports the wide range of commercial activities conducted in close proximity to them and affects the value of near-river property. Local government benefits from the higher level of rates obtained from these properties.

The diversity of those benefiting from the rivers, the variety of opportunities to gain access to the rivers and shorelines, and the difficulty of defining the extent of benefits, prevent development of a simple and cost-effective way of recovering costs.

The third option derives from the proposition that the problem arises as a consequence of the way in which the State has developed, and that the community as a whole has benefited to varying degrees from that development. Therefore the community should bear the cost of dealing with the consequences.

This option will require negotiation of cost-sharing arrangements between State and local governments and determination of incentives provided to commercial operations and land-holders to change current practices. The Task Force believes that the costs of implementing the Action Plan should be considered a general community cost and be funded, principally, from State Government revenue and revenue of relevant local governments on a basis to be determined by consultation between the parties.

6. Summary

The Action Plan addresses the management of nutrients entering the Swan-Canning system. Nutrient availability is one of the main reasons excessive algal blooms are occurring. The Action Plan recommends controlling them at their source and minimising their entry into the system. It also emphasises the need to restore and rehabilitate important natural habitats - in the catchments and wetlands and along foreshores, drainage lines and streams - in order to improve retention of nutrients.

The Action Plan provides the background, the context and the rationale used in developing its recommendations. The Actions identify requirements in both the rural and urban catchments. Some of the recommendations are original to the Swan-Canning system, while others are new and some can be considered as representing current and acceptable management practice. All are relevant. All recommendations require immediate action to provide improvements in the system over both the short term and long term. Although the Action Plan has been developed for implementation over the next five years (1999-2004) clean up activities will need to continue for at least 20 years.

Recommendations are grouped into a four-point Action Plan summary:

- The first group of recommendations encourages more effective Integrated Catchment Management and recommends changes to existing urban, industrial and rural land-use practices to reduce nutrient losses.
- The second group is directed at using planning, regulatory and land-use management tools to ensure that new developments and changes to land-use will minimise nutrient export.
- The third group encourages further development of river intervention techniques to modify conditions in the river to reduce algal blooms.
- The last group recommends continued monitoring of river health and the progress of the Action Plan, filling critical gaps in knowledge and, importantly, the reporting of this progress to the community.

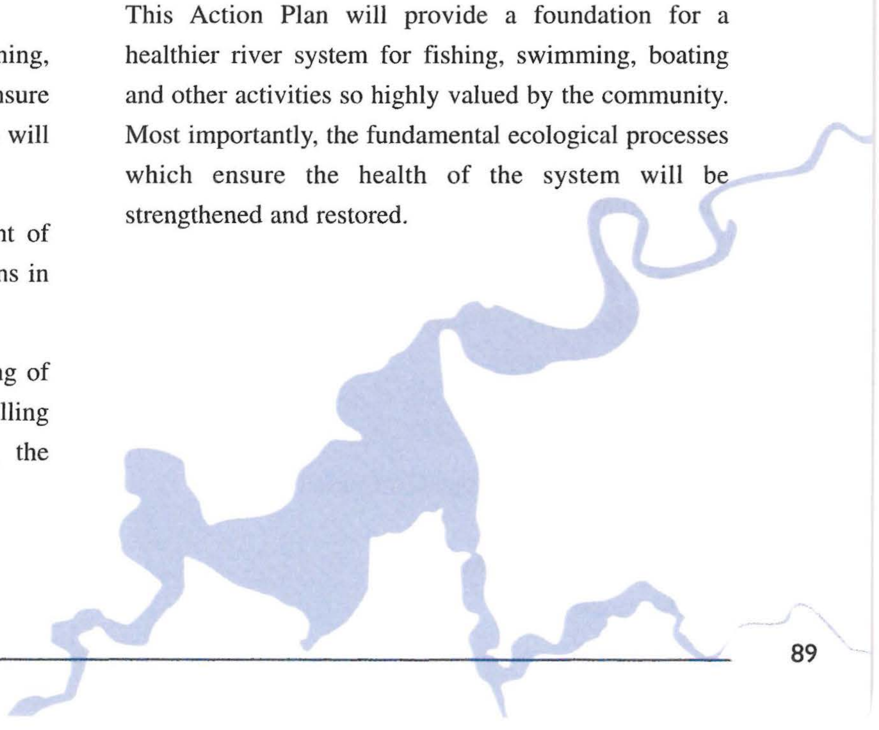
To implement these recommendations, strong support must be given to ICM, on-the-ground restoration work and improvements to catchment and river planning and decision-making. Intervention techniques will need to be further developed and used to reduce algal blooms while the catchment slowly returns to health. Improved government coordination, accountability, reporting to the community and community awareness and involvement are all essential aspects of the program.

The Action Plan advocates a strong alliance between the community and the Government. This alliance must involve stakeholders right across the greater Perth Metropolitan Area, including land-holders, farmers, catchment groups, city residents, businesses, local governments and State agencies. Appropriate funding and support and diligent work by this alliance will yield dividends that will enhance the health of the Swan-Canning system, a resource worthy of protection.

The Action Plan has been developed to provide recommendations of action that will lead to an enhancement of the quality of the Swan-Canning system. Consideration of punitive measures for non-compliance will be required in the development of the various management guidelines to be developed in the SCEPP CMP.

The large number of public submissions and comments that were received has improved the Action Plan. The Task Force acknowledges and appreciates the public involvement in this ambitious Plan.

This Action Plan will provide a foundation for a healthier river system for fishing, swimming, boating and other activities so highly valued by the community. Most importantly, the fundamental ecological processes which ensure the health of the system will be strengthened and restored.



7. Further reading

Action for the Future: The Swan-Canning Rivers Cleanup Program (1995)

Swan-Canning Cleanup Program: Progress towards a Cleanup Plan (1997)

Swan-Canning Cleanup Program: Technical Report series (1999):

- The Catchment of the Swan-Canning River System
- River Intervention Techniques Report
- Management Modelling Report
- Communication Plan

These publications describe the Swan-Canning Cleanup Program and the major projects undertaken. They discuss catchment management planning for the most problematic catchments in terms of nutrient export to the rivers, river intervention and soil remediation trials, water quality monitoring and community initiatives.

8. Acknowledgments

A large of number of people and organisations have helped develop and assemble this document. Many individuals in the Water and Rivers Commission, the Swan River Trust and many other organisations were extremely helpful in providing their professional advice and review. The Task Force and the Swan River Trust wish to acknowledge their contribution. In particular Silvana Affolter for her excellent administrative support and document preparation. The following individuals and organisations are recognised for their help:

Marie Andersson (WRC/SRT)
Louisa Barnacle (SRT)
Bob Becu (WC)
George Begg (Environmental Advisory Services)
Liz Berry (Berry Graphics)
Ben Boardman (WRC)
Jason Bryne (WRC)
Antonietta Davy (WRC)
Dave Deeley (Evangelisti & Assoc.)
Rob Donohue (WRC)
Grant Douglas (CSIRO)
Patrick George (WRC)
Ross George (ex AGWEST Task Force member)
Robert Gerritse (CSIRO)
Rosemary Glass (BICM)
Mary Gray (Swan Catchment Centre)
Sandy Griffin (Curtin University)
Sarah Grigo (WRC)
Brett Harrison (Banksia Environmental Mapping)
Alan Hill (WRC)
Karen Hillman (D.A. Lord & Associates)
Wes Horwood (DEP)
Was Hosja (WRC)
June Hutchison
Bob Jeffrey (Soil Management Consultant)
Barry Johnson (SRT)
John Jones (ex SCCP Manager)
Jeff Kite (WRC)
Verity Klemm (WRC)
Syl Kubicki (WRC)
John Lambie (EBICG)
Tim Larcombe (SRT)
Ian LeProvost (ex WAERF Task Force member)
Brian Lloyd (AGWEST)
Ian Loh (WRC)
Kathryn McMahon (WRC)
Linda Moore (WRC)
Peter Nash (Swan Catchment Centre)
Charlie Nicholson (ex DEP Task Force member)
Joanne O'Donnell
Luke Pen (WRC)
Margaret Platell (Murdoch University)
Hartley Read (EBICG)
Nicole Siemon (SRT)
Frank Smith (Wordsmith)
Garrick Stanley (ex WRC Task Force member)
Lloyd Townley (ex CSIRO Task Force member)
Kerry Trayler (Swan Catchment Centre)
Paul Trotman (MfP)
Harry Ventriss (WRC)
Wilma Vincent (Curtin University)
Mark Warner (WRC)
Jon Warren (AGWEST)
Allan Watson (Perth Editorial Services)
Stephen Wong (WRC)

Appendices

1. Glossary

1.1 Acronyms

AGNPS	Agricultural Non-Point Source Pollution Model
AGWEST	Agriculture Western Australia
ANZECC	Australia and New Zealand Environment and Conservation Council
AQUIFEM-N	A groundwater model called Aquifer Finite Element Model - N layer
BFB	Bush Fires Board
BICM	Bayswater Integrated Catchment Management
BMP	Best Management Practice
C&T	Department of Commerce and Trade
CALM	Department of Conservation and Land Management
CG	Catchment Group
CMP	Catchment Management Plans
COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWR	Centre for Water Research
DEP	Department of Environmental Protection
DNR	Department of Natural Resources
DOLA	Department of Land Administration
Ed. Dept.	Education Department of Western Australia
EPA	Environmental Protection Authority
EPP	Environmental Protection Policy
FWA	Fisheries Western Australia
FEFLOW	A groundwater model
FMP	Foreshore Management Plan
FRP	Filterable Reactive Phosphorus
GIS	Geographic Information System
HD	Health Department
ICM	Integrated Catchment Management
Ind. Assoc.	Industry Associations
LASCAM	Large Scale Catchment Model
LCDC	Land Conservation District Committee
LCG	Local Community Groups
LG	Local Governments
MfP	Ministry for Planning
MOU	Memorandum of Understanding
MRD	Main Roads Western Australia
MRS	Metropolitan Regional Scheme
MUC	Multi Use Corridor
NHT	Natural Heritage Trust
NIMP	Nutrient Irrigation Management Plan
NLP	National Landcare Program

OWR	Office of Water Regulation
PA	Partnership Agreement
PUWBM	Perth Urban Water Balance Model
SAICM	Swan-Avon Integrated Catchment Management
SCC	Swan Catchment Centre
SCCP	Swan-Canning Cleanup Program
SCEPP	Swan-Canning Environmental Protection Policy
SOE	State of the Environment
SPP	Statement of Planning Policies
SRT	Swan River Trust
TINS	Turf Irrigation Nutrient Study
TPS	Town Planning Schemes
Treasury	WA Department of Treasury
WAERF	Western Australian Estuarine Research Foundation
WAMA	Western Australian Municipal Association
WAPC	Western Australian Planning Commission
WC	Water Corporation
WRC	Water and Rivers Commission
WSD	Water-Sensitive Design
WSUD	Water-Sensitive Urban Design (a subset of WSD)

1.2 Terms

Anoxia	Lack or absence of dissolved oxygen.
Best Management Practices	See Section 5.2.2
Compensation basin	Many stormwater drains discharge into compensation basins and detention ponds to allow temporary storage of runoff and reduce the need for large capacity storm drains.
Constructed wetlands	Artificial water bodies constructed to meet a number of human purposes.
Dewatering	Discharge of water to lower the watertable to enable construction to occur.
Diffuse source of pollution	Discharge of nutrients and other contaminants from small producing sources. These small sources are usually too small to be licensed or controlled with legal mechanisms. Up to 70% of all water pollution comes from diffuse sources which are dispersed and sporadic in their contribution to waterways degradation.
Environmental auditing	Environmental auditing has three main components: • identifying sources of contaminants and the timing of their contribution to rivers and estuaries (spatial and temporal information); • testing compliance with water quality targets (compliance monitoring); • measuring progress towards meeting water quality targets (trend detection).
Eutrophication	See Section 3.6
Filter feeders	Aquatic organisms which obtain their food by filtering water and eating phytoplankton and other small organisms floating in the water.
Filter strips	Segments of land, often grassed or vegetated, over which water flows, encouraging deposition and absorption of nutrients and pollutants.

Food chain	The animals and plants in an environment that are involved in the transfer of energy and food (e.g. algae, zooplankton) that grow and provide food for fish, crabs, prawns, birds and humans.
Hypoxia	Low levels or a deficiency of dissolved oxygen.
Infiltration trenches	Small linear excavations which temporarily detain nutrient and pollutant-containing water and allows it to soak into the ground.
Meiofauna	Microscopic animals in the sediment and water column that are at the very bottom of the food chain.
Microphytobenthos	Microscopic algae, bacteria and other organisms capable of photosynthesis that are involved in cycling nutrients in the sediment and water column and provide food for the bottom of the food chain.
Integrated Catchment Management	See Section 5.1
Nitrification	See Section 3.4
Nutrient loads	See Section 5.4.1
Oxic	Having high levels of dissolved oxygen.
O_2	Oxygen
pH	Measure of acidity or alkalinity in water and sediments.
Phosphate	See Section 3.4
Photosynthesis	The conversion of light energy to sugar and oxygen during the day and to carbon dioxide at night, allowing plants to grow and live.
Phytoplankton	See Section 3.3
Point sources of pollution	Discharge of relatively large amounts of contaminants and nutrients to waterways and the environment. These large amounts come from single sources such as factories, abattoirs, livestock holding yards and fertiliser factories. They are usually licensed and are required to meet certain discharge requirements by the DEP, local governments and other government agencies.
Porous pavement	Brick, bitumen and other hard surfaces that allow nutrients and pollutants to drain and soak into the ground underneath them.
Salt wedge	See Section 3.2
Sedimentation detention ponds and basins	Ponds and basins that allow nutrients and pollutants to settle and deposit to the bottom.
Stream restoration	See Section 4.3.14
Swales	Landscaped shallow trenches or drains that collect and filter water before it enters the ground or flows to a pond.
Terracing	Step-like landscaping of hills and slopes that breaks the downward flow of water, which may contain nutrients and other pollutants and helps prevent erosion.
Treatment train	The successive use of a number of structural, chemical and source-control features incorporated in drainage lines and including water-detention and nutrient-stripping basins. The aim is to improve water quality before it reaches rivers and wetlands.
Water-Sensitive Design	See Section 4.3.1
Wetland filters	The use of flood-tolerant vegetation in a wetland environment to encourage deposition and absorption of nutrients and pollutants in water.
Zooplankton	See Section 3.3

2. Issues associated with the Tax Act for restoring catchments and foreshores

- Potential instruments include tax rebates, tax deductibility for capital and ongoing expenses and donations to legitimate conservation organisations (as registered with Environment Australia). The use of some of these tools may require changes to the *Tax Act*.

- Section 75D of the *Tax Act* extends tax deductibility to include the costs associated with the preparation and implementation of approved farm plans. Through 1998 changes to the Tax Act, the capital costs as well as ongoing costs of resource protection may now be included.

- Under the *Tax Act* (Section 75D) "approved" farm plans are not required to be prepared within the context of a catchment plan, nor are they required to be appraised by a conservation agency or catchment group. It will be important to ensure that farm plans meet the objectives of Catchment Management Plans and regional planning documents, particularly town planning schemes that endorse and apply the principles of nutrient reduction.

- Section 78 of the *Tax Act* encourages the donation of private lands to conservation organisations through a relaxation of the qualification criteria. Provision may need to be made for the management of these lands (weeds, firebreaks, ferals, fences, etc.), with possibly a stewardship role linked to Section 75D (where a person, other than the landholder, may incur a management cost for land held by a registered conservation organisation).

- The proposed changes to Section 78 of the *Tax Act* would allow tax deductions to be made by land-holders who enter into a joint contract (caveat) on the title of their property with an appropriate conservation body (i.e. listed on the register held by Environment Australia), requiring the land to be managed in perpetuity for conservation. This form of private land conservation should be encouraged, since many land-holders will prefer to retain their land, even though they have legally precluded any further clearing or development potential, rather than relinquish ownership entirely.

- Promotion of these aspects of the *Tax Act* would be likely to secure large areas of remnant vegetation for conservation purposes. Provision for assistance with their management is likely to be needed.

- It should be established that farm plans will only be "approved" when they are consistent with the hierarchy of sub-catchment and catchment plans, which in turn require endorsement by regional Catchment Coordinating Groups (for example, Blackwood and Swan-Avon groups in WA) and peak natural resource authorities in each State.

- Changes to the tax deductibility of Landcare actions were announced in May 1998 by the Federal Treasurer. Rebates of up to 30 cents in the dollar invested in land restoration were outlined in recent Federal budget papers. The implications of these changes need to be reviewed and applied to restoration efforts in the Swan-Canning system.

3. Nutrient concentration classifications in tributary inflows to the Swan-Canning system between 1987 and 1998

3.1 Classifications of total phosphorus concentrations in tributary inflows to the Swan-Canning system between 1987 and 1998

Waterway	1987	1987-88	1987-89	1988-90	1989-91	1990-92	1991-93	1992-94	1993-95	1994-96	1995-97	1996-98
Swan River:												
Avon River	low	low	low	low	low	low	low	low	low	low	low	low
Helena River	low	low	low	low	low	low	low	low	low	low	low	low
Jane Brook	low	low	low	low	low	low	low	low	low	low	low	low
Susannah Brook	moderate	low	low	low	low	low	low	no data	no data	low	low	low
Bennett Brook	moderate	moderate	moderate	moderate	moderate	moderate	moderate	low	low	low	low	low
Blackadder Creek	moderate	moderate	low	low	low	low	low	low	low	low	low	low
Bayswater MD	extreme	extreme	very high	high	moderate	moderate	moderate	moderate	moderate	moderate	low	low
Ellen Brook	extreme	extreme	extreme	extreme	extreme	extreme	extreme	extreme	very high	very high	very high	very high
South Belmont MD	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Claisebrook MD	moderate	moderate	moderate	moderate	moderate	low	low	low	low	no data	no data	no data
Canning River:												
Bannister Creek	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	low	low	low	moderate
Bickley Brook	no data	no data	no data	no data	no data	no data	no data	no data	no data	low	low	low
Upper Canning River	low	low	low	low	low	low	low	low	low	low	low	low
Yule Brook	low	low	low	low	low	low	low	low	low	low	low	low
Mills Street MD	high	high	high	high	high	high	high	high	high	high	high	high
Southern River	very high	very high	very high	high	high	high	high	high	high	high	moderate	moderate

3.2 Classifications of total nitrogen concentrations in tributary inflows to the Swan-Canning system between 1987 and 1998

Waterway	1987	1987-88	1987-89	1988-90	1989-91	1990-92	1991-93	1992-94	1993-95	1994-96	1995-97	1996-98
Swan River:												
Avon River	low	low	low	low	low	low	low	low	low	low	low	low
Helena River	low	low	low	low	low	low	low	low	low	low	low	moderate
Jane Brook	low	low	low	low	low	low	low	low	low	low	low	low
Susannah Brook	moderate	moderate	moderate	moderate	moderate	moderate	moderate	no data	no data	moderate	moderate	low
Bennett Brook	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Blackadder Creek	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Bayswater MD	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Ellen Brook	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate
South Belmont MD	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	low
Claisebrook MD	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	no data	no data	no data
Canning River:												
Bannister Creek	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	high	high	moderate
Bickley Brook	no data	no data	no data	no data	no data	no data	no data	no data	no data	moderate	moderate	moderate
Upper Canning River	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	low	low	low
Yule Brook	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate
Mills Street MD	moderate	moderate	moderate	high	high	high	high	high	high	high	high	high
Southern River	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate

Where possible the classifications were made using the last three years of data from routine monitoring carried out in tributary inflows to the Swan-Canning estuary since 1987.

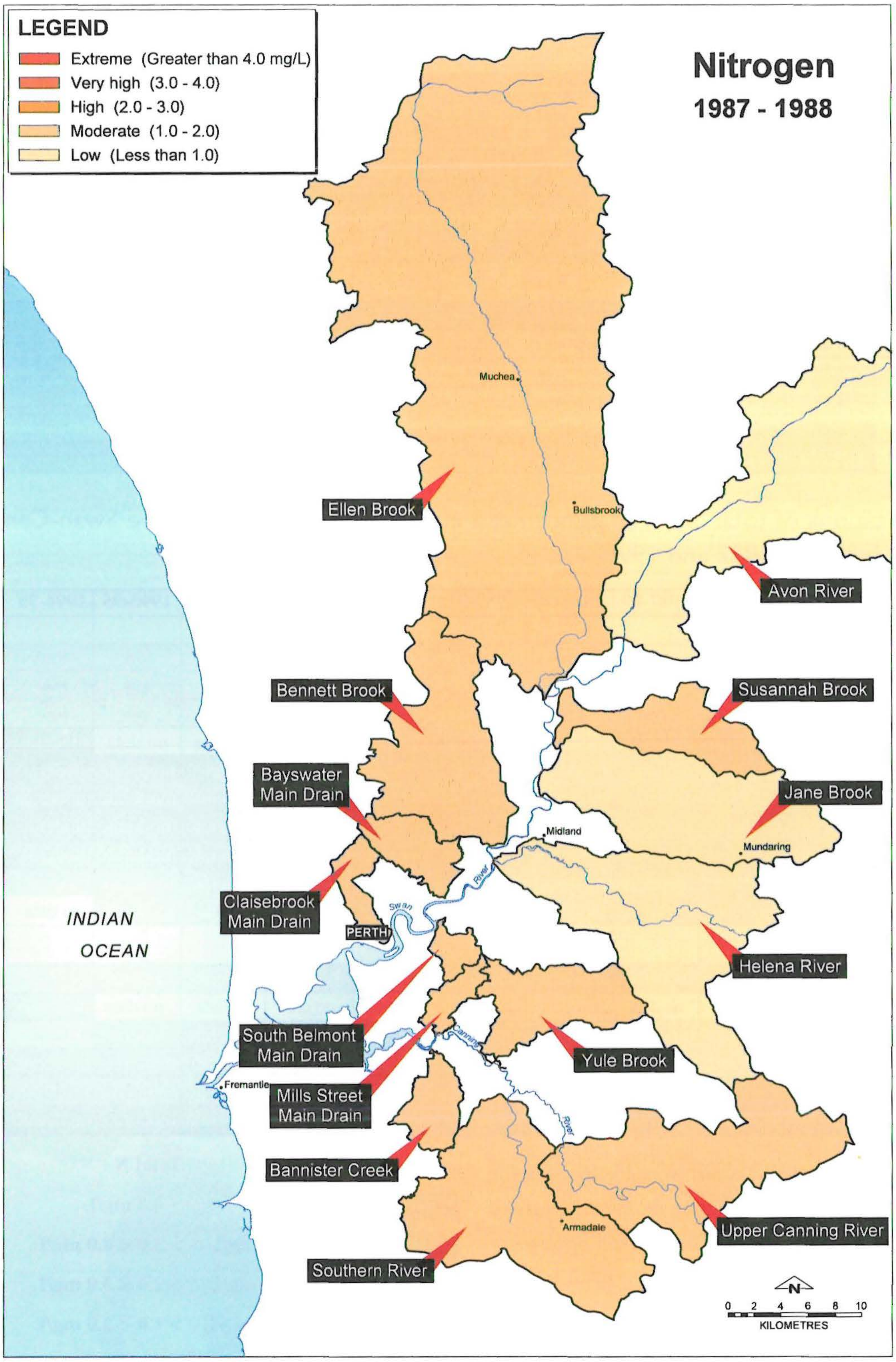
	Total P	Total N
extreme	> 0.5 mg/L	> 4.0 mg/L
very high	> 0.3 < 0.5mg/L	> 3.0 < 4.0 mg/L
high	>0.2 < 0.3 mg/L	> 2.0 < 3.0 mg/L
moderate	> 0.1 < 0.2 mg/L	> 1.0 < 2.0 mg/L
low	< 0.1 mg/L	< 1 mg/L

ANZECC limit

4. Nitrogen and phosphorus classifications based on concentrations for the sub-catchments of the Swan-Canning system between 1987 and 1988

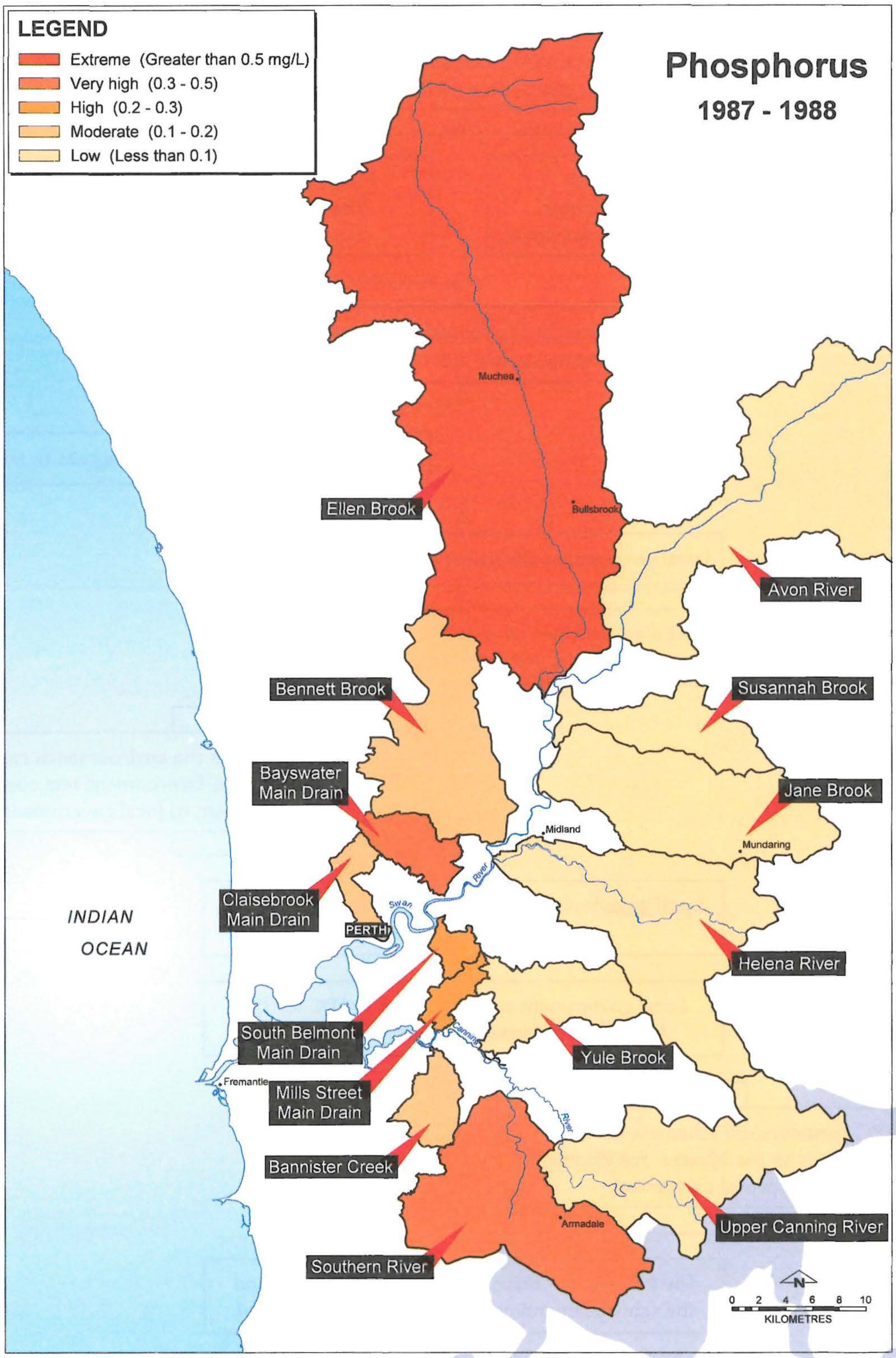
4.1 Nitrogen 1987-1988

This original classification map shows the large number of catchments exporting excessive amounts of total nitrogen into the Swan-Canning system. When compared to the latest (1995-97) total nitrogen map (Figure 10) it is evident some progress has been made. However, many of these sub-catchments can easily slip into a higher and more damaging classification if catchment initiatives are not maintained, and it is critical that total nitrogen import into the Swan-Canning system is drastically reduced if the frequency of algal blooms is to be reduced.



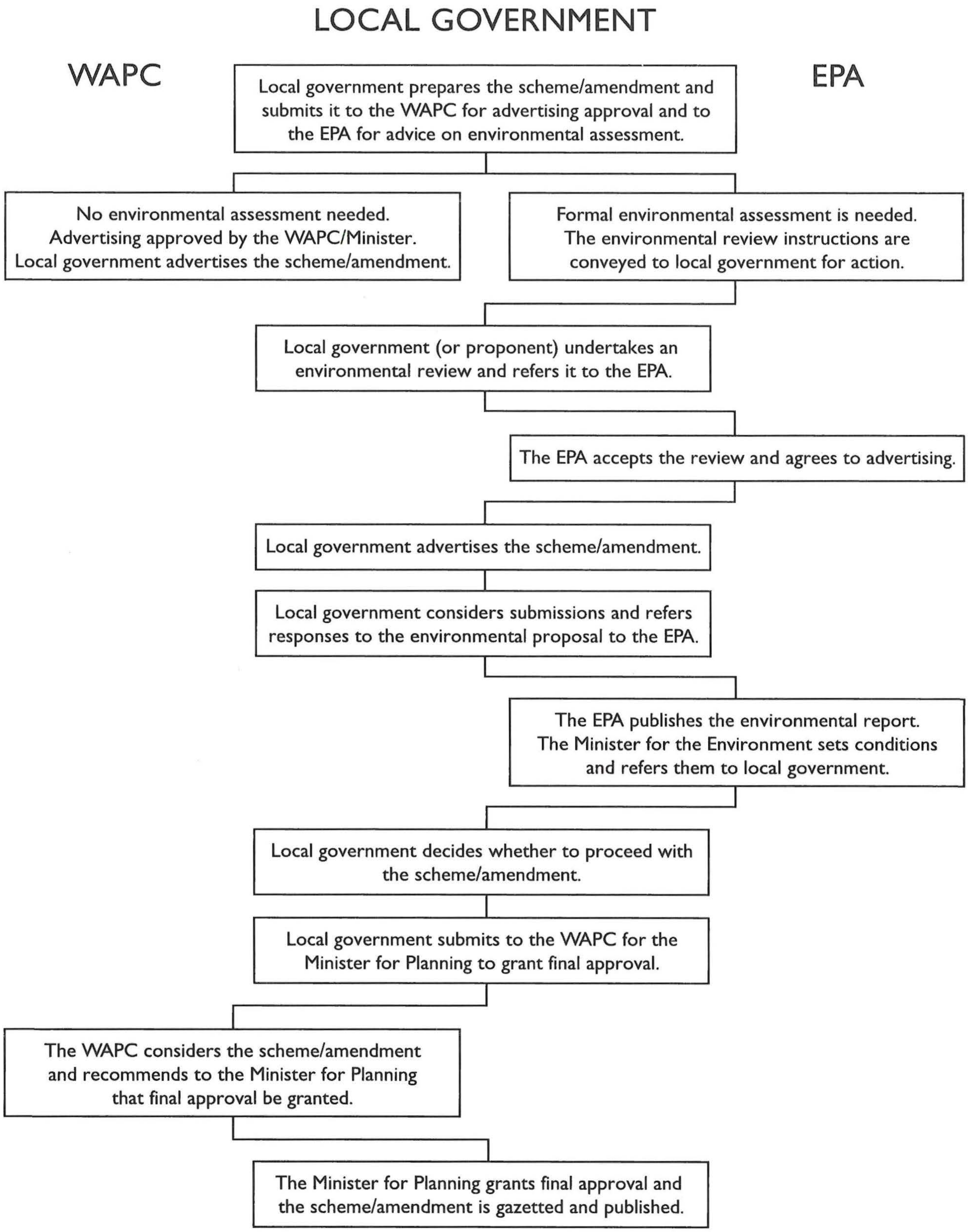
4.2 Phosphorus 1987-1988

This original classification map shows the large number of catchments exporting excessive amounts of total phosphorus into the Swan-Canning system. When compared to the latest (1995-97) total phosphorus map (Figure 11) it is evident that considerable progress has been made. However, many of these sub-catchments can easily slip into a higher and more damaging classification if catchment initiatives are not maintained.



5. Town planning scheme processes

TOWN PLANNING SCHEME PROCESS UNDER THE *TOWN PLANNING AND DEVELOPMENT ACT 1928*



GENERALISED ORGANISATION FRAMEWORK FOR PLANNING IN WA

6. Perth's current public water sources

Surface water sources	Mean yield gL/annum	Groundwater sources	Mean yield gL/annum
Mundaring Weir & Lower Helena Pumpback	36.0	Deep artesian bores groundwater schemes	18.5
Churchmans Brook Dam	3.7	Mirrabooka	20.0
Wungong Dam	20.6	Wanneroo	45.0
New Victoria Dam	6.0	Jandakot Stages 1 and 2	9.8
Canning Dam	37.7		
Others importing into the Swan-Canning system	106.1	Others in the Swan-Canning system	26.0
Total surface water yield	**210.1**	**Total groundwater yield**	**119.3**
		TOTAL SYSTEM YIELD	**329.4**

gL = gigalitres

Bend on the Swan River, Guildford. Broad vegetated foreshores help water quality and river health.

Notes