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Sustainability and Water Resources Management for the Northern Adelaide Plains, South Australia

Volume 1 of 2

Nicholas S. Fleming

Thesis submitted for the degree of
Doctor of Philosophy
in The University of Adelaide
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Sustainability and Water Resources Management for the Northern Adelaide Plains, South Australia

Volume 1 of 2:
Thesis Chapters 1 to 15

Volume 2 of 2:
Appendices to Thesis

"Sustainability is a carefully chosen journey
rather than an end point."

After: Sustainable Human Habitat Consultants,
(in Foulsham & Munday Pty Ltd, Ecoweb, 1994)

"We do not inherit the Earth from our parents,
we borrow it from our children."

Kenyan Proverb

"Water is the driving force of Nature."

Leonardo da Vinci

"In a very real sense, water is life."

Young, Dooge & Rodda, 1994

"Water will be *the* issue for the 21st Century."
"All the water we will ever have is here now."

Veltrop, 1996

"The design of the city is, in itself, an expression of culture."

South Australian Planning Review, 1992

Statement of Originality

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Signed: *Nicholas Stuart Fleming* Date: 16 March 1999

Abstract

The role of humankind as a part of Nature, rather than ruler of it, is now being recognised more widely than at any other time in modern history. Throughout the course of the 20th century, human beings have exploited the available natural assets to such an extent that their very survival on Earth is threatened. The traditional patterns of industrialisation and development, which embody a short sighted view of natural resource use, cannot be allowed to continue.

The concept of sustainable development has evolved as a positive response to these concerns. The subject is explored at both the philosophical and practical levels, with a focus upon water resources and urban development. The Northern Adelaide Plains is used as a case study. Simulation of urban growth patterns and water resources management has been undertaken as part of the case study. Innovative techniques have been employed, such as the use of Artificial Neural Networks to model regional water consumption. Volumetric runoff coefficients have also been developed to enable the prediction of stormwater yield in the temperate climates characteristic of southern Australia.

Clearly planning decisions made now are crucial to the sustainability of human societies. The costs and benefits of development are distributed over long periods of time, particularly for public infrastructure projects. It is therefore necessary for decisions to be made in an open manner, addressing all the important factors, and following a precautionary approach. An innovative, simple and practical tool has been developed called the *Matrix for Evaluation of Sustainability Achievement* (MESA). Quantitative as well as qualitative data can be used jointly in the decision making process which does not rely solely on economics to arrive at a decision. The theory and an application of this tool are presented.

MESA is shown to be a useful decision making tool. While the MESA process is valuable in itself, the ability to actually incorporate the views and aspirations of a diverse community is unique. The assessment process is structured to be totally transparent, open for debate and discussion, providing information on the relative merits of each alternative.

Recommendations for future work and research are provided.

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Appendix M	Economics of water infrastructure and pricing
Appendix N	Water main and sewer design calculations
Appendix O	Economics of the construction of wastewater treatment plants
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1

Introduction

For thousands of years, people have lived in relatively small and simple communities, where change occurred slowly. Technologies used in everyday life were simple, and communities were largely dependent upon their immediate environs for their sustenance. People tended and cared for their lands using skills and practices handed down over the centuries. Adverse environmental impacts occurred locally and went relatively unnoticed. This is because the natural ecosystems were able to assimilate these local impacts.

On the whole, these uncomplicated lifestyles continued until the beginning of the 19th century when the world's population was around 1 billion. Change occurred however, as the development of the steam engine spawned the Industrial Revolution. Further inventions provided new sources of power for transport, mining, and manufacturing, providing a substantial increase in industrial productivity when compared to previous centuries. It was not until the latter half of the 1800s that these technologies were exported from Europe, and so the global effects were slow to be realised. Even in the late 1800s, the world as a whole was seen to be vast, with huge regions virtually unexplored by the Europeans. Indigenous peoples were inhabiting these regions.

By contrast, the technological growth and pace of change in the 20th Century has been rapid and continues to accelerate. In the early 1900s, the global population was around 1.6 billion people and rising more quickly than ever before. This was, in large measure, attributable to increasing life span rather than increasing birth rates, particularly in developing countries. New medicines, improved transportation and communication, improved water supply and sanitation systems all contributed to an improvement in the quality of life, but most particularly of persons living in the cities of the industrialised nations. These gains came at a price, however. Pollution and environmental problems were now common – some cities living under a pall of smoke and soot – although the problems were generally local.

By the 1950s, aeroplanes and improved communication had begun to bring the peoples of the world, now around 2.5 billion, into greater contact. Industrial growth had multiplied per capita consumption of natural resources in many countries. As consumption grew, air and water pollution became more widespread, as did the concern about the cumulative impact of toxic industrial products on living species.

Between 1950 and 1990, there was a doubling of world population to 5.2 billion people, and world economic activity increased fourfold. The global demand for water had increased by a factor of about 9 since 1900, reaching approximately 4.5 million gigalitres per year (Rodda, 1992). To local concerns about environmental degradation were added new, global worries. The pressures of agricultural and industrial development began to crowd out and extinguish species of flora and fauna at a rapid rate, visibly eroding the carrying capacity of the planet's soils, forests, rivers, lakes and oceans, and alter its atmosphere (after Hammond, 1991).

The world's population is now growing at a rate of more than 90 million people per year, a rate which is without precedent. Ninety-five percent of this increase occurs in developing countries (Green, 1992 in Stewart, 1996).

Global population projections made during the early 1980s predicted between 8 and 14 billion people sometime during the next century. Revised estimates, taking into account the faster than expected population growth of the 1980s, suggest that between 11.3 and 14 billion is a more likely outcome (WCED, 1987; Schmit, 1990). Yet at the present and with only half that many people, one in every five people go hungry, and in many parts of the world malnutrition is rampant (Veltrop, 1996).

The human impact on global ecosystems is not only about absolute numbers of people. It depends on what people do and how they consume resources. Much of the environmental degradation has been caused by neglect, with loss of biodiversity due to ignorance, and pollution of rivers and oceans a result of indiscriminate dumping of waste (Veltrop, 1996). It has become increasingly evident that the rising global population, and resource consumption and waste disposal practices, are threatening our existing institutions, and has fundamental implications for the very survival of humanity. Only recently has a response of substance emerged.

In 1983, the United Nations established a body called the World Commission on Environment and Development (WCED). The Commission was charged with investigating and recommending ways by which human life on Earth could be sustained, and made more just, prosperous and secure by the year 2000. In 1987, the Commission tabled their report titled *Our Common Future* (WCED, 1987). At the core of the report was the principle of 'sustainable development'.

Our Common Future is arguably the most important statement on the environment this century, and unequivocally declares that dependence of our institutions, the economy and mankind upon the natural environment must be recognised for development to be sustainable. The Commission highlighted many issues that must be addressed to pursue sustainable development, however the actions cannot be specifically prescribed but must evolve. For this reason the Commission preferred to indicate general directions to be explored rather than a blue-print for action.

1.1. The Research Agenda and Objectives

This thesis explores the subject of sustainable development in the context of the urban environment. In particular, consideration is given to the management of the most pervasive and fundamental of resources – water.

How to measure progress toward sustainability is the primary focus of this thesis. Decision makers need a tool or method to aid the decision making process and the identification of development that is supportive of the pursuit of sustainability.

An important, secondary objective is to explore the practical implications of sustainability, 'fleshing out' the general directions provided by WCED (1987). In particular, the intent is to identify a more sustainable form of urban infrastructure. A case study is adopted, that of the Northern Adelaide Plains, to aid the investigations.

The **goals of this research** are therefore:

- To develop a simple and effective **decision making tool** that enables the economic, environmental and social aspects of development proposals to be addressed simultaneously, to identify the most sustainable course of future development; and

- to identify the character of **urban form**, and particularly the nature of water services and infrastructure, that is most supportive of sustainability in the region of the Northern Adelaide Plains in South Australia.

The innovative process of research to achieve these goals is discussed further below. The structure of this thesis is illustrated in Figure 1.1.

1.2. Content of This Thesis

The course of exploration begins with an in depth analysis of the meaning and current thinking on sustainable development or 'sustainability'. **Chapter 2** provides a broad discussion on the subject, firstly reviewing the evolution of the environment movement; identifying the environmental problems that are faced at the local, national and global level; and the response that sustainable development offers to these problems. The issues of national security, economics, equity and carrying capacity are also explored. The conclusion is reached that sustainability is more about a journey than a destination, and that there is a need to develop methods that can help us to determine whether we are on the right course.

Alternative methods and tools that are used to evaluate the desirability of development projects, policies and strategies are discussed in **Chapter 3**. The nature, role and limitations of environmental impact assessment are discussed. Environmental economics and methods developed to incorporate environmental concerns and externalities into monetarily based decision making are also addressed. The question is raised whether economics holds the solution to our problems, and the suggestion is made that it does not.

Chapter 4 provides an introduction to a new tool that has been developed through this research to aid multiple objective decision making for sustainability. The Matrix for the Evaluation of Sustainability Achievement (MESA) has been developed to enable the evaluation of a number of alternative projects with simultaneous consideration of multiple objectives, without needing to resort to placing dollar

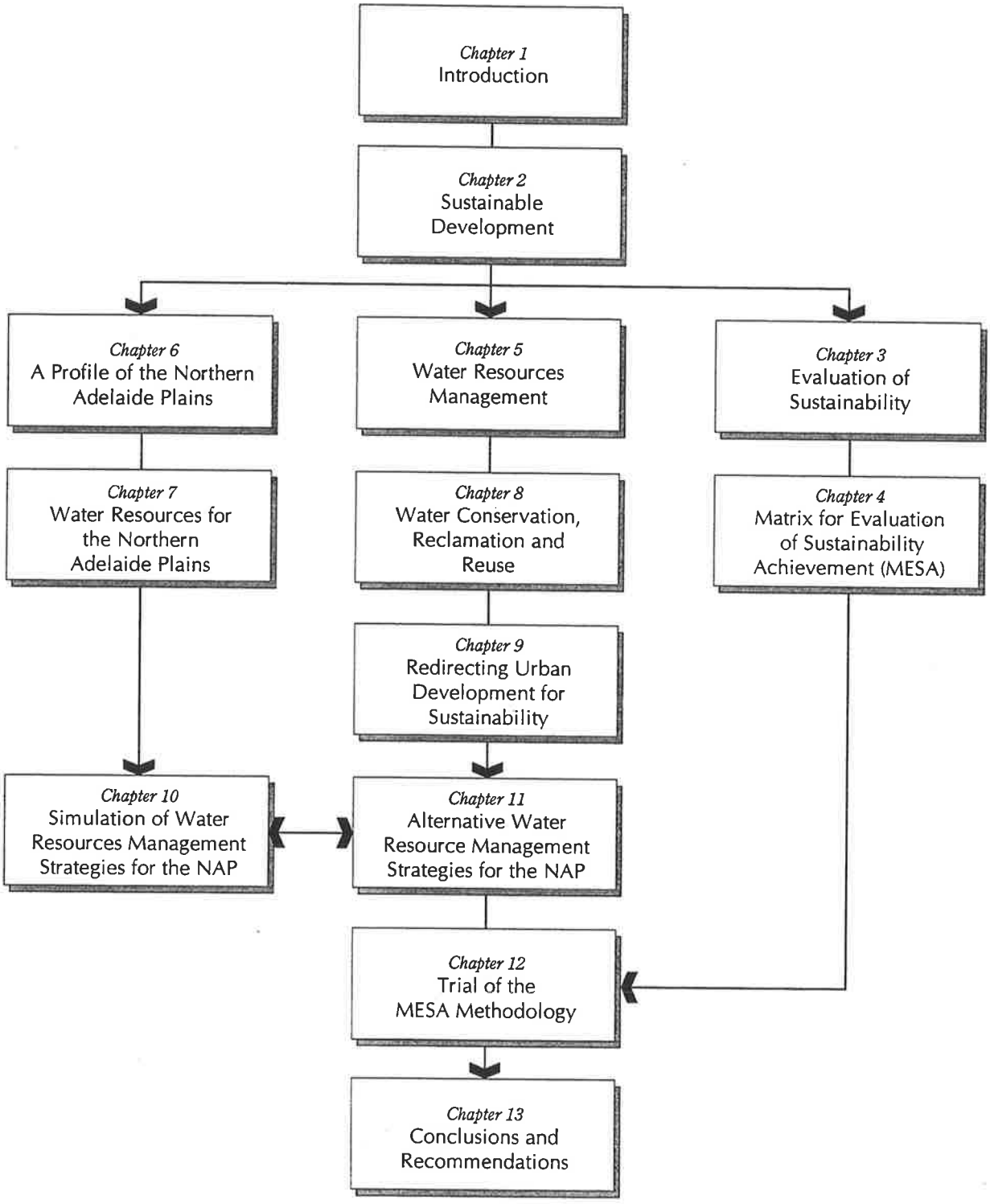


Figure 1.1
Research Process and Thesis Structure

values on costs and benefits. The philosophical, theoretical and mathematical basis of this method is presented. MESA constitutes one of the main contributions of innovation arising from this research.

In **Chapter 5**, the content of Chapter 2 is developed further with particular consideration of environmental and economic problems in relation to water. Possible solutions to these problems are considered, leading to the proposition of a set of guiding principles for more sustainable water resource management.

Following Chapter 5, a new line of discussion is pursued to establish a case study. This case study arises out of existing conditions of unsustainable water resource management on the Northern Adelaide Plains (NAP) in South Australia. Along this line of investigation, the ultimate objective is the development of alternative strategies for water resource management in the NAP study region, and the evaluation of their contribution to the pursuit of 'sustainability' using the MESA methodology. **Chapter 6** provides the reader with an introduction to the study region of the Northern Adelaide Plains. The natural and physical environment are described, with discussion on the direction of future development as described in recent literature and planning documents.

Given the focus upon water resources management, **Chapter 7** forms a complete summary of the characteristics of water resources available to the Northern Adelaide Plains. Rainfall, surface water, groundwater, stormwater and sewage effluent are all covered in terms of temporal and spatial distributions, water quality, and consumption.

Having defined the characteristics of the study region, alternative water resource management technologies that could contribute to more sustainable water management are identified in **Chapter 8**. Examples of Australian and international application of these technologies are provided. Advantages, disadvantages, limitations and knowledge gaps are also discussed.

For the development of water resources to be effective in achieving desirable economic, environmental and social outcomes, water must not be considered in isolation from land management. Urbanisation, in particular, has had a dramatic effect upon surface water catchments and the land within them, as well as degradation of the quality of surface and ground waters available for use. New approaches are emerging to the management of water within urban catchments, which often involve re-engineering existing urban areas or adopting new technologies in developing areas. Yet the problems of urban areas extend beyond that of water management, as can be found in **Chapter 9**. This chapter encapsulates the latest thinking on the design and function of our urban areas. The problems generated by our conventional form of urban development are presented, together with the solutions proffered by the various disciplines in planning, social sciences and engineering. The conclusion is reached that many of the benefits to be gained by adopting a new urban development philosophy tend to come together in the form of an 'urban village'.

A water resource and urban form model was constructed to simulate alternative development strategies, thereby providing information for the evaluation of the

alternatives. The tools used throughout the research for data interpretation and modelling are discussed in **Chapter 10**. Special features include the use of artificial neural networks for water consumption modelling, and the derivation of volumetric runoff coefficients for the prediction of stormwater yield in urban and rural areas.

In **Chapter 11**, alternative strategies for urban development and water management on the NAP are developed. Three (3) scenarios are developed ranging from perpetuation of conventional urban development (i.e. the status quo), through to the more radical proposal involving progressive redevelopment of the NAP toward higher density urban villages.

Now, both the MESA method and the plausibility and desirability of alternative futures for the NAP could be tested against public opinion and professional critique. **Chapter 12** reports on the program of public consultation and professional assessment that was developed and implemented for this purpose. The advantages and disadvantages of each alternative development strategy are assessed by experienced professionals. The outcome is both an improved understanding of what is possible and desirable from an urban development and water management perspective, as well as an evaluation of the MESA method as a decision making tool.

Conclusions of the research, and recommendations relating to water resource management, urban form, application of the MESA method, and further research are offered in **Chapter 13**.

At the conclusion of the main body of this document is a list of Abbreviations, and an exhaustive Bibliography summarising the literature reviewed in this research.

2

Sustainable Development

In the quest for economic development, human beings have exploited the available natural assets to such an extent that their very survival on Earth is threatened. The struggle to meet the aspirations of soaring populations within existing economic and institutional frameworks has driven people to adopt a short sighted view of natural resource use. The concept of *sustainable development* has evolved as a positive response to these concerns of natural resource depletion and environmental degradation.

This chapter introduces the range of environmental problems that have been the impetus for this response; examines the slow growth of the environmental movement; the nature of sustainability; and the reasons why environmental issues must be purposefully addressed and resolved.

2.1 The Nature of Environmental Problems

The adverse environmental impacts resulting from the exploitation of natural resources are becoming increasingly evident.

In 1970, the major environmental problems were perceived to be local: smog, DDT, oil spills, jet exhausts, and mercury. By 1990, the list and scale of environmental problems had grown to global proportions, to include desertification, rising sea levels, temperate and tropical rainforest depletion, forest die back, acid rain, toxic contamination of food and water supplies, soil contamination and erosion, species extinction, freshwater scarcity, groundwater depletion, marine pollution, fisheries collapse, ozone depletion, greenhouse gas build-up, climatic change, and urban sprawl (Roseland, 1992).

As the number of environmental catastrophes grow, so, it appears, does their frequency. Recent examples include the Bhopal gas leak, the nuclear meltdown at Chernobyl, the Rhine chemical spillage, the mud-slide in Columbia, the Mexican liquid gas explosion, drought and famine in Africa, and the raging jungle fires of Indonesia.

Tolba (1990) reports that 11 million hectares of tropical forest are being lost every year, mainly to land-clearing for crops and cattle ranching. Forests used to cover

more than 40 percent of the Earth's land surface, but deforestation has imposed the fastest land use change of its scale in human history (Myers, 1997). The World Wide Fund for Nature (WWF) reports that nearly two thirds of the world's forests have been destroyed, and that at current rates of deforestation, virtually no forests would be left in countries such as Malaysia, Pakistan and Thailand in less than 50 years (Skotnicki, 1997). The costs of this forest destruction are long-term soil erosion, substantial contribution to the accumulation of greenhouse gases in the atmosphere, and irrevocable loss of plant and animal species which are becoming extinct at the rate of hundreds or even thousands of species per year. Over 70 percent of Czechoslovakia's forests are estimated to be damaged by air pollution. In the rest of Europe (except for France that has 23 percent of its trees damaged by acid rain), the ratio ranges between 30 and 70 percent (Tolba, 1990).

Six million hectares of new desert form annually. Thousands of lakes and rivers are biologically dead or dying. There is growing toxic contamination of water and soils. In India, the soils of 130 million hectares of land have been classified as degraded beyond the point of productive use (nearly 40 percent of that country's land area). In Poland, 25 percent of the soil is regarded as contaminated beyond the point of safe use, and only 1 percent of water is considered safe for drinking (Ramphal, 1990). About 35,000 km^2, which is 11 percent of Poland's land area, is classified as an area of ecological disaster (Niemczynowicz, 1992). Nearly one fifth of the planet's entire productive top-soils has been lost through soil erosion, salinisation, water-logging, wind erosion and urban expansion (Tolba, 1990). The list goes on.

Humans are now using about 12,000 times as much energy as they were 400 generations ago when farming was first introduced (IUCN, 1980). This comes mainly in the form of fossil fuel usage. Developments in Western countries have resulted in a massive increase in the level of resource and energy use and waste production by human society, imposing heavy new ecological pressures on the biosphere. Total energy use is growing at about 2% per annum. Nearly 80% of this energy use and waste production is occurring in the industrialised nations, which constitute about 25% of the world population (Boyden & Dovers, 1992). While the greatest energy usage at present, and for the foreseeable future, is in the industrialised world (refer to Table 2.1 after Boyden & Dovers, 1992), the highest relative rates of growth in energy use are in the developing regions.

The increase in the amount of carbon dioxide in the atmosphere, as well as other greenhouse gases such as methane, nitrogen oxide and CFCs, is expected to result in an increase in the mean global temperature of between 2 to 5 degrees Celsius over the next 50 years (Boyden & Dovers, 1992), and recent trends are consistent with the view that the warming of the Earth is already under way.

Gaseous by-products of fossil-fuel combustion, especially sulphur and nitrogen oxides, are serious air pollutants in many areas, and appear to be largely responsible for the acid rain problem. Large areas of forest are dead or dying from this cause, and many thousands of lakes are found to be strongly acidified with detrimental effects on the aquatic life-forms.

The consumer societies of the Western World are also generating ever increasing quantities of solid wastes. In Sydney, Australia, per capita waste production has

been increasing at the rate of 8-9 percent per year, and Australia is second only to the USA in its per capita municipal waste production when compared with that from leading industrialised countries. The plastic content of this waste is rising progressively.

Table 2.1
Human and Environmental Indicators for Industrial and Developing Countries

	Industrial Countries	Developing Countries	World
Population, millions (1990)	1,210	4,081	5,292
Annual Average Growth, %	0.5	2.0	1.6
Life Expectancy, years (1987)	74	62	65
Daily calorie supply (1986)	3,390	2,480	2,650
GNP per capita, USD (1987)	10,760	650	3,100
Arable land per capita, ha	1.5	0.7	0.8
Primary Energy Use, GJ/capita/yr (1989)	205	22	63
Total CO_2 emission, mtc[1] /capita/yr (1987)	3.2	0.4	1.0
Desertification of Drylands, %	< 40	> 60	

(1) mtc: million tonnes carbon

Any concern for the declining state of natural ecosystems should be equalled by concern for our economic systems and institutions. Environmental degradation hits at the heart of a developed economy because it effects the resource base that supports it. While these impacts can be serious in industrialised countries, they can be devastating to the developing nations. Domestic and international pressures on developing economies can be enormous, resulting in the over exploitation of their environmental resource base through mining, forestry, energy production, and agriculture.

For this reason, the global environment cannot be separated from the political, economic and moral issues posed by a world in which there is great wealth and poverty, with superpowers and vulnerable microstates trying to coexist, and with tenuous legal and institutional arrangements preserving international order. A more sustainable form of development should become a goal for all countries, since present development trends leave people poor and vulnerable, as well as destroying the environment that forms the basis of development.

2.2 A Growing Environmental Awareness

The concept of 'sustainability' has only gained international prominence in recent years, however the concept has existed somewhat longer. Indeed, the urban and industrial roots of environmentalism in the US and elsewhere goes back to the late 1800s (Pezzoli, 1997), though the community-wide concern of environmental problems emerged from the early 1960s. As early as 1961, Rachael Carson's *Silent Spring* had highlighted a need for concern for the effects of humans on the natural environment. A further cascade of warnings emerged via publications such as *The*

Limits to Growth, *Global 2000*, the *World Conservation Strategy* and most recently *Our Common Future*, identifying that until now what we have called 'development' is in fact jeopardising our future.

2.2.1 The International Environmental Movement

A grass-roots environmental movement grew in the United States of America during the 1960s. Realisation of the need to curb environmental degradation was given some formal recognition through proclamation of an annual 'Earth Day' in 1970. The environment continued to emerge as a strong national issue within the USA. In the same year and with congressional and presidential elections on the horizon, President Richard Nixon proposed to Congress the establishment of an Environmental Protection Agency (EPA) as an umbrella organisation to manage the national effort to 'heal the environment' (Nixon, 1970; Russell, 1987).

At the international level, it was not until 1972 that concerns about environmental damage became the topic of serious political discussion. In Stockholm, during June of 1972, the United Nations held a conference on the Human Environment where the theme was 'Only One Earth' (Strong, 1972). The attendance and discussion was dominated by developing countries and served to illustrate that the rich and poor countries held very differing perspectives on the idea of environmental protection. The developing countries of the world, China in particular, offered the West a new, expanded perspective on environmental issues. Environmental protection was seen to be a luxury that only the rich members of the global community could afford. Yet in many areas, the USA did not prove to be a staunch supporter of the environment (Aaronson, 1972). Several major resolutions were achieved however, and included: halting the release of toxic chemicals beyond the 'capacity of the environment to render them harmless', protecting seas, developing international law for compensation to the victims of pollution and environmental damage caused outside a country's jurisdiction, and recognising the equal stature of all countries in discussion of environmental problems. However, the success of the conference was not in the recommendations that were approved, as they were generally weak and not enforceable. It was rather that the Western nations were forced to view environmental problems in a global perspective. A notable exception was that the meeting did lead to the establishment of the United Nations Environment Program (UNEP).

In 1980, the document *World Conservation Strategy: Living Resource Conservation for Sustainable Development*, was published by the International Union for the Conservation of Nature and Natural Resources (IUCN), UNEP and the World Wildlife Fund (WWF), in collaboration with the Food and Agriculture Organisation (FAO) of the United Nations, and the United Nations Educational, Scientific and Cultural Organisation (UNESCO). The document placed emphasis upon conservation, defining it as:

> *'... the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations.'*

In December 1983, in response to a UN General Assembly resolution, the UN Secretary-General appointed the Prime Minister of Norway, Dr Gro Harlem Brundtland, as the Chair of an independent World Commission on Environment and Development. The mandate of the Commission was three-fold (Roseland, 1992):

- to re-examine the critical issues of environment and development and to formulate innovative, concrete, and realistic action proposals to deal with them;

- to strengthen international co-operation on environment and development and to assess and propose new forms of co-operation that can break out of existing patterns and influence policies and events in the direction of needed change;

- to raise the level of understanding and commitment to action on the part of individuals, voluntary organisations, businesses, institutes and governments.

In April 1987, the Commission tabled their report titled *Our Common Future* (WCED, 1987). At the core of the report is the principle of 'sustainable development', which very significantly, gave tremendous political credibility to a concept many others had worked on over the previous decade (Roseland, 1992). *Our Common Future* is arguably the most important statement on the environment this century.

Symbolic of the new found urgency to address environmental problems was the devotion of *Time* magazine's 1989 New Year's issue to *Endangered Earth: Planet of the Year*. Two months after this magazine was published, one of the worst ocean oil spills in history occurred when the tanker Exxon Valdez ran aground off the coast of Alaska. The accident spilled almost 38 million litres of oil, which covered some 2,600 kilometres of ocean and coastline. Unfortunately, it took this incident to focus world-wide attention on the dangers of the long distance tanker transportation of oil (Schrecker, 1993).

Canada and the Scandinavian countries have demonstrated the most respectable record of commitment and achievement on environmental problems. In 1991, Canada released its first *Green Plan* – a response by the Canadian government to a nation-wide consultation process addressing environmental problems. The Green Plan addressed clean air, water and land; sustainable use of renewable resources; protection of special spaces and species; the Arctic; global warming, ozone depletion, and acid rain; environmentally responsible decision making; and minimising the impacts of environmental emergencies (Anon, 1991b).

The Brundtland Report acted as a catalyst for international progress on development and environmental issues, including negotiation of a range of international treaties and conventions (CoA, 1992). These developments culminated in the UN Conference on Environment and Development (UNCED) which was held in Rio de Janeiro, Brazil during June 1992. This was the first official follow up to the Stockholm conference. Issues on the conference agenda included the transfer of environmentally sound technology, protection of the atmosphere, protection of forest ecosystems, protection of biological diversity, land degradation and desertification, protection of freshwater resources and waste management. Equitable

representation and involvement of non-government organisations, from both developed and developing nations was a high priority (PCUNCED, 1991).

Runnalls (1992) concluded that many factors prevented the 1992 UNCED conference from being an unqualified success, among them being the absence of a workable agenda, the recalcitrance of the United States, the failure of both Japan and the European community to show leadership, and the reluctance of developed nations to provide extra funding for sustainable development projects. Nevertheless, some achievements were noted, including a heightened awareness by world leaders of the need for urgent action, and signs that government departments with economic mandates were prepared to consult those with environmental ones.

Sustainability was also the core theme at the 1996 Habitat II Conference held in Istanbul. Habitat II (the 'City Summit') was the last major United Nations conference to be held this century, and addressed two major themes: adequate shelter for all; and sustainable human settlements development is an urbanising world. Habitat II concluded with the *Habitat Agenda* – '... a global call to action at the international, national and local level for the development of sustainable human settlements in the world's cities, towns and villages into the first two decades of the next century' (Pezzoli, 1997).

2.2.2 Environmental Awareness in Australia

In Australia, the *World Conservation Strategy* provided a framework for the development in 1984 of a National Conservation Strategy. Subsequently in 1989, the Prime Minister issued a statement on the environment entitled *Our Country, Our Future* which stressed the importance of the achievement of sustainable development in Australia (Moffatt, 1992). The report declared:

> *'... the crux of the issue in implementing sustainable development is establishing mechanisms that ensure an integration of economic and environmental considerations both now and in the future. Reaching that integration can only be a co-operative process.'*

In June 1990, the Commonwealth Government set about the task of identifying what Australians needed to do to embrace the concept of sustainability. A discussion paper was subsequently released as a first step in the process of developing a national sustainability strategy for Australia. Nine working groups were established to examine the implementation of sustainability principles in sectors of the Australian economy, those being agriculture, forestry, fishing, mining, energy production and use, manufacture, tourism and transport; their findings were reported in November 1991. Water was addressed with a series of inter-sectoral and cross-sectoral issues such as health, population, urban issues, the coastal zone, employment, gender and Aboriginal issues, reported on in January 1992. In all, these eleven reports contained over 500 recommendations on ways of working toward sustainability (CoA, 1992). A *National Strategy on Ecologically Sustainable Development* and the *National Greenhouse Response Strategy* were released late in 1992, founded upon the recommendations of the ESD Working Groups.

Business groups, unions and professional bodies have also developed positions and guidelines on the environment. The Institution of Engineers, Australia, published its *Policy on Sustainable Development* in July 1989 which highlighted that it was an engineer's professional responsibility to contribute to the achievement of sustainable development. This position was further reinforced in 1992, when the Institution published its strongest statement on, and support for, sustainable development in its *Environmental Principles for Engineers* (IE Aust, 1992).

While Australia and many other countries have developed environmental policies and development strategies, international action to address global environmental threats still remains highly inadequate.

Russell (1987) noted that the easy part of meeting the environmental challenge of the 1990s was the scientific and technical. The hard part lies in accomplishing the shifts in attitude, behaviour and institutions needed to achieve the reorientation towards sustainability. Upon reflection, progress in all areas during the past decade has been slower than is desirable or necessary. Greater government leadership and industry participation will be required to match and progress the existing community support for sustainable development.

2.3 The Concept of Sustainability

The concept of sustainability, or ecologically sustainable development (ESD) as it is referred to in Australia, is a response to poor ecological management and rapidly growing community concern for the environment. It presents one of the greatest challenges to government, industry, business and the community.

The sustainability concept gained international prominence with the release of the report *Our Common Future* (WCED, 1987). Commonly referred to as the Brundtland Report, it was a strong call to political leaders to take action to manage environmental resources.

While there are many descriptions of sustainable development (refer to Table 2.2), the essential goal is the improvement of the quality of life of present and future generations. The best known definition was that offered by the Brundtland Commission, who defined sustainable development as:

> *'... development that meets the needs of the present without compromising the ability of future generations to meet their own needs.'*

The Brundtland Report went further by stating (Colby, 1990):

> *'(Sustainable development is) ... a process of change in which exploitation of resources, the direction of investments, the reorientation of technology development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.'*

Fundamental to the achievement of this goal is the recognition of the interdependence of the environment and economy. Sustainability is about

supporting activities that will contribute to economic, environmental and social well-being, rather than contributing to one at the expense of the others. Four concepts central to the goal of sustainable development are equity, carrying capacity, biological diversity, and risk management.

2.3.1 Equity

The concept of sustainable development implies continuity and therefore a time dimension. The central aim of sustainable development is the retention of opportunities and wealth for future generations, no less than that available to present generations. The use of resources in the present must be equitable in providing for the varied needs of people of different race, culture, sex and age, in all the countries of the world. It is also a necessary and moral obligation that a similar fairness and equity be exercised between generations.

Table 2.2
Conceptual Definitions of Sustainable Development

- Meeting the needs of present generations without compromising the ability of future generations to meet their own needs (WCED, 1987).
- Conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased (Commonwealth of Australia, 1992).
- Integration of conservation and development on a long-term basis to provide social and economic benefits, without compromising the needs of future generations (IE Aust, 1992).
- Improving the quality of human life while living within the capacity of supporting ecosystems (IUCN *et al*, 1991).

2.3.2 Carrying Capacity

Carrying capacity is a term used to describe the maximum level of resource use and waste discharge that can be sustained without causing long-term harm to ecological systems. The carrying capacity of a system is finite, but with advances in technology and policies for resource control, the productive yield for future generations could be improved.

The productive capacities of exploited species and ecosystems needs to be determined to ensure that utilisation does not exceed those capacities. It is important to recognise that ecosystems altered by human activities (such as exploitation of associated or naturally linked species, and pollution) are more prone to serious damage, and the exploitation level from which the species population is unable to recover would be substantially lower.

2.3.3 Biodiversity

The protection of biological diversity and the maintenance of ecological processes and systems is essential to the achievement of sustainability. Their significance for the survival of humanity and all other living systems cannot be overstated (ESDWGC, 1992a).

There are few places where the character and composition of natural ecosystems has not been degraded. Development has resulted in a significant reduction in the level of natural biodiversity.

There are many benefits to be achieved by the preservation of biological diversity. The consumptive and productive uses, the 'right to exist', and the retention of options for the future, should all be addressed in any planning and development process, especially where native habitats and natural systems may be altered.

2.3.4 Dealing Cautiously With Risk

In order to preserve natural capital and to develop patterns for its wise use, options need to be considered for the use of renewable and non-renewable resources, and for the potential for substitution with man-made resources. This raises the issues of uncertainty, irreversibility and substitution.

Situations involving uncertainty need to be treated cautiously. Our knowledge of the functioning of natural systems, their resilience and their responses to external influences, is limited. Coupled with the uncertainty of costs and benefits from future technology, there is the potential for development to cause serious ecosystem damage, or to limit options for future generations.

Often developments have resulted in the permanent loss of habitat and species, or have caused serious degradation necessitating long-term and expensive remediation programs, if remediation is even possible. In Australia, it is only now that problems such as dryland salinity due to widespread clearing, and the salinisation of major water courses such as the River Murray, are being addressed.

The destruction of many rainforests around the world has undoubtedly resulted in the extinction of many species, the serious decline in others, as well as limiting possibilities for finding the ingredients for new fuels, medicines, crop varieties and other products. In addition, many environmental and natural resources simply have no man-made substitute.

The issues of risk and uncertainty impinge upon a wide range of economic and environmental decisions. The aim must be to maintain economic development whilst preventing irreversible ecological damage, and ensuring restoration of degraded environments.

2.3.5 Discussion

Following the release of *Our Common Future,* the term 'sustainable development' was mistakenly used to imply environmental protection *or* sustained economic growth, but not a combination of both. In contrast, the Brundtland Commission argued very strongly that sustainable development requires economic growth. It was recognised that 'the problems of poverty and under-development cannot be solved unless we have a new era of growth in which developing countries play a large role and reap large benefits' (Schrecker, 1993). For these reasons, reviving growth was the first of several objectives the Commission identified as strategic imperatives.

There is no necessary conflict between economic and environmental goals; both have to be pursued simultaneously. Clearly, without environmental protection it is not possible to sustain development, and without development, it is not possible to protect and restore the quality of our environment and improve the quality of life for all the world's citizens (after Thomas & Codner, 1991). Emphasis is therefore placed on the interdependence of environmental conservation and economic development. Resources can be used in a managed rather than pristine environment, while ensuring the maintenance of environmental diversity and major environmental systems. The limits of development are not seen as absolute, but rather are determined by the effectiveness of technology and social organisation.

The definition of sustainable development is also quite broad. It should not be seen as a vague objective though. Rather, it indicates the substantial complexity of the subject, and the difficulty of interpretation and translation into action. Jenkins (1991b) offers some guidelines to aid implementation of the sustainability concept:

- limit human impact on ecosystems to a level that is within its carrying capacity;
- maintain the stock of biological wealth;
- use non-renewable resources at a rate that does not exceed the creation of renewable resources;
- ensure that the use and costs of resources and environmental management are equitably distributed;
- promote technologies that increase the benefits from a given stock of resources;
- use economic policy to help maintain natural wealth;
- adopt an anticipatory, multi-disciplinary approach to decision making; and
- promote and support cultural values that are compatible with sustainability.

It is also important to recognise that the term 'development' includes material as well as non-material well-being, satisfaction and quality-of life matters.

Thus, the concept of sustainability provides the ingredients for effective natural resource management and economic growth. Many issues must be explored and conflicts resolved before the best recipe for use of these ingredients is found.

2.4 The Many Dimensions of Sustainability

As the global population expands and economies decline, there is a growing need for new systems of resource management to meet people's needs and aspirations. There is universal agreement that resources should be used sustainably, but the means to achieve this objective is ill-defined. Can population growth be constrained? Should change be driven from the 'top down' or 'bottom up'? Should resource management evolve from techniques of the industrialised countries, or adopt 'indigenous' methods and an upgrading of traditional local-level institutions? How can the scientific and traditional approaches be integrated? These problems must be addressed and will inevitably affect all sectors of society. Some of them are explored further below.

2.4.1 Population Growth

The growth of the world's population remains a major stumbling block to future sustainability. According to recent estimates (UN-DIESA, 1991), the global population is increasing at a rate which is threatening our existing institutions and has very fundamental implications for the very survival of human-kind. In large measure, changes are accounted for not so much by changing birth rates (which in most regions are slowly declining) but by increasing longevity, particularly in developing countries (Young *et al*, 1994).

In 1950, the world population stood at 2.5 billion. It approached 4 billion in 1975 and reached 5 billion in 1986 (Colby, 1990). By 2025, the global population is expected to soar over 8 billion. This growth is projected to occur at a rate of 80 million/annum, rising to around 90 million/annum around the year 2000, an annual increase of population that is roughly equal to the present population of Bangladesh.

While the growth in global population is clearly of concern, it is the population trends of the developing world that paint a particularly bleak picture. The fastest population growth rates tend to occur in countries with low per capita income, poor social capital, heavy reliance on labour intensive agriculture and weak institutional infrastructure. The high population growth and existence of large families is in part due to the tendency for parents to bear many children with the intention that they will support them in old age. A relatively high infant mortality rate and poverty encourage this thinking and thus a high birth-rate results.

It has been observed that with the transition of less developed countries to industrialised countries, there is a significant decrease in the population growth rate and a rise in per capita income (Dasgupta, 1992). An argument would therefore exist to bring the Third World up to western levels of affluence. However current western levels of consumption are unsustainable regardless of Third World population. It is commonly recognised that the population of the industrialised nations constitutes only a small fraction of the global population. However, these same nations are responsible for the majority of world resource consumption. IUCN *et al* (1980) report that one Swiss person consumes more than 40 Somalis!

The increase in population is exacerbated by rising per capita consumption of resources. This places severe pressure on environmental systems, especially those associated with the production of food, fibre and timber. The production and disposal of waste is an associated problem. Of particular concern is the associated pressure on water supplies. Water is needed for direct human consumption, but is also essential for the production of food, in manufacturing and for the preservation of natural ecosystems.

Can the growth of the global population be allowed to continue? Hardin (1968) addressed this important question in his controversial article called *The Tragedy Of The Commons*. Hardin stated that 'a finite world can support only a finite population; population growth must therefore eventually equal zero.' Some may argue that this finite population has already been exceeded.

It would seem that some finite population exists, but is not necessarily stationary in time. Technological advances may increase the sustainable yield from a given resource base, and therefore increase the sustainable 'no-growth' population. Given the current trends of environmental decline, restraint in population growth is necessary, however. This will require educational, social and economic incentives to reduce birth rates, coupled with strategies to reduce the impact of the present population on the environment (Harwood, 1991).

2.4.2 Common Property

Linked with population growth, development and environmental degradation is the concept of common property. Common property resources are a class of resources for which exclusion from use is difficult. Examples are air, water and open space. It is difficult to control access to these resources by users, and each user can reduce the welfare of others by over-use or pollution of that resource. The resources cannot be owned by anyone, are freely accessible, and fully available to any user (Berkes, 1989).

In a controversial paper written by Hardin (1968), the abuse of common property resources was related to over population. Hardin considered that by linking the concept of (human) freedom to breed with a belief that everyone has an equal right to the use of common property resources, the world would be locked into a course of self destruction. He further argued that unrestricted access to common property resources is only justifiable with a small population. Hardin concluded that there is the need to abandon the freedom to breed, and that education, rather than an appeal to conscience, would reveal this necessity to people. There was seen to be no technical solution to avoid the misery of over-population.

The problem of management of the global commons extends to societies that are fluid. Where societies have large numbers of individuals only in casual contact, and where all have access to the common resources, the 'tragedy' as discussed by Hardin (1968), is relatively likely. Predictably, the problems associated with common property resources are often found in urban areas.

Berkes (1989) suggests that a traditional approach to resource management can have significant application in future development. This would involve group cooperation and participation at a local scale. Just as traditional knowledge of medicinal plants is now no longer ignored by medical scientists, traditional practices in common property resource management must be taken seriously by planners and developers.

It may therefore be advantageous to structure our society into smaller, more involved and caring communities, so that the use of common resources for long term sustainable yields is more likely. In societies with tight communal control over resources, persistent cheaters are likely to be caught and free ridership penalised. Small communities are not pleasant places for those who violate the local rules and norms of co-operative behaviour.

2.4.3 Urban Development

The impacts of population growth are particularly evident in the urban areas of both the developing and industrialised nations.

WCED (1987) noted that by the year 2000, Third World countries would need to increase their capacity to produce and manage urban infrastructure and services by 65 percent, just to maintain extremely inadequate conditions. In the western world, urban sprawl and its associated effects have been recognised as degrading the environment. Traffic congestion causes air pollution, urban runoff and effluent disposal pollute the water, and suburban development causes loss of productive agricultural land. Uncontrolled physical expansion of cities also has serious implications for the economy. The provision of housing, roads, water supply, sewers and public services at the fringe of a sprawling city often become prohibitively expensive.

Ellyard (1991) considered the problems of urban Australia and suggested that 3 options exist for the future – the possible, the probable and the preferred. He proposes that effort be directed into the development of a preferred future, and the removal of a non preferred present. Ellyard has suggested six missions for urban Australia to be achieved by the year 2030; these are outlined in Table 2.3.

With increasing pressures imposed by population growth on infrastructure, financial capabilities, and the environment, new goals for urban development are needed. Governments must develop explicit settlement strategies to guide the process of urbanisation, to take the pressure off the largest urban centres. Smaller towns and cities should be established, more closely integrated with their rural hinterlands. This will require alteration of many existing government policies – taxation, food pricing, transportation, health, industrialisation – that work against the goals of settlement strategies (WCED, 1987).

2.4.4 Economics

The modern economic system that governs the consumption of resources and the distribution of wealth has generally failed to satisfy people's expectations of equity

Table 2.3
Missions for Development of Australia's Urban Centres

Mission 1	Growth of Australia's primary cities should be totally curtailed by 2030, with regional and country centres accepting any growth after then. Cities are already too large, and by getting bigger, dis-economies of scale will dominate.
Mission 2	Create jobs at the same rate as we encourage people to live in regional Australia, emphasising jobs for a 'clever country' or a 'brain based economy'. To ensure this end, our best educational centres should go to the regional centres. A transition to a brain based economy is in line with sustainable development, by moving towards a less resource intensive, high technology work force, involved in information technology, communications, environmental management, education and training.
Mission 3	By 2030 all Australian cities have a density of at least 35 persons per hectare. Such an urban density would allow more effective and safer public transport, better infrastructure and more energy efficiency. In addition, all large developments would require a residential component.
Mission 4	Invent our way towards an ecologically sustainable world. The creation of new products, services and technologies would also hold the potential for immense economic benefit. We need new ways to clean up water, for recycling sewage and removing environmental contaminants from both water and air, as well as preventing their infusion in the first place. We could move our cities underground, lit by natural light from deep atria. Development of more 'smart' buildings to minimise work journey. A new emphasis on public transport and light rail. Inclusion of science of human ecology and ecosystem planning in all planning processes, along with waste management.
Mission 5	Promote a significant cultural change to developing a society with goals of life-long learning, with an enterprising and caring culture.
Mission 6	The creation of a preferred future city, through the development of vision driven planning – driven by the people to a common vision.

and happiness. Human economic activity has consumed a substantial proportion of the natural resource reserves and with a detrimental impact. Yet, it has been acknowledged by the Brundtland Commission that economic development *is* necessary, together with environmental restoration, to achieve sustainability.

Sustainable development does not dictate zero or negative economic growth. 'Green' economic growth can deliver higher material standards of living and higher standards of environmental quality if the right economic policies, supportive of environmental protection objectives, are adopted. Some economists will argue that economic growth is fundamental to sustainability, because it provides finance for new investment to replace old environmentally damaging assets or for environmental restoration, and also offers a mechanism for wealth redistribution.

Weissmann (1991) proposes that the failure of economics is due to the fundamental assumption that the market processes are endless and reversible, whereas life is only ongoing and irreversible. Economics is based on the ideal that material and energy are convertible from one form to another and cannot be lost, as shown by the closed cycles of theoretical economics in Figure 2.1. This premise effectively permits reversal of the direction of time. This leads to the (false) assumption in economics

that any environmental damage can be 'cleaned up' with the expenditure of money, namely pollution abatement.

Market economies have inherent incentive structures which, it is argued, serve to conserve resources to generate economic growth. In a market economy, as a resource becomes scarce its price rises. Proponents of economic growth argue that as natural resources are depleted the market ensures that:

- less of the resource is used since its price is higher; and
- new sustainable resources are used instead of exhaustible minerals and fuels.

However, markets cannot be relied upon to protect the environment because of the peculiar characteristic of environmental resources – they are 'common property' goods which are commonly owned by everyone. Being jointly owned, such goods are available free of charge and hence people have an incentive to overuse and abuse them. For these reasons, the economy has become disembodied from nature, in theory and in practice.

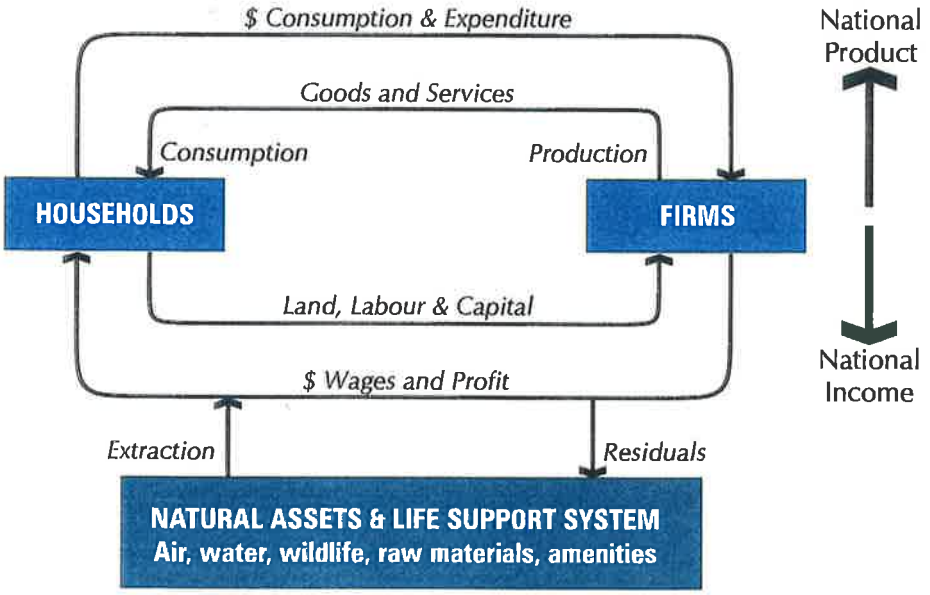


Figure 2.1
Circular Flow of Economic Production & Environmental Interaction

In essence, economics treats the environment as a free good which is over used and abused. Economists would therefore propose that development strategies ensure that the environment is properly valued and polluters are made to pay for using or damaging the environment. The Business Council of Australia supports this view (in Jenkins, 1991e) and states that:

> *'The key to preventing environmental misuse and achieving sustainable development lies in the provision of correct structures of incentives for all users of the environment.'*

Yet, it must be recognised that new investment will only contribute to a sustainable outcome if the institutional frameworks of economic policies are right. Resources

have to be priced at their true value, the tax system has to avoid stimulating activity that detracts from the environment, measures of government spending have to reinforce environmental values, and new project approval processes must provide rapid and certain outcomes.

Some further conflicts that require the resolution of economics with the environment are discussed below.

2.4.4.1 Discounting

Cost-benefit analysis frequently plays a significant role in the decision making process for new developments. Unfortunately, cost-benefit analysis often tends to be biased against ecological concerns. This is due to difficulties of measurement and valuation of natural assets, irreversibility issues, and the discount rate. This topic is explored further in Chapter 3.

2.4.4.2 National Accounts

The national income accounts are undoubtedly one of the most significant social inventions of the twentieth century. They serve to divide the world into 'developed', 'developing' and 'under-developed' nations, and their political and economic impact can scarcely be over-estimated (Repetto, 1988). Yet a serious problem exists with the way a nation's economic wealth is defined, and it is central to the problems of resource exploitation. It is the way national accounts are established – as an information framework for analysing the performance of the economic system alone, without consideration of externalities.

Externalities are factors that are involved in any given production process but don't add to the cost of the finished product; examples are environmental resources such as air, water and soil. No economic value is associated with these resources, and thus they are excluded from economic analysis. This means that a country could exhaust its mineral resources, cut down its forests, erode its soils, pollute its aquifers, and hunt its wildlife to extinction, but measured income would rise steadily as these assets disappeared (Repetto, 1988) and a wasteland resulted.

The assumption is that natural resources are so abundant that they possess no marginal value. It confuses the depletion of valuable assets with the generation of income. Thus it promotes and seems to validate the idea that rapid rates of economic growth can be achieved and sustained by exploiting the resource base. The result can be illusory gains in income and permanent losses in wealth. Ideally, income would be thought of as the maximum amount which the recipient could consume in a given period without reducing the amount of possible consumption in a future period (Edwards & Bell, 1986).

National income is conventionally measured and evaluated in terms of Gross National Product (GNP); that is the total value of goods and services produced during a given period. Natural resource assets are used to produce these goods and services and to finance economic growth, especially in resource-rich countries like Australia. Yet nowhere in economic statements is the loss of a valuable asset reflected. GNP has weaknesses as an overall measure of economic performance due to many other inconsistencies and omissions. For example, GNP fails to include

production within the home, knowledge and the stock of skills possessed by the work force.

Increasing awareness of these shortfalls has resulted in efforts to improve the system of national accounts. The Australian income and product accounts were revised in 1971 in accordance with the United Nations System of National Accounts (SNA), to include a measure known as Net National Product (NNP). NNP is equivalent to GNP adjusted for depreciation of the value of capital assets. For example, the value of structure and equipment can decline with use and over time as a result of both physical wear and of obsolescence due to technological improvements. While NNP is a more logical and appropriate indicator, it has received less attention because of the difficulties in estimating the depreciated value of assets, and the closeness of short-term movements in GNP and NNP, reducing the incentive to determine accurately the latter.

The United Nations has now, in concept at least, endorsed accounting for certain natural resources. SNA requires inclusion of forests and subsoil assets (oil and gas reserves) although the depletion of natural resources has not been addressed. Two approaches to asset valuation have been endorsed for use with natural resources:

- the use of values derived from market transactions in assets, and
- the use of the present value of the estimated flows of future income from the assets to be valued.

In the United States and Europe, further modifications to GNP have been proposed via the inclusion of environmental damages in monetary terms. There are limits to monetary evaluation however, set mainly by the remoteness of resources to the market economy, hence the difficulty in assigning any reliable value.

The need remains for meaningful or alternative yardsticks to GNP to be developed which quantify the impact of resource degradation, and do so in a manner that economic and business planners, policy makers, and the public can comprehend and act on.

2.4.4.3 Resource Pricing

Economic theory fails to protect the environment when financial incentives for resource exploitation are greater than environmental capacities. Traditional economic evaluation methods that include discounting encourage short term exploitation of resources over long-term resource management. There are also instances when placing a monetary value on resources is not enough, hence it may be necessary to confine resource use to a sustainable level. The economic argument is that population needs can be met through price increases, technology improvements, replacement by substitutes and development of new resources. However, Cherfas (1986) provides examples to demonstrate this is not always so.

Market forces can be brought to bear on both individual and corporate consumers. Natural resource policies can be considered economically efficient if consumers are made to pay the true and full cost of the consumption of these resources. A lower price would stimulate consumption in excess of the economically optimum level.

The costs of resource use can be modified by pollution charges, making it cheaper to treat discharges or re-use their wastes, or through taxation to modify consumption patterns and prices, and control resource use. Problems exist, however. Pollution charges are seldom high enough to offer sufficient incentive to reduce emissions (Jenkins, 1991d) and so pollution still continues – ideally pollution activities would cease. Revenue collected is often used to develop pollution control measures. This is a reactive rather than preventative approach to environmental management.

Furthermore, many government policies provide subsidies that promote inefficient natural resource consumption. Many environmental problems can be eliminated by the removal of these subsidies, which can be justified on environmental and economic grounds. Changes to eliminate an environmental subsidy are not always welcome. Yet in a broad sense sustainable development imposes no new costs, in that the environmental costs are already being incurred. Someone is bearing them now or will bear them in generations to come; it is only equitable that those who are using the resources should pay fully for their exploitation without passing on both the environmental and economic burden.

2.4.5 Institutions and Policy

The last decade has seen dramatic change in international politics and relationships between nations, in economic prosperity, as well as in our understanding of the natural environment and our impact upon it. These changes have not been accompanied by changes in our international institutions, however. Many economic and environmental inequalities are upheld by outdated institutions and increasingly irrelevant policies. Even the relevance of the United Nations in its present form is under scrutiny (Tolba, 1990). In addition, most government policy assumes that existing community attitudes and values will not change substantially (ESD Working Groups, 1992). Yet, as economic and environmental pressures increase, community values would certainly alter. A clearer understanding of the values embodied in existing policies, and the factors influencing them, is therefore important to policy development and decision making.

The Australian ESD Working Groups (1992) considered that for policy integration to be effective, acknowledgment of the interdependence of society, the economy and the environment is a central requirement. This requires change in decision making, largely at a government level.

A difficult area of policy development is that of environmental protection, and of biodiversity in particular. Demand for many natural resources such as gas, oil, coal, forests, fishery stocks, as well as tourism and agriculture, will grow as population grows. At the same time, environmental pressures will demand resource conservation in this situation of reducing supply. Habitat protection and species conservation, and policies to cope with this, will therefore become more important and politically contentious.

Policies must also be flexible, and encompass strategies to react to situations of risk and uncertainty. An example of risk is the threat of global climate change. The prediction of global warming of 2-5°C by 2050 would result in temperatures higher

than at any time in the previous 150,000 years. This would have implications for precipitation patterns, storm frequency and intensity, and soil moisture levels amongst other things, as well as the need for populations to adapt to an unprecedented rate of temperature and climate change.

Given the centrality of economics to our markets and institutions, it is generally considered necessary to bring environmental resources within the economic framework in some manner. Governments must therefore adjust the framework of laws, institutions and incentives that govern any market operations to accord with these new needs, and the need will exist to act decisively at times when the markets are ineffective in delivering the desired results.

Part 3 of the ESD Working Groups (1992) *Intersectoral Issues Report* concentrates exclusively on Policy Integration in Institutional and Administrative Organisations. The key recommendations are presented in Table 2.4, some of which have already been implemented by the Resource Assessment Commission (1992) and the Commonwealth Environment Protection Authority (CEPA, 1994).

Table 2.4
Key Recommendations for Policy Integration and Reform

- That a program of broad inter-governmental and public consultation be developed.
- Development of resource assessment methods (e.g. option value estimation, risk-benefit analysis, extended environmental cost-benefit analysis etc.).
- A high priority be accorded to work on the evaluation and development of techniques for environmental impact assessment.
- Initiation of a task force to develop the appropriate institutional arrangements to utilise mediation and conflict resolution mechanisms in resource management.
- Ecologically sustainable development can be incorporated as a fundamental objective into statements of organisational missions, corporate goals and objectives and operational planning processes of government departments and instrumentalities at all levels, and that these form the basis of institutional accountability through regular reporting of progress towards achieving these goals.
- Development and environmental agencies responsible for management and assessment of environmental impact assessment be required to develop their capacities to utilise more systematic and advanced methods for the assessment of impacts, for the valuing of environmental and social resources, and for the application of alternative policy instruments for achieving sustainable objectives.
- Pollution control and resource management authorities develop environmental impact management regimes together with strengthened sanctions including disclosure and penalties. Regulatory authorities should undertake more systematic and frequent auditing for the purposes of ensuring compliance with standards, adapting standards and goals as conditions change, and reviewing the effectiveness of the environmental impact assessment process.

Addressed briefly below are two issues of specific concern that are covered in the great bulk of literature on sustainable development.

2.4.5.1 Infrastructure Development

To enable establishment of new towns and cities, integrated with rural areas, will require changes in policy that would currently work against the goals of settlement strategies, such as taxation, food pricing, transportation, health and industrialisation.

Additionally, decentralisation of funds, personnel and political power will be necessary to ensure sustainable development strategies are tailored to the needs of the local community. The resources of local community groups must be harnessed towards the goal of sustainable development.

Future development of infrastructure for water supply and sewage treatment, pricing structures, transferability of entitlements between land holders, and water management policies, will require that all users are offered more self regulation over the distribution and efficiency of use of these resources.

2.4.5.2 Development Decision Making

There are four main policy instruments in Australia that influence development (Jenkins, 1991c):

- economic evaluation (discounted cash flow analysis or cost-benefit analysis);
- statutory planning through development controls and land-use zoning;
- environmental impact assessment; and
- pollution control requirements via licensing procedures or emission standards.

Currently, in any development decision, the economic criterion (short-term gain) is generally the most significant for the decision on viability. Environmental factors are given appropriate consideration, as required by law, however this often goes only so far as to consider mitigation measures for negative environmental impact. Whether the proposed resource usage is supportive of sustainable development or in the interests of the community in the long-term, is not part of the EIA process.

Similarly, land-use zoning in its current form is restrictive on development. Zoning essentially controls minor changes in land use about the urban fringe. It is not an effective tool in ensuring sustainable land use, and only segregates land uses that have been considered to be incompatible (e.g. residential housing and heavy industry). Planners are now beginning to question this philosophy.

Pollution controls relate mainly to prevention of excessive point source emissions since, in general, it is difficult to associate an increase in the ambient pollution level with a specific polluter. However it is the ambient level which is of most concern from the point of view of sustainable development, indicating that pollution levels should be maintained below environmental damage thresholds.

In terms of environmental impact assessment, Jenkins (1991a) concludes that 'Environmental Impact Assessments may provide information for sustainable development, but are not a vehicle for it.' Further discussion on this topic is presented in Chapter 3.

2.4.5.3 Actions for Institutional and Policy Improvement

Governments must begin to make the key national, economic and sectoral agencies directly responsible and accountable for ensuring that their policies and programs support development that is economically and ecologically sustainable. A multi-disciplinary decision-making approach is required, ensuring that all aspects of a proposal are adequately considered in plans, designs and decisions.

Major gaps in existing national and international law relating to the environment must be resolved, to recognise the right of present as well as future generations to an environment adequate for their health and well-being.

Sustainable development should also be incorporated into the mission statements and operational planning processes of private corporations, government departments and instrumentalities. This would form the basis of institutional accountability, with regular reporting of progress towards achieving these goals.

Development of resource assessment methods, such as option value estimation, risk-benefit analysis, and extended environmental cost-benefit analysis, should be accorded a high priority, along with evaluation and development of techniques for environmental impact assessment.

Pollution control and resource management authorities need to develop environmental impact management regimes together with strengthened sanctions including disclosure and penalties. Regulatory authorities should undertake more systematic and frequent auditing for the purposes of ensuring compliance with standards, adapting standards and goals as conditions change, and reviewing the effectiveness of the environmental impact assessment process.

2.4.6 Third World Development

Pollution has traditionally been seen as a by-product of wasteful lifestyles and dirty production processes in the industrialised countries. However, poverty can be as degrading to the environment as it is to humans.

The imperatives of daily survival can force families to think and live short-term, to over-graze grasslands, to over-exploit soils to maximise immediate yields, to cut down dwindling forest stocks for farmland or firewood, to destroy the few resources available to them. The millions of tonnes of dung that rural people burn annually are badly needed to regenerate soils already highly vulnerable to erosion now that the plants that bind them are withering away. Moreover, the process is circular, since it is poor people and poor countries that depend more than others on land and natural resources for survival and these same resources are consequently more vulnerable to environmental deterioration. What makes this situation so acutely critical is that all the signs point to the incidence of poverty growing in the Third World (after Ramphal, 1990; Young *et al*, 1994).

The plight of the less developed countries continues to worsen because of rising debt-servicing payments, dropping export revenues, disappearing investment flows,

and accelerating resource destruction. Traditional subsistence agricultural techniques and environmental maintenance practised by the indigenous tribes is over-run as is the natural resource base, as production is geared to the generation of export earnings required to service debts and the quest for economic development.

This vicious cycle by which poverty causes ecological degradation, and which in turn leads to more poverty, can be broken only by development. The poor can hardly be requested to stop using their immediate resources, and to be subjected to short-term misery, for the long-term good. Conservation must therefore be combined with measures to meet short-term economic needs.

Debt therefore remains the most urgent problem facing developing countries, particularly those in Latin America, Asia and Africa. The debt problems must be resolved before these countries can be expected to turn their attention to the pressing agenda of poverty and interlocked economic and ecological decline.

These problems cannot be tackled in isolation from those national and international factors that perpetuate large scale poverty. Unsustainable development by poor people is therefore related to the present inequitable distribution of wealth. This is why those concerned with the environment in Latin America and Africa see links with international economic problems. North-South capital flows (e.g. development aid and debt payments) are diminishing in real terms. In 1989 the developing nations transferred to the rich countries $43 thousand million more than they received in new aid and loans (Tolba, 1990). This situation has been exacerbated by the recent collapse of the former Soviet Union. Fundamental realignments in the politics and economics of eastern Europe have occurred, as well as a complete change in the world military balance. The direction of flow of aid may change, with aid going to central and eastern Europe rather than to the least developed countries (Young *et al*, 1994).

2.4.7 National Security

The traditional barriers between the East and West are toppling. Destruction of the Berlin Wall brings the unification of East and West Germany; Russia shuns the socialist system after 75 years and explores the capitalist market economy; and there is demilitarisation of the East-West super-power conflict. Yet a new security threat is emerging as a result of the global environmental problems.

'Environmental stress' has become a major source of political tension and military action in the world. Amongst the several ecological threats which may force a redefinition of 'national security' are (Colby, 1990):

- Increasing numbers (in the millions) of 'ecological refugees' caused by severe degradation of living standards and environmental quality.
- Regional conflicts over access rights to 'common property resources' such as water. In the Middle East the serious shortage of water is looming as a more serious threat to regional peace than competition for petroleum (Myers, 1989; Smith, 1993).

- The possibility of reaching the proportion of the Earth's limits of net primary productivity (photosynthesis) that may be safely expropriated by man, perhaps sometime in the next half century as the world's population doubles again.
- Discontinuous climate variations as a result of global warming and the Greenhouse Effect, causing disruptions in the world's most productive agricultural sectors.
- Major health crises due to damage of the ozone layer, especially increased occurrences of cancer. Even if ozone harmful products could be replaced immediately with substitutes, due to lags of decades between emissions and upper atmosphere effect, major health problems will still occur.
- The broad-scale loss of biodiversity and genetic resources, such as rain-forests and coral reefs, whose true economic and ecological values are unknown (and possibly will never be known), but which can reasonably be estimated as being very large.

Tolba (1990) suggests the time has arrived for the development of a United Nations body charged with the task of preventing conflicts arising from environmental problems. The body would promote co-operation through international programmes to ensure environmentally sound and sustainable development. Tolba proposes that it be linked to a function of ensuring that transboundary environmental impact assessment of major developments are conducted.

Governments should assess the cost effectiveness, in terms of achieving national security, of money spent on armaments compared with money spent on reducing poverty or restoring the environment. Military expenditures represent an enormous pool of capital, human skills and resources, a large proportion of which could be shifted to more productive purposes. Many thousands of dollars are being saved by the process of demilitarisation, and by diverting even a few days of the annual global military budget (estimated at $1 million million million) to environmental protection, could make an enormous difference (Tolba, 1990). Nations might find many instances in which their security could be improved more effectively through expenditure to protect, preserve and restore basic environmental assets than it could by expenditure on arms.

2.4.8 Culture and Education

It has been suggested by Boyden & Dovers (1992) that it is the human aptitude for culture that has created the severe threats facing the world population. Western culture has created a social system that is characterised by activities, patterns of consumption, dominant assumptions, expectations and values which are not consistent with ecological sustainability, and therefore, with the survival of mankind. Myers (1997) agrees that the triad of problems of population, environment and development are joined by a fourth in consumption, which may be very difficult to change because it is so deeply entrenched in the culture of most societies. It must be recognised that it is culture, and not the natural environment that must be controlled if our species is to survive.

Successful cultural adaptation will not take place until society is educated about the deficiencies in our current lifestyle. The missing ingredient is understanding of

nature and the human place in nature (Boyden & Dovers, 1992). The solution to the 'culture problem', as with the population problem, is non-technical. That is, it has little to do with a change in the techniques of natural science, and everything to do with human values.

Education of environmental matters is imperative, particularly for the information and persuasion of consumers, though economic instruments will remain very important.

Education for human resource development is similarly important. There must be development of technical knowledge and capabilities, and creation of new values, to help individuals and nations cope with rapidly changing social, environmental and development realities. The education curriculum must also expand to incorporate the experience and wisdom of all traditions and cultures. The traditional values of communities living on the land should be tested and embraced, with adaptation to current and future needs rather than casting them aside.

2.4.9 Technology

Many essential human needs can only be met through goods and services provided by industry. A continuing flow of revenue and employment from industry is also essential to the achievement of sustainability. Nevertheless, industry can be very polluting and energy intensive. Tolba (1990) has stated that unless appropriate technologies which eliminate CFCs, reduce CO_2 emissions, increase process efficiencies, and cyclic production systems are developed and implemented in the industrialised nations, and transferred to the developing parts of the world, there seems to be no doubt that our mutual destruction will be assured. A new era of economic and industrial growth must therefore be built upon technologies that are less energy-intensive, and where wastes are minimised and recycled.

Cars should be made much more efficient, with improved combustion processes and emission controls, and the adoption of new renewable fuel sources. At the same time, it is important that the need for cars also be reduced. Emphasis should be placed on development of cheap, clean, mass transit systems.

The transportation of fuels by pipelines and ships needs to incorporate improved emergency control systems. Improved systems must be developed to process and use human waste. In addition, engineering improvements are needed to develop practical solar and geothermal power generation, wind power and biomass generation. In the search for these new technologies, consider must be given to the resource usage in their development, and the resources required for their operation. The use of the scarcest resources must be minimised, and substitutes employed wherever possible. Virtually all manufactured by-products should be reusable or recyclable.

Experience in some industrialised nations has proved that anti-pollution technology has been cost-effective in terms of health, property, and the avoidance of environmental damage. Many industries have become more profitable because they are more efficient. While economic growth has continued, there has been a change

in the consumption of raw materials to renewable or recyclable substitutes, and new technologies offer further efficiencies.

Clearly, many technological shifts, improvements and new developments are required. But perhaps the most fundamental goal is the development of cheap, 'clean' energy sources. Improvements in energy efficiency can be more economical than developing new energy supplies. While energy efficiency policies must be the forefront of national energy strategies for sustainable development, energy efficiency can only buy time for the world to develop 'low-energy paths' based on renewable sources. Clean, renewable energy must be the foundation of the global energy structure during the 21st century.

2.5 Is Sustainability Achievable?

There can be discussion and documents on sustainability and the costs and benefits of the concept, while the media can continue to report on environmental problems, but no progress toward sustainability will be achieved if the general public have no interest in living sustainably. There must be the will among the greater portion of the population to protect the natural environment and preserve a decent standard of living for future generations.

Individual perceptions of the environment clearly depend upon where people live, on their economic circumstances, and on their cultural and religious backgrounds. A great danger is that the very perceptions and goals that have caused the developed countries to consume a disproportionate share of the world's environmental resources, and to pursue unsustainable patterns of economic activity, are being emulated by the developing countries (Holdgate, 1990).

Most people consider only themselves when making choices and decisions. They are often unaware of the far reaching and possibly global impacts of their daily choices. Personal level decisions and actions can have global ramifications since our individual actions have significant collective impacts. It is therefore necessary to bring people's attention to the impacts their own daily patterns. By developing people's understanding of the environment, they may become motivated to take the actions that are required. In the developed countries in particular, many people do not understand the impacts they can create. North Americans, in particular, have a great effect on the world environment. They are responsible for approximately 36% of resource consumption by humans, but constitute only 6% of the global population (Stapp & Polunin, 1991).

People living in resource rich countries also find it difficult to relate to the strains imposed upon nations struggling for survival. Even though the destruction of the rainforests and fishery stocks is very real, and does impact upon them, it is easy to overlook and ignore the extreme gravity of the situation. Thus it is essential to illustrate people's connections to these situations.

Political ideologies, language differences, and the desire for power, also lead people to place local and national interests above global issues. Another inhibiting factor is the preference by humans for instant recognition or response, a concern for the

immediate and the tangible. However environmental hazards often develop over time (other than oil spills and similar catastrophes), and take many years for the slowly building consequences to reach visible proportions. People may also resist the need to tackle the environmental crisis, because it seems that to do so would mean dismantling the whole fabric of society.

This selfishness and exploitive nature largely characterises human societies. In fact, a most powerful mode of exploitation is prevalent throughout most societies – capitalism. Capitalism is merely an expression of basic human nature – selfishness. (In fact, Medlin (1991) proposes that the reason for failure to arrive at a classless society by means of socialist revolution is this same basic selfishness.) Human selfishness, while not being a seemingly inseparable part of human nature, however, is not fundamental to human society. What is fundamental is cooperation. Human competition, even in its most intense form as in warfare, is an intensely cooperative activity. What is suggests it that the existence of human selfishness does not mean that people cannot or wont collaborate in the pursuit of sustainability.

Indeed, encouraging signs have emerged most notably within the last decade. The force of public opinion on environmental issues has become manifestly stronger, better founded on scientific evidence of real hazards, and more insistent in its demands for action than at any time in the past. An informed public and mobilised public opinion can make a substantial difference in determining the behaviour of governments in response to sustainable development.

2.6 Recent Initiatives for Sustainable Development

There have been many efforts to implement environmentally 'safe' technologies throughout the world for many years. In the United States of America and Israel in particular, much effort has been placed into recycling of wastewater for various applications. Throughout the world, recycled paper is now used in large quantities, whereas ten years ago its use would have been contemplated seriously by few. However in many cases, these initiatives have been driven by purely economic reasons, without deliberate consideration of the environment.

International co-operation to address global threats from the perspective of environmental protection also remains highly inadequate. A conspicuous example is the debate over the reduction of Greenhouse gases. With the reduction of gas emissions a key topic of discussion at the world environment summit in Kyoto, Japan on 1 December 1997, the industrialised nations have demonstrated an inability to reach a consensus on uniform reduction targets. While the US and Great Britain have argued strongly for substantial reductions, Australia has taken a notable position of 'rigid opposition', refusing to agree to legally binding reduction targets (Denholm, 1997; Lederer, 1997).

Nevertheless, efforts are being made to put into practice the concept of sustainable development. The community planning body for Ventura County (located north-west of Los Angeles in southern California) detail their vision for the future in their discussion document *Ecological Planning Principles for Sustainable Living in Ventura County* (Smyth *et al*, 1991) as:

> *'To develop a sustainable lifestyle in Ventura County that accommodates ecological urban and rural communities. To preserve local viable agricultural and forestry lands, native habitats, mountains, rivers, coastal areas, and other valuable resources. To live within our means and not mortgage away the future, or reduce choices for future generations. To recognise that human beings and human habitat are a part of the ecosystem and its beauty. To accept that cities are as natural to human beings as the biosphere is to this beautiful planet and that they are an integral part of our own creative evolution as a species. To use democratic, collaborative processes as a community to shape the future of our cities and our county in exciting, harmonious and meaningful ways.'*

The document outlines eight principles that were established by the community as objectives and policy guide-lines for the future development of their local district. Design and policy criteria, and a list of questions designed to promote thought on the subject, accompany each principle description. The principles are:

- Protect, preserve and restore the natural environment.
- Establish true-cost pricing as the basis of economic viability.
- Support local agriculture, business, products and services.
- Develop clustered, mixed use, pedestrian oriented ecological communities.
- Utilise advanced transportation, communication and production systems.
- Maximise conservation and develop local renewable resources.
- Establish recycling programs and recycled materials industries.
- Support broad based education for participatory governance.

An Australian initiative involves development of a high technology city called the 'Multi-Function Polis' (MFP) to be sited in northern Adelaide, South Australia. The development is loosely based upon similar developments in France, Germany and Canada, but has a greater emphasis upon the environment and sustainable lifestyles. The goals for the MFP are built upon the essential elements of sustainable development – people, technology and environment. It is planned as a model of conservation and management of natural resources, as well as a key linkage point for Australia with the Asia-Pacific region in science, technology, education, the environment and communications (MFP Management Board, 1991). A series of interconnecting villages will be built. People will be able to choose to live, learn, work and engage in a range of recreational activities without travelling long distances. The design and operation of the villages will involve much more efficient use of energy, recycling of stormwater and wastewater, and an improvement of waste management in general. The villages will be designed to maximise the use of in-village transport, with cars (the source of much world air pollution) parked in secure, serviced interchanges on the periphery of each village. Streets and public spaces will be scaled for people rather than cars.

Elsewhere in Australia there are many initiatives that are supportive of sustainability. The establishment of land and water management boards with funding to implement catchment based programs of environmental restoration and natural resource management are notable examples. The boards are often complemented by government or community funded action groups such as Greening Australia, Landcare, and Waterwatch, just to name a few. The use of wind farms for energy generation is growing. In South Australia, a wind farm is in operation in the state's

north at Coober Pedy, with proposals to trial a 21 storey wind turbine south of Adelaide, and also to construct a farm supplying the national energy grid in the state's south-east, west of Mt Gambier (Kelton, 1997; Hurrell, 1997). Projects are underway to develop strategies for the development of sustainable cities, focussing on Whyalla in South Australia and Geelong in Victoria. Numerous residential property developments have had a similar focus, such as Andrews Farm and Regent Gardens in South Australia, and Caroline Springs in western Melbourne. Unfortunately, the bold visions for some of these developments have not been realised due to market, institutional and political reasons. Other initiatives and thinking on matters of urban development are explored in Chapter 9.

These initiatives are a positive step toward achievement of sustainability. Yet, the concept of sustainability has only recently gained international recognition, while environmental concerns have existed for decades and the fundamental principles for centuries. The number of publications on the topic far outweigh the number of genuine attempts to adopt sustainable systems in commerce, manufacturing, agriculture and lifestyle. Even Canada's *Green Plan* was widely criticised as a pure 'public relations' document, with few commitments to increase spending, no overall vision, and no sense of urgency (Anon., 1991d). The question is whether the community desire and political will exists to tackle the difficult issues and embrace cultural change for sustainability. Planning and assessment processes need to be revised to embody the desire for sustainable development.

2.7 Conclusions

The global ecological crisis provides, for the first time in history, a common interest which embraces the whole of human mankind (Medlin, 1991). The concept of sustainable development must be central to the way we work and live – a starting point, from which rule-of-thumb decision criteria and 'social guidelines' can be developed. It is important to see it as a process that is just the beginning of a new approach to decision making, and an overall change in community attitudes and consumer demand patterns.

The onus lies with no one group of nations. Developing countries face the life threatening challenges of desertification, deforestation, and pollution, and endure most of the poverty associated with environmental degradation. The global population is suffering with the disappearance of rainforests in the tropics, the loss of plant and animal species, and changes in rainfall patterns. Industrial nations face the life threatening challenges of toxic chemicals, toxic wastes, and acidification. All nations may suffer from the releases by industrialised countries of carbon dioxide and of gases that react with the ozone layer, and from any future 'resource wars'. All nations will have a role to play in changing trends, and in righting an international economic system that increases rather than decreases inequality, and that increases rather than decreases numbers of the poor and hungry.

As the amount of biodiversity is reduced, and as the environment is degraded by economic processes, economic activity may become less resilient when subjected to environmental and other shocks (Tisdell, 1990) in much the same manner that

natural species with limited genetic diversity become less resilient to adapt to changing environmental conditions.

A possible outcome is a division of humankind in competition for the ever reducing resource base. Alternatively, as the crisis becomes more acute, it will unite people across the barriers of class and gender, race and nationality, in the task of destroying all such barriers. World security depends upon building due respect for all nations and cultures, and the fact that people all over the world have rights to reasonable complements of acceptance, peace and human dignity – now and in the future.

The environment must be treated as an asset and not as a free good. Strategies should ensure that the environment is properly valued and polluters are made to pay for using or damaging the environment. We need a new growth measure that incorporates natural capital as an asset, and accurately reflects the extent to which development has been achieved at the cost of environmental degradation.

3

Evaluation of Sustainability

The aim of evaluation is to facilitate choice, by arranging data into a concise summary of the relative strengths and weaknesses of alternatives relative to the defined objectives.

The criteria against which the merits of the alternatives are assessed depend on the project and the defined objectives. Project evaluation may have to consider technical, economic, financial, legal, environmental, social, political, risk and sustainability aspects of performance, as indicated in Table 3.1. Simple projects often only undergo evaluation for their technical and financial feasibility, whereas larger and more complex projects that are likely to impact more broadly upon the community and environment will require environmental, social, risk and political assessments as well.

Some approaches to evaluation rely upon numeric data aggregation techniques, such as cost-benefit analysis (CBA) and risk assessment. Others are social, institutional or legal processes which may make use of qualitative techniques – for example, environmental and social impact assessment, conflict management and the law courts (Hollick, 1993).

Quantitative evaluation methods need not necessarily be used to arrive at a rational[1] decision, but very often they form part of the decision making process. Project evaluation typically requires more than one type of rationality (Hollick, 1993). Technical and economic rationality are needed to determine the feasibility and means of achieving the objective, while environmental, social, legal and political rationality are required to varying degrees to limit and manage conflicts of interest over what should be done. To a large degree, technically proven alternatives are most often selected on the basis of economic rationality.

Economically rational decisions are concerned with allocating scarce resources between competing objectives in order to achieve the greatest possible benefit. Quantitative evaluation of economically rational decisions is only possible when all relevant factors and objectives can be measured in a common unit such as dollars. If this cannot be done, it is impossible to aggregate the costs and benefits of each alternative to determine which provides the greatest net benefit.

1 Simon (1957) defines a rational decision as one that is consistent with the values, alternatives and information that are weighted by the individual or group in making the decision.

Table 3.1
Categories of Evaluation Criteria (after Hollick, 1993)

Criterion	Description
Technical	Can an engineering system be designed to perform the desired function?
Economic	Would the benefits of the project exceed the costs? Which alternative would give the greatest excess of benefits over costs?
Financial	Can the funds be raised to undertake the project?
Legal	Can approval be obtained for the project from planning, environmental and other controlling bodies? Would the project infringe any legal rights?
Environmental	Will the project satisfy environmental protection laws and community concerns?
Social	Will the social impacts of the project be acceptable to the community?
Risk	Will the risks to life, property and health meet legal requirements and be acceptable to the community?
Sustainability	Will the project help to meet the needs of this generation without impairing the ability of future generations to meet their own needs?
Political	Can the approval of local, state and national governments be obtained?

The trend toward the inclusion of more factors in the economic system makes it possible to extend economic evaluation techniques to more and more decisions. However, it is impossible to price many personal and social objectives, and therefore there is the need to look beyond economics if society, as distinct from profit orientated companies, is to make rational decisions.

Different people have different objectives and, even if they have similar ones, are likely to give them different priorities. The problem for evaluation is therefore to find some way of combining the preferences of individuals and groups to find the course of action that would be preferred by society as a whole. Market economics provides a mechanism of social choice for goods that are traded, but is inadequate where non-market factors such as environmental quality, aesthetics or many issues pertaining to sustainability are involved.

So how can sustainability be evaluated, given that the State and Commonwealth Governments of Australia require that ecologically sustainable development be a consideration in the assessment of major development proposals? As yet, conventional economics seems not to be able to satisfactorily address or promote sustainability. EIA is a method by which issues of sustainable development can possibly be addressed.

3.1. Environmental Impact Assessment

A variety of influences combined in the 1960s to produce an environmental movement which, in legal and institutional terms, climaxed in the United States with the enactment of the *National Environmental Policy Act 1969* (Morgan *et al*, 1992). Environmental impact assessment (EIA) had its origin in this Act, which required that all federal projects or private ones that involved federal properties be subject to EIA. Since that time EIA has been adopted in many countries throughout the world and

has undergone various changes, to the point where procedures may vary considerably. Hollick (1986) notes that the common ground may be little more than the undertaking of an assessment of the adverse environmental effects of some types of projects before decisions are made to proceed.

The primary goal of EIA is to minimise the environmental damage that could occur as a result of the implementation of development projects. The outcome of the EIA process is usually a formal document, generally termed an Environmental Impact Statement (EIS). An EIS usually addresses the following topics:

- substantiation of the need for a project;
- a description of the proposed project;
- a description of the existing environment;
- the mitigation measures proposed to ameliorate adverse impacts; and
- an indication of alternatives considered (Jenkins, 1991).

What constitutes 'the environment' can vary widely. Most EIA is focussed upon the biophysical or natural environment and may include some consideration of issues such as natural beauty and aesthetics. In some instances, EIA is extended to address the man-made or built environment. A few systems, notably in the United States, define environment very broadly so that EIA also encompasses a full consideration of social impacts as well.

Two approaches have tended to be taken in determining whether EIA is initiated to assess a project. In the first, detailed regulations list the type of project which must be assessed. In the second, the decision is based on a brief preliminary assessment which may or may not be made available for public comment. Responsibility for then making a decision often lies with government. The basis upon which EIA is implemented can therefore vary dramatically from government to government.

Regulations in the United States stress that analysis of alternatives is at the heart of EIA. However, in some jurisdictions the EIA is used primarily to determine the conditions under which the project can proceed rather than for evaluating options. The consideration of project alternatives is likely to provide better environmental outcomes, since it should stimulate lateral thinking about the nature of the project rather than a narrower focus on mitigating impacts (Hollick, 1993).

Coordination of policies across national borders is also becoming increasingly important with regard to international environmental issues. Thus it is no longer satisfactory for environmental impact assessments to concentrate on local environmental effects. They also must take into account the contributions of the project to sustainability, including acid rain, ozone depletion and the Greenhouse Effect. The extension of EIA to cover sustainability introduces new complexities and presents many challenges, most of which are yet to be resolved.

3.1.1. Environmental Impact Assessment in Australia

Australia's approach to environmental management and development, places great emphasis on the production and evaluation of an EIS for project decision making.

The Australian Government and the State and Territory governments with powers under their various Acts require that EIA be carried out for projects of major social, economic or environmental importance. The Australian Government administers EIA procedures under the Commonwealth *Environment Protection (Impact of Proposals) Action 1974*. Under this Act, not all projects are subject to assessment; only those likely to impart a significant impact will be assessed.

In South Australia, the procedures for conduct of an EIA were originally defined by the *Planning Act 1982*. More recently, these procedures have been revised and superseded, with EIA now implemented in accordance with the *Development Act 1994*. The output of an EIA is a report called an Environmental Impact Statement (EIS).

Figure 3.1 provides an outline of the EIA procedure under this Act (after Harvey & Ferguson, 1994). The EIA legislation within the *Development Act 1994* maintains the status quo in a number of areas but has introduced a number of changes, including public meetings, incorporation of an Assessment Report, and consultation with other government agencies such as the EPA.

The application of EIA in South Australia also focuses on project development proposals and project management rather than policies, programs or the drafting of legislation. Furthermore, the division between major and minor projects has changed, so that the EIA process is reserved only for a few of the largest or most controversial major projects, with non-appealable decisions on EIA projects to be made by the Governor, or delegated to the Development Assessment Commission.

The legislative requirement for an EIA under the former *Planning Act 1982* relied upon Ministerial discretion rather than any set of guidelines or criteria. This resulted in an ad hoc triggering mechanism which had a strong dependence upon departmental advice and precedents for similar projects. The *Development Act 1994* has improved this situation, embodying review criteria in regulations which emerged from a national review of EIA procedures (ANZECC, 1994). In addition, to give more certainty to developers, the *Development Act 1994* now provides for an 'early no' in the EIA process but has stopped short of giving an early yes or an in-principle agreement.

Where both the South Australian and Commonwealth EIA processes are applicable, the Commonwealth Environment Protection Agency (CEPA, which is responsible for administering the Australian Government's environmental protection legislation) and the Environmental Impact Assessment Branch of the SA Department of Housing and Urban Development (DHUD) generally agree on a joint process that satisfies the requirements of both Acts (Rust PPK, 1996).

The major implications of the Development Act for EIA are that the decision on all EIS projects are to be made by the Governor with no appeal rights, decisions on Crown developments are made by the Minister, there is cross referencing and referral to the EPA, and an Assessment Report becomes part of the required documentation and has to be considered in the decision making (Harvey & Ferguson, 1994).

Steps in the EIA Process

1. Proponent submits application for development or mining production tenement
2. Minister or Government decides that EIS is required
3. Early 'no' decision possible by Governor (no right of appeal)
4. Minister sets guidelines (public consultation 4 weeks, EPA consultation no time frame)
5. EIS is prepared by proponent
6. EIS is placed on public exhibition for 6 weeks or longer (public meeting held, Government agency comment, EPA referral)
7. Proponent provides response to submissions and Government comments
8. Government agencies comment
9. EIS, submissions and proponent response are assessed by DHUD in Assessment Report which is publicly released
10. Minister decides what amendments, if any, are necessary to the EIS, This can occur at any time. Also, a PAR may need to be prepared.
11. Proposals exempt from decisions under Act, by regulation or an indenture agreement
    - e.g. National Parks and Wildlife (Schedule 14), Housing Trust, Urban Land Trust, TAB, and State Bank (Schedule 13), and indenture agreements

    Section 49 or 50 proposals
    - MHUD may issue directions to the proponent

    Section 48 Declarations
    - Governor decides on application

    Section 75 proposals
    - MME decides on tenement or refers to Cabinet

LEGEND

9 Step previously included under the *Planning Act 1982*

10 Step new to the EIA process in SA, introduced in the *Development Act 1994*

DHUD	Department of Housing & Urban Development
EPA	Environment Protection Authority
MHUD	Minister for Housing & Urban Development
MME	Minister for Mines & Energy
PAR	Planning Assessment Report

After Harvey & Ferguson, 1994

Figure 3.1

EIA Procedure Under South Australian Development Act 1994

At the Commonwealth level the enactment of EIA legislation was a major step forward in environment protection in Australia. The process has remained relatively unchanged since its inception in 1974 however. Yet to be effective and efficient, the process needs to reflect the changing needs of environment protection in Australia, including changes that have occurred in the environment in that time, and to incorporate current community perceptions of what is an appropriate role for the Commonwealth Government in meeting these needs. Environmental groups have indicated that the Commonwealth's EIA process is no longer sufficient in its present form (CEPA, 1994).

In response, the Commonwealth Government, through CEPA, have initiated a public review of EIA within the wider context of other major initiatives to improve environmental protection nationally.

The *Intergovernmental Agreement on the Environment* came into effect in May 1992 which provided the consensus from all levels of government on the need for more nationally consistent and improved approaches to environmental issues, including EIA. Subsequently, ANZECC began work on the *National Agreement on Environmental Impact Assessment* to streamline and clarify the roles of governments in EIA, and to increase certainty and efficiency of the process (after CEPA, 1994). The review also provided the opportunity to integrate the recommendations contained in the *National Strategy for Ecologically Sustainable Development* (ESDWG, 1992), and to address many reform recommendations arising from the 1992 Rio Declaration and Agenda 21, as well as treaties such as the climate change and biodiversity conventions.

The outcomes are yet to be finalised, and some practitioners have suggested that EIA is no longer an appropriate tool where there is the desire to promote projects that contribute to sustainable development. Regardless, it seems most probably that EIA will remain the preferred environmental assessment procedure, but with a range of modifications to address many of the current limitations.

3.1.2. Some Limitations of EIA

The effectiveness of EIA procedures at influencing decisions is affected by the extent to which the process is discretionary. EIA has often been introduced as an administrative measure rather than through legislation. In this case, its application is almost completely at the discretion of relevant government agencies, and political pressure can be brought to bear to exempt particular proposals.

Where EIAs are implemented they can be affected by personal or organisational bias. Bias can take a number of forms, including failing to mention or playing down certain impacts, failing to consider all phases of a project, leaving out or failing to collect certain information, making over-optimistic or unduly pessimistic predictions of the effectiveness of mitigation measures, and using personal value judgements of the significance of factors or impacts. Bias can be countered in two ways: by controlling preparation of the impact assessment, and/or through a process of review.

The quality and effectiveness of public involvement is significantly determined by the form of review process. In many cases, members of the public are invited to submit written comments on the EIS, which are then analysed and considered. Participants can become very frustrated by this process, however, as they see their contributions apparently neglected, distorted or misunderstood with no possibility of correction. Public involvement can be far more effective though if it starts early in the EIA process, particularly if the public have a role in 'scoping' the assessment study.

A public review of EIA procedures undertaken by the Commonwealth Environment Protection Agency (CEPA, 1994) found that key issues for the public included who should decide when impact assessment was required, and how environmental conditions are set on proposals. A report prepared by the Bureau of Industry Economics (BIE, 1990) suggests that the two greatest concerns for industry are the potential for costly delays and uncertainty associated with the assessment process.

The majority of public submissions also expressed concern that the current environmental impact assessment legislation and its administration were focussed on a legislative process rather than on outcomes.

Under the current legislation, the Commonwealth EIA legislation applies to projects which raise environmentally significant issues of national or international importance, and only if the project is being undertaken by a Commonwealth agency or is subject to some other Commonwealth approval. Projects may not therefore be subject to the Commonwealth assessment process even when they raise environmentally significant issues of national of international importance (CEPA, 1994).

The current process for triggering is also of limited effectiveness in securing effective and efficient protection of the environment in that it can be:

- uncertain and unpredictable;
- inadequate at providing information to the public and proponents;
- not timely enough; and
- not effective in implementing sustainable development (CEPA, 1994).

In most cases, EIA is used at the pre-development stage to determine whether or not a project should proceed, or more often, under what circumstances. The EIA process as it now exists in South Australia has been criticised on this basis by Fookes (1987) who considers it is merely a review of potential environmental effects and possible mitigation measures, rather than a critical part of the decision making process.

A proposed revision to the Commonwealth EIA process is the addition of a schedule of *designated developments* (CEPA, 1994) which defines those proposals likely to raise environmentally significant issues of national or international importance. Proposals so designated will require a decision of the Commonwealth Government on whether Commonwealth assessment is appropriate. This type of approach has been implemented overseas in Canada and the European Community. Within Australia, New South Wales and Queensland use some form of designated developments procedure. Such a process has several advantages including:

- pre-determined and publicly known parameters against which to assess activities and plan future developments;
- encouragement for more environmentally responsible proposals including integrated environmental management;
- a quicker and more administratively efficient assessment process;
- avoidance of delay in the assessment process and due to reduced conflict resulting from increased public confidence in the EIA process; and
- improved certainty (CEPA, 1994).

Adoption of the EIA review criteria should improve certainty for project proponents and will reduce the previous practice of 'shopping' amongst the states for the least costly and time consuming environmental impact assessment of their project. The division between major and minor projects will, however, not be clear in many cases (Harvey & Ferguson, 1994).

Harvey & Ferguson (1994) consider that one of the most significant issues in re-drafting of the South Australian EIA legislation was the omission of the possibility of a PER or Public Environment Report which was contained in the draft of the Development Act. This would have allowed an environmental assessment to be carried out for projects which have a lesser environmental impact but still require investigation and public reporting. This is not available, although modification to the EIA process has meant that guidelines written for an EIA can be more focussed, resulting in an EIS possibly addressing only one or two issues.

Damania (1992) has criticised the process for not enough public involvement, lack of public accountability for decision making, a failure in accounting for all the costs and benefits of a project and a failure to assess the cumulative impact of developments.

However, due to the difficulties of predicting project impacts, there can be large discrepancies between the predicted and actual environmental consequences. Strict monitoring programs and adaptation of management should therefore be a requirement of projects given approval to proceed after an EIA review. Unfortunately, relatively few EIA procedures have made adequate provision for this, greatly reducing the long-term effectiveness of the system. Hollick (1993) notes that Western Australia was one of the first places in the world to recognise the need for ongoing management as part of EIA, and it still has one of the most advanced systems in this regard.

Beanlands & Duinker (1984) identified concern about the lack of scientific approach and data employed in EIA, and undertook an study supported by Canadian governments and industries to address this issue. A review of over 30 EIAs found little evidence of applications of ecological concepts such as eutrophication, bio-accumulation, and nutrient cycling in the design of studies or prediction of impacts. The only ecological theme that gained consistent attention was that of species-habitat interactions. Furthermore, spatial and temporal boundaries were usually limited to the extent and duration of the project, and were not generally influenced by ecological considerations such as species migration and rates of recovery from stress. Monitoring plans were seldom linked to pre-project baselines and rarely was

a feed-back loop incorporated to allow for possible modifications to project design or operations. These findings were substantiated by another major review of EIAs reported by Rosenberg (1981).

A reform nominated by the Commonwealth is post-approval monitoring, partly addressing the previous concerns. Other proposed reforms include:

- a public statement of no significant impact for decisions not to assess projects;
- the introduction of public scoping as a standard element of assessment;
- project specific time schedules;
- the development of comprehensive criteria for determining environmental acceptability of projects undergoing EIA;
- establishment of strict assessment criteria based upon the nature and value of the receiving environment;
- improvements to public participation; and
- improved accessibility to the external review of Commonwealth EIA decisions.

A further issue is that even the best assessments are of limited value if they are only prepared for a small fraction of the projects which might significantly damage the environment. Assessment of government policies, regulations and legislation is rare. Harvey & Ferguson (1994) consider that the conduct of EIA on government policies and programs is a major area of national agreement that has not been implemented but which is extremely important.

CEPA (1994) concede that EIA cannot deal effectively with the environmental consequences of government policies, plans and programs. Similarly, project assessment can only deal with cumulative and regional impacts of development in a limited manner. These and other issues that remain to be addressed include:

- the assessment of cumulative, incremental and regional impacts;
- the assessment of social and health aspects of environmental change;
- the assessment of government policies, plans and programs;
- the assessment of overseas impacts of Australian activities; and
- improving linkages between environmental impact assessment and planning and pollution controls.

3.1.3. Does EIA Cover the Requirements of ESD?

Although the integration of ESD principles into EIA has been strongly advocated at the national level, this has yet to be successfully undertaken in South Australia and other states, and remains a challenge for the future. Some other states have attempted the use of EIA to assess policies and programs but this has not occurred in South Australia (Harvey & Ferguson, 1994).

To a very large extent, EIA is an unsuitable process or mechanism for the promotion of sustainable development because it is a reactive process, that *may* only be initiated in response to a particular development proposal. It is not proactive in terms of encouraging resource conservation or equitable outcomes.

Some intragenerational equity issues can be addressed using EIA, such as the mitigation of impacts on certain groups within the community, but often even this facility is weakened by public involvement of limited effectiveness, and elimination of the right of appeal over development decisions.

The lack of scientific information, or the desire or capability to include the available scientific information, is also limiting in many respects. Given that the functioning and fundamental synergies of many ecosystems are still not well understood, informed decisions about their carrying capacities and ability to assimilate adverse impacts are difficult to make. The project proponent is rarely willing to invest either the time or money to implement any substantial scientific research or monitoring to improve the available data set.

The cumulative impacts of a project or the implications for biodiversity can be even more difficult to assess. Ironically, it is found in hindsight that many of the most serious problems of environmental degradation have resulted from the cumulative effects of many small developments, such as creeping urbanisation, or land use changes on individual farms. EIA is unable to deal with this problem because in its current form it usually focuses upon major projects.

Kozlowski (1990) advocates the integration of ecological considerations into the project planning process from the outset through the concept of 'framing' development by spatial, quantitative, qualitative and temporal environmental dimensions indicated in the planning process. From these dimensions development constraints could be derived, which could be overcome but at varying investment, ecological or aesthetic costs and represent environmental thresholds to development. Kozlowski (1990) embodied this concept in the Ultimate Environmental Threshold (UET) method, which essentially incorporated the concept more frequently referred to in the recent literature as ecological *carrying capacity*, as the framework within which proposals would be formulated.

The issues addressed within EIA are often constrained to those issues that are much better understood, but resulting in an over-simplified and false outcome. The other risk is that a precautionary approach is rarely adopted where there is concern over potential impacts but little hard data upon which to base advice. A project will typically be allowed to proceed unquestioned where there "is no scientific data to suggest detrimental impacts will result".

To promote sustainable development requires some other approach, probably involving the development of resource management plans or regional management strategies that encompass existing resources as well as new proposals for resource use. It also requires that these plans be monitored and changed when required. Techniques such as *adaptive environmental assessment* (Holling *et al*, 1978) have been proposed for this purpose.

Alternatively, the process of preparing an EIS must therefore become pro-active in encouraging sustainable resource management. Jenkins (1991a) considers that the requirements for practice would need to be expanded to encompass two additional content criteria that are included in the United States legislation:

- the relationship between local short-term uses of man's resources and the maintenance of long-term productivity, and
- irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

In addition, development monitoring should occur following 'completion', to provide a further 'react and cure' mechanism for adverse environmental impacts, to complement the development planning 'predict and prevent' efforts. This would provide more scientific data on the cumulative impacts of the project, ecosystem responses and the ability to incrementally modify some projects to further mitigate or enhance the environmental outcomes.

Ideally, much more rigorous evaluation of alternative development options would occur at an early stage, taking into account the broader social and environmental costs which are inherently longer term economic costs.

3.2. Economics and the Environment

The integration of the environment into development economics also dates from the 1960s, but environmental economics still does not play a major role in the leading economic development textbooks or other well-known treatises on the subject.

Environmental protection and resource management for sustainable development requires government regulation, which to some degree conflicts with the modern trend in development economics in the 1980s and 90s toward market freedom and deregulation. Most environmental economists believe in competitive markets and favour economic incentives over 'command and control' instruments for achieving environmental and resource conservation goals. Nevertheless, requiring producers to internalise the social costs of their pollution, or preventing private owners of natural resources from depleting or degrading resources required by future generations, necessarily entails some government intervention in markets or interference with private property rights (Mikesell, 1992).

To a considerable degree, sustainable development expands the role of government in regulation and in directly controlling the use of natural resources. However, the objectives of control differ from those of the past. Government intervention is not designed to promote economic growth, but rather to prevent economic activity from overwhelming the pollution absorptive capacity of the environment, or depleting or degrading the natural resource base.

In a similar way to the role of government, the function of economics has not changed, but the focus and parameters have begun to shift to those of *environmental economics*.

It is not a pre-occupation with social and ecological issues, nor the principle of 'polluter pays' that distinguishes environmental economics from conventional economics. Rather, it is the goal of maintaining the natural resource base, including the capacity of the environment to assimilate wastes, for the use of future

generations so that their opportunities to maintain or advance their well-being are undiminished.

The environment provides resources that are the raw materials of many production processes, and other important services to humans and other life forms. All economic activities, including consumption, create waste: effluents into water bodies, air pollution, and solid wastes. Some of these wastes must be absorbed into natural systems. There are, however, limits to the capacity of the air, water and land to assimilate waste without impairing their functions in production, in supporting life, and in providing environmental amenities.

Environmental economics aims to integrate the natural resource cycle with the economic process. Sustainable development provides the additional economic objective to maximise the supply of natural resource inputs on a sustained intergenerational basis, while keeping the flow of waste products at a level below which they can be assimilated without impairing the productivity of the natural resource base. This process cannot be achieved by the economic system alone, and requires feedback of scientific data for the modification of economic instruments such as prices, taxes and subsidies.

To deal with resources in terms of their contribution to economic growth and development, the monetary value of the resources needs to be assessed. Resources have value not only for commercial production, but also for the direct use they provide to humans as well as to other living creatures. Where there are competing uses for a resource, its use should be that which yields the highest social value that is favoured.

The monetary costs of destroying or degrading environmental assets needs also to be estimated. The costs of rectifying environmental damage are frequently much greater than the costs that would have been incurred to protect the environment in anticipatory assessments had first been undertaken. Bad environmental decisions, almost by definition, usually turn out to be bad economic decisions as well (James, 1991).

According to Tietenberg (1988), the correct way to reflect the cost of environmental services provided by nature is to consider their *opportunity cost* – the net benefit foregone because the resources providing the service can no longer be used in their next most beneficial use. For example, the opportunity cost of saving a river for white-water rafting is the foregone net benefit (after accounting for the cost of generation and distribution) of hydro-electricity. An alternative approach, to minimise the opportunity cost, may be to incorporate the needs of rafting in the operational strategy of the hydroplant.

Failures of the markets to adequately incorporate all costs of resource use are often complemented by failures in government policies. In many cases, the charters and operating rules of public agencies create conflicts that lead to environmental damage and degradation of natural resources. A common failure of government policy occurs with administered prices. James (1991) provides the case of irrigation water which is frequently supplied to farmers at a very low price which rarely covers the cost of provision. Under-priced irrigation water results in excessive use,

disturbing groundwater regimes and damage to downstream activities and the environment through increased salinity.

Taxation policy is another area where government policy has been responsible for the misuse of natural resources. Until recently, Australian farmers had received a tax deduction for the costs of clearing land. Indeed, a typical condition of land leases was the clearance of specified minimum amount of land, potentially driving excessive clearance and fuelling environmental degradation. Now with the concern about the rate of deforestation and its effects on soil erosion and land salinisation, the tax system has been changed to support land rehabilitation and reafforestation.

The decision to conserve natural resources for the use of future generations is a social decision, not a private one. Only the government, can carry out this mandate, and would most likely be effective through the use of appropriate and integrated policies of taxation and economic incentives.

Positive incentives designed to mould economic behaviour include tradeable rights to use the environment, tax offsets on investments in environmental improvement programs, and the provision of information on technologies and management practices that simultaneously achieve more efficient production and resource protection. Considerable effort and commitment is required to fix these problems which are at the root of one of the most pervasive and influential of societal systems - economics!

Some policies also need to be global rather than national. However, we cannot abandon national development economics for global economics where few policy instruments exist and agreed goals are difficult to reach and harder to implement. Every nation realises it will be harmed by a deterioration of the global environment. However, taking unilateral action to protect the global environment at a considerable economic cost will not provide commensurate benefits, unless all or most countries take the same action (Mikesell, 1992).

To a large extent, the theory and practice of conventional economics will remain the same. Sustainable development simply serves to broaden and shift the development objectives. Greater emphasis should, however, be placed on preserving renewable resources and conserving exhaustible ones. Non-monetary social costs and benefits will need to take on a larger role in cost-benefit analysis of particular projects and programs. Mikesell (1992) quite correctly observes that sustainability criteria will complicate economic analysis, however, by requiring the determination of monetary equivalents for non-monetary social benefits and costs associated with all economic activity.

Since projects and programs have important impacts on future economic behaviour, it is easier to introduce sustainable development practices into new projects and systems than into the operation of old ones. Therefore it is important to consider how projects are selected and how to incorporate sustainable development criteria in the selection process.

3.3. Cost Benefit Analysis[2]

The development of cost-benefit analysis (CBA) as a practical technique dates from the *Flood Control Act 1936* in the United States (Pearce, 1983). While the theoretical foundations of CBA can be traced back to nineteenth century welfare economics, the main body of theory was not developed until the 1950s thus significantly lagging behind its practical application.

Cost-benefit analysis is concerned with ensuring that the benefits of decisions exceed the costs. CBA seeks to quantify costs and benefits by using the dollar values of goods and services which are traded in the market, and is not concerned with the morality of decisions, but only with the balance of the aggregated benefits and costs. This is not to say that moral considerations can not be included in CBA, because the technique can be modified to incorporate preferences or value judgements. However under normal circumstances, CBA is biased towards the status quo with regard to issues of income distribution and equity.

3.3.1. Cash Flow and Discounting

The costs and benefits of a project are usually distributed over a long period of time, particularly for large public infrastructure projects. During implementation of a project, a large capital investment will usually be required to establish the project which could be spread over a period of a few years. After this establishment phase, benefits will start to accrue and will be used to off-set the initial development cost. Normally, there are also ongoing operation and maintenance (O&M) costs that must be covered. Clearly, a project can have many costs and benefits associated with it that can occur at different times. The cash-flow diagram, illustrated in Figure 3.2, is a useful means of displaying these transactions. For each time interval shown on the horizontal axis (usually months or years) benefits are plotted upwards and costs downwards.

In order to determine whether a project is worth undertaking, or to compare it with alternative projects, it is necessary to compare the accumulated benefits against the accumulated costs. In conducting such an evaluation, it must be recognised that benefits or costs incurred in the future cannot be directly compared with those incurred at the present, due to the effects inflation, interest rates and the preference of people to consume goods now rather than later. It is necessary to discount future benefits and costs, reducing the series of transactions over time, in order to make them directly comparable with benefits and costs incurred at the present time. This is achieved by using discounting formulae and a *discount rate* which reduces the value of any payment by a certain percentage for each year in the future the transaction occurs.

2 The following discussion builds upon the work of Cassimatis (1988), Barbier et al (1990), Dandy & Warner (1990), Hollick (1993) and Thampapillai (1993). For a more complete discussion of cost-benefit analysis refer to these sources, as well as James & Boer (1988); Pearce & Turner (1990); Rees (1990); Tietenberg (1988) and Winpenny (1991).

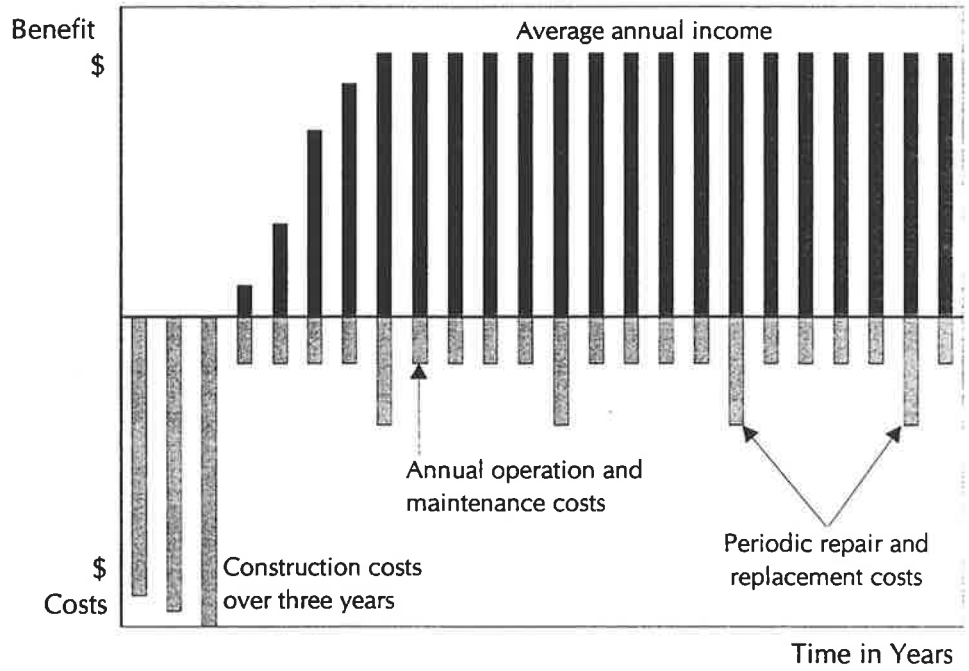


Figure 3.2
Example of a Cash Flow Diagram

The *present value* (PV) for any series of costs or benefits of an amount A over N years is given by the following equation:

$$PV = A_0 + \sum_{n=1}^{N} \frac{A_n}{(1+i)^n} \qquad (3.1)$$

This formula is based on the assumption that each payment in the series occurs at the end of each time interval; A_0 is the payment made in the beginning of the first year.

While there are a number of criteria that can be adopted to assess the economic merit of a project, the net present value and benefit-cost ratio are used most often. The *net present value* (NPV) is the difference between the present value of costs and benefits. If the NPV>0, the project is profitable and suitable for further consideration.

3.3.2. Benefit-Cost Ratio

The *benefit-cost ratio* (BCR) is widely used for evaluating projects in the public sector. As normally defined, it is the present value of all benefits divided by the present value of all costs. Any project with a BCR greater than 1 is worthwhile, and the alternative with the highest ratio should be selected.

In evaluating public projects, planners must attempt to identify all the benefits, disbenefits, and costs associated with the project as well as the amount of

investment required to construct it. It is the distinction between benefit and costs, and more particularly whether a cost should be treated as a disbenefit, that plagues the use of the BCR method.

3.3.3. The Discount Rate

The discount rate can have a significant effect on the results of project evaluation. Reducing the discount rate can have a number of effects on the type of project selected, principally to increase the number of projects that are economically viable, and also to favour the capital-intensive projects in which most costs occur relatively early. A low discount rate also discourages staged projects, thus decreasing flexibility to adapt to changing conditions in the future, and increasing the risk of tying up capital in redundant or obsolete projects.

Increasing the discount rate discourages investment in projects with large capital costs, and benefits spread over a long period, because the present value of the long-term benefits is greatly reduced compared with the initial capital costs. It favours short term projects with quick results, and staged projects in which capital investment is delayed.

Capital expenditures for public projects are usually funded from government revenues, loans obtained from the private sector, or from fees paid by the users of the project. Therefore, the question arises as to what should be the appropriate discount rate or what economists call the *social discount rate*.

Some argue that the discount rate should be equal to the cost at which the governments borrow money from the capital markets. Others believe that it should be higher to reflect the social opportunity costs of funds invested by the government that otherwise would have been invested in the private sector. Still others believe that when a public project produces a product or provides a service comparable to those produced by the private sector, the discount rate should be equal to that used by the industry.

More recently, opinion has become divided on the effect of the discount rate on natural resource depletion and the environment. Difficult questions arise on the issue of inter-generational equity and the distribution of costs and benefits between generations. There are no easy answers to such questions because we cannot know the desires of future generations or the technologies or options that will be available to them.

Environmentally unsound forms of development are usually justified economically through a variety of cost-benefit analysis techniques. They usually tend to be strongly biased against ecological concerns because of measurement and valuation difficulties, irreversibility, and the discount rate. A view commonly held by conservationists is that ecologically sound management of natural resources entails the imposition of short-term costs to secure substantially long-term benefits, and so low or zero discount rates can be desirable from an ecological perspective.

Mikesell (1989) confirms that some social scientists have also suggested the use of artificially low discount rates for the valuation of future benefits and costs, but that the use of arbitrary discount rates destroys the logic and consistency of the valuation process. In practice, the discount rate used by analysts of public projects is determined by the policy guidelines of the government agency that oversees the projects.

The question of how far into the future we should attempt to carry the economic analysis is another issue central to the evaluation of sustainability. Pearce *et al* (1989) proposed an elegant solution to these dilemmas. They suggested that each generation should take responsibility for passing on to the next one at least as much capital wealth as it inherited. Capital wealth was defined to include natural resources and the environment as well as economic and intellectual capital. Furthermore, contrary to conventional economic theory in which forms of capital are interchangeable, the unique and non-substitutable nature of environmental capital is recognised and should be considered separately and largely non-renewable or non-interchangeable.

This approach, if interpreted literally, would prevent almost any project from proceeding, because relatively few projects have no adverse impact upon the environment. The criterion should therefore be applied to programs of corporations or government agencies rather than to individual projects. The negative effects of one project could be compensated by the positive effects of others. If necessary, a company could undertake environmental rehabilitation projects for the specific purpose of off-setting the impacts of its other activities. Mikesell (1989) and Trudinger (1991) support the environmental compensation approach, Indicating that the resource cost that represents depletion must be re-invested to avoid capital consumption. They note that compensating measures do not necessarily need to be applied at the same site, although they should be closely comparable to the nature of the environmental losses.

Thus by treating natural resources as capital assets in social accounting, inter-generational equity can be promoted without resorting to zero or artificially low social rates of discount.

3.3.4. Intangibles

Early cost-benefit analyses excluded intangibles from the quantitative analysis, confining them to a discussion in the accompanying text. Intangibles are items that for which a monetary value is difficult to assign, such as scenic beauty, the value of human life, or the preservation of a whale species. Invariably, intangibles have been ignored in the decision taking process, with decision makers normally concentrating on the numerical data rather than grappling with the supposedly unquantifiable effects.

More recently there has been a shift to incorporate intangible items in the economic analyses, particularly those relating to the environment. The value of intangibles can have 3 distinct components: the use, option and existence values. The *use value* is derived from the actual use of the good, such as using a nature reserve for

recreation or living in a quiet neighbourhood. The *option value* is the amount people are willing to pay to retain the option to use the resource. The *existence value* relates to willingness to pay for something regardless of any personal use or future potential use. Hollick (1993) reports that studies in the past few years have indicated that option and existence values for environmental resources may be very high because large numbers of people are willing to pay small amounts to protect them.

There are two approaches to estimating dollar values of intangibles. First, if there is another good or service with a market price which reflects the willingness to pay for the intangible, it is possible to analyse the market to determine a *shadow price* for the intangible. For example, the value of an outdoor recreation area might be estimated by determining how much people pay in travel and equipment costs to make use of it. The second approach, *contingent valuation*, is applicable where even shadow prices do not exist and involves the creation of a hypothetical market and prices by asking people what they would be *willing* to pay, for example, to save the blue whale. In general, shadow prices can be determined only for use values, whereas contingent valuation can be used to estimate option and existence values as well.

3.3.5. Equity

Cost-benefit analysis implicitly assumes that the present distribution of wealth in society is optimal. Also, the criterion of willingness to pay may bias results against the poor, who have little ability to pay. As such, CBA tends to give more weight to the interests of the rich than to those of the poor, reinforcing the current distribution of income and wealth in the community.

There are a number of methods that can be employed to overcome this deficiency, the two most effective being: the introduction of compensatory government policies; and the modification of the cost-benefit analysis to take into consideration distributional effects.

Firstly, adjustments can be made to taxes and welfare payments to compensate groups (rather than individuals) in society that may become disadvantaged as a result of the cumulative effects of a range of projects (rather than on a project-by-project basis). The law can also be used for enforce minimum performance standards, in areas such as environmental quality, health, safety and wage rates. These two approaches can provide powerful and flexible means of dealing with equity issues over society as a whole, but cannot prevent cases of individual hardship and community opposition to particular projects.

Alternatively, the dollar amounts representing different costs and benefits can be weighted differently according to the utility they represent to the people paying the costs or receiving the benefits. Mikesell (1992) comments that weights have been established so that they are inversely proportional to income, or in relation to marginal tax rates which are seen to reflect society's judgement of the relative values of a dollar to different income groups.

3.3.6. Discussion

Traditionally, corporate or governmental developers have tended to endorse the cost-benefit analysis approach because of its perceived rationality and favour for development over conservation. Their commitment may begin to wane, however, as environmental considerations and intangibles are incorporated into the economic evaluation process, often represented by very large dollar values. Environmentalists will likely remain sceptical of economic processes and their typically pro-development outcomes, particularly of the selection of discount rates. Sadler *et al* (1991) note that conventional economic discounting does not support conservative decisions for the benefit of the future, when considered against the costs of future fixes, or when such decisions are in competition with present day development options. Hence, it should be clear that cost-benefit analysis, despite its appearance of quantitative rigour, is far from being a precise and objective evaluation method.

There are many other problems with an economic approach to project evaluation, even if a resource accounting or environmental economics approach is adopted:

- In the case of the environment, the cost of resource use is often difficult to quantify, nor do the costs necessarily fall on the users of the resources.
- Economic theory suggests that reduced supply will result in higher prices and substitution with another product. In many cases, the environmental commodity (such as water) has no substitute and can therefore be degraded or depleted.
- Classical economics cannot account for shifts in demand resulting from moral choices by consumers.
- Market prices are often affected by taxes, subsidies and rationing. Therefore the real marginal cost may not be obvious.
- Valuations of costs or benefits where no market exists are very difficult. Furthermore, it is frequently argued that such evaluations are unethical (eg. in the case of affects on human health and life).
- There will be a wide variation in the importance attached to certain types of benefit, depending on the real income of the recipients. It is generally considered that the demand for environmental goods increases with real income.

Hence, normal economic rules of efficient resource allocation do not apply.

3.4. Other Evaluation Tools

The difficulties associated with the application of cost-benefit analysis and economic methods have generally led to a search for alternative quantitative methods for project evaluation. To date, none of the available methods threaten to displace cost-benefit analysis but can serve as useful complementary tools. They also provide a further insight into the problems of evaluation methods in general.

One of the earliest approaches to integrated development planning that promoted sustainability principles was offered by Ian McHarg (1969) in his famous book titled *Design with Nature*.

The objective of an improved method should be to incorporate resource values, social values and aesthetic values in addition to the normal criteria of engineering and economic considerations. The objective should be to identify a solution that provides the maximum social benefit at the least social cost, where social benefit is defined to include all economic and environmental impacts as well.

Some other, better known and innovative alternatives to cost-benefit analysis are discussed here as an introduction to the field. For more detailed discussions, refer to Goicoechea *et al* (1982), Nijkamp *et al* (1990), Hollick (1993) and others.

3.4.1. Multi-objective Planning

Multi-objective planning originated in the water resources field in the United States. It aims to separate different types of costs and benefits under different objectives so that each can be measured in suitable units rather than all being quantified in dollars.

The method can be most easily explained by examining two project evaluation criteria: area of uncleared habitat and the net present value. Consider that for a given area of uncleared land the net present value of the project can be calculated. The merits of the project, in terms of net present value, are evaluated over a range of areas of uncleared land. As a result a function between cleared land and NPV can be developed as illustrated in Figure 3.3.

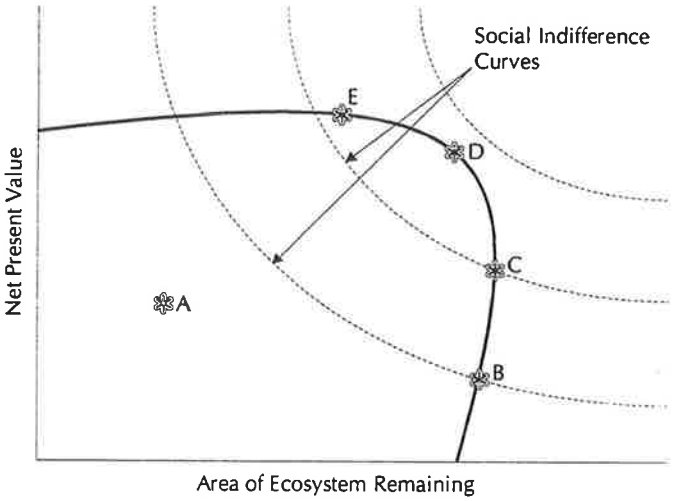


Figure 3.3
Transformation Curve for Habitat Clearance for Development

When comparing the alternative conditions of the project relative to the evaluation criteria, a condition that is represented by a point which is above and to the right of

another is better because it would provide greater economic benefits and higher environmental quality. In Figure 3.3 therefore, points C, D or E could describe the optimum project in comparison to A.

In order to choose between these 3 options it is necessary to introduce what is called an *indifference curve*. The indifference curve is constructed on the premise that society will always be willing to trade a unit of habitat, say, for a certain economic gain or increase in NPV without feeling worse off. These relationships can be plotted as in Figure 3.3 producing curves which are concave upwards to the right, in recognition of the fact that the exchange value of any good increases as it becomes more scarce. The higher the indifference curve lies, the greater the total satisfaction. On this basis, point D defines the optimum project. This result differs from that produced using cost-benefit analysis which would select point E as it represents the greatest economic return.

Mathematical optimisation techniques enable these concepts to be extended to more than two objectives. Unfortunately, it is often extremely difficult or costly to define the community's indifference curve, severely limiting the applicability of the technique.

3.4.2. The Battelle Checklist

A checklist is a list of factors that should be considered in project evaluation, often used simply to ensure that important issues are not neglected.

The Battelle checklist was designed to provide a single environmental quality index for use in multiple-objective assessment of water resource projects (Dee *et al*, 1973), and included 78 items categorised under the headings of ecology, pollution, aesthetics and human interest.

The measured or estimated parameter values for a project are converted to a common numerical range, typically between 0 and 1. This is necessary to facilitate aggregation and weighting. To assist with the transformation process, Dee *et al* (1973) developed a set of 78 transformation curves to enable conversion of parameter values to *environmental quality* (EQ) values between 0 and 1. Examples of the transformation curves are provided in Figure 3.4.

The relative importance of each parameter was assigned by distributing 1000 *parameter importance units* (PIUs) amongst the 78 parameters. The performance of each alternative project was then evaluated as the sum of the *change* in EQ for each parameter multiplied by its PIU:

$$\text{Project Score} = \sum_{i=1}^{78} \Delta EQ_i \times PIU_i \qquad (3.2)$$

The application of the Battelle checklist is hampered by a number of limitations. While some of the transformation curves are reasonably objective having been based upon sound scientific principles, others a highly subjective. The method also assumes that each of the 78 parameters are independent of one another and that

there would not be double-counting of project impacts. The distribution of PIUs is also very important to the final results, but can also be very subjective. A notable strength of the Battelle method is that is makes value judgements explicit and open to debate.

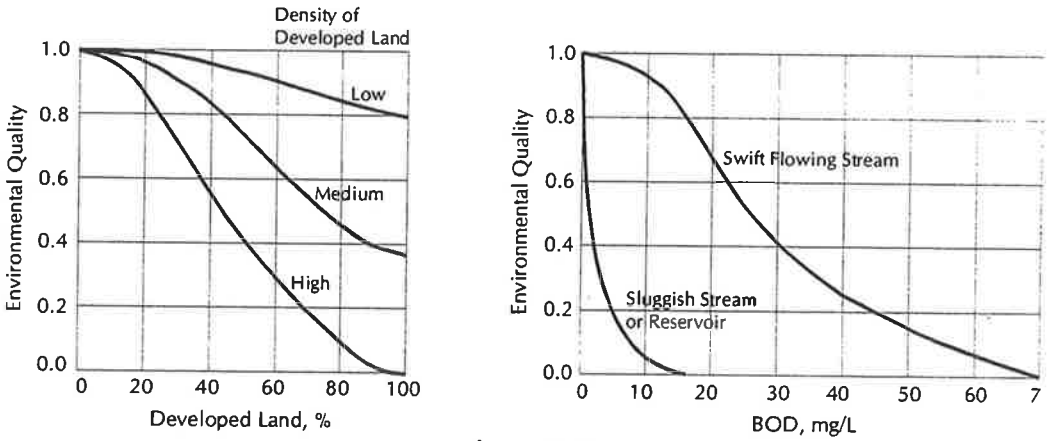


Figure 3.4
Examples of Transformation Curves from the Battelle Checklist
(after Dee et al, 1973)

3.4.3. The Leopold Matrix

Like checklists, matrices are often used as a means of ensuring that all important factors are considered in project evaluation, but often in far greater detail. The Leopold matrix lists 100 actions which may be part of a project and 88 possible environmental factors, enabling identification of up to 8,800 potential impacts.

The first step in using the matrix is to consider each interaction in turn, marking cells with a diagonal line where an impact may occur for the project being evaluated; refer to Figure 3.5. Two numbers are then assigned to each interaction. The first, above and to the left of the diagonal line represents the magnitude of the impact on a scale of 0 to 10. A negative sign (-) indicates a cost and a positive (+) indicates a benefit. The second number, below and to the right of the diagonal line, indicates the importance of the impact.

Unfortunately, while the matrix provides a detailed summary of project impacts there is no means of aggregation to a single index. Double counting is not avoided with this method either. Thus decision makers can be left with a complex array of information which must then be subjectively assessed.

3.4.4. Urban Sustainability Reporting

Associate Professor Virginia Maclaren of the Department of Geography, University of Toronto considers that the next most important step for sustainability is to determine whether or not actions at the local level are leading a community to become more sustainable. She sees that a significant barrier to accomplishing this

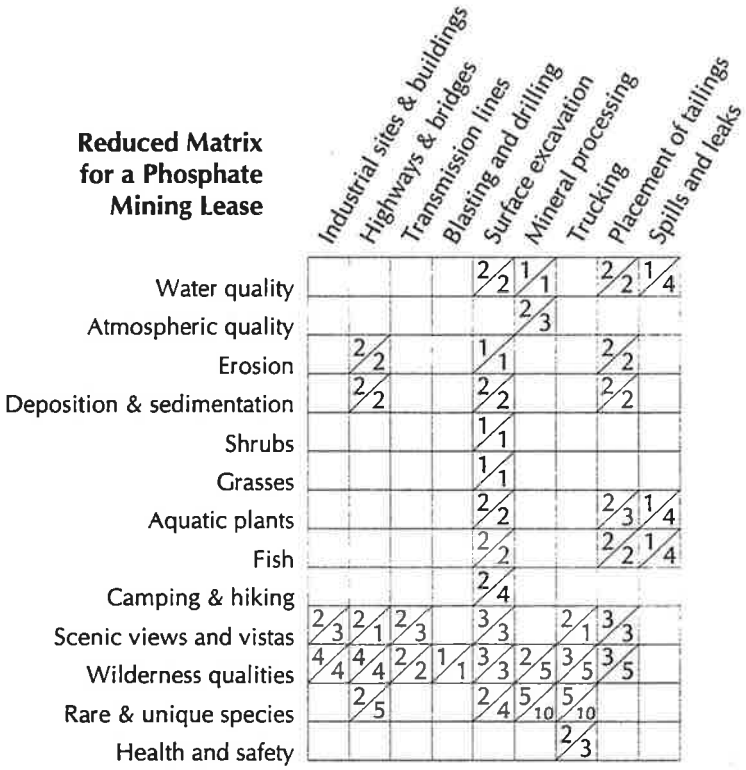


Figure 3.5
Extract from the Leopold Matrix

task is the absence of a clearly articulated methodology for reporting on urban sustainability.

The current range of social and environmental reporting is inadequate to address sustainability issues. State of the Environment (SOE) reports describe and analyse conditions and trends of significance of the natural environment, and is not broad enough to be called sustainability reporting. Healthy City Reporting has a suitably broad focus, but with a much stronger emphasis on human health. Quality of Life reporting does examine economic, social and environmental conditions and the links between them, but does not have the same concern for inter-generational equity issues as sustainability reporting. According to Maclaren (1996), some alternative form of analysis and reporting is required, and proposes the following.

3.4.4.1. Indicators

A suitable set of indicators are required to measure and report on the progress to sustainability. Most indicators are simplifications of complex phenomena, and therefore a wide, but manageable, range of indicators should be used to obtain the broad picture.

Urban sustainability indicators can be distinguished from simple environmental, economic and social indicators by the fact that they are:

- integrating,
- forward looking,
- distributional, and
- developed with input from multiple stakeholders in the community.

Maclaren (1996) illustrates how indicators can be integrating by taking the example of the unemployment rate. She notes that the unemployment rate is an integrated indicator because it is a measure of both economic stress and social stress.

The indicators can also be forward looking by incorporating information on *trends*. But because trends provide information on past conditions more so than the future, the indicators can be enhanced if they are linked to reference points that define intermediate steps in the move toward sustainability. The two main types of reference points are targets and thresholds. Whereas targets are levels that must be met in the future if sustainability is to be achieved, thresholds are levels that should not be exceeded.

Another type of forward looking indicator is the *predictive* indicator, which relies solely on mathematical models for the future state of development. Population levels and growth estimates are common predictive indicators. Uncertainty is inherent to this type of indicator, and so combination with a third type of indicator, such as *conditional* indicators, can be useful. Conditional indicators depend on a form of scenario development, where numerous forecasts or predictions are made; they answer the question: "If a given indicator achieves a certain level, what will the impacts and levels of associated indicators be in the future?"

Sustainability indicators should also be developed to distinguish between local and non-local impacts, and other intra-generational issues to provide a measure of distributional effects.

A final characteristic is the manner in which the indicators are developed. This history of the social indicator movements suggests that the most influential, valid, and reliable indicators have been those that were developed with input from a broad range of participants (Innes, 1990). This lesson is especially applicable to the development of sustainability indicators, since sustainability is such a value-laden and context-sensitive concept.

The development of sustainability indicators is a great challenge though, because of the complexity of the economic-environmental-social relationships involved and due of the absence of a commonly understood measurement unit comparable to the monetary units employed in economic indicators.

A problem can arise when composite indicators are sought, to obtain a simple measure of sustainability, or to aggregate many indices. How to weight the individual indicators, how to standardise different measurement units, and whether to choose a multiplicative or additive aggregation technique has been found to be limiting to the development of composite indicators (Ott, 1978; Innes, 1990). Despite these problems, some composite indicators, such as the Human

Development Index[3], have gained considerable popularity because they reduce the information contained in several individual indicators down to a single number.

3.4.4.2. Developing an Urban Sustainability Report

The Urban Sustainability Report is a compilation of the indicators and a description of how they were chosen. In addition, the Report provides discusses the evaluation of whether the indicators are showing progress towards or away from sustainability and suggest how or whether the indicators could be improved. It may also recommend the kinds of policies or programs that are needed to improve progress towards the community's sustainability goals.

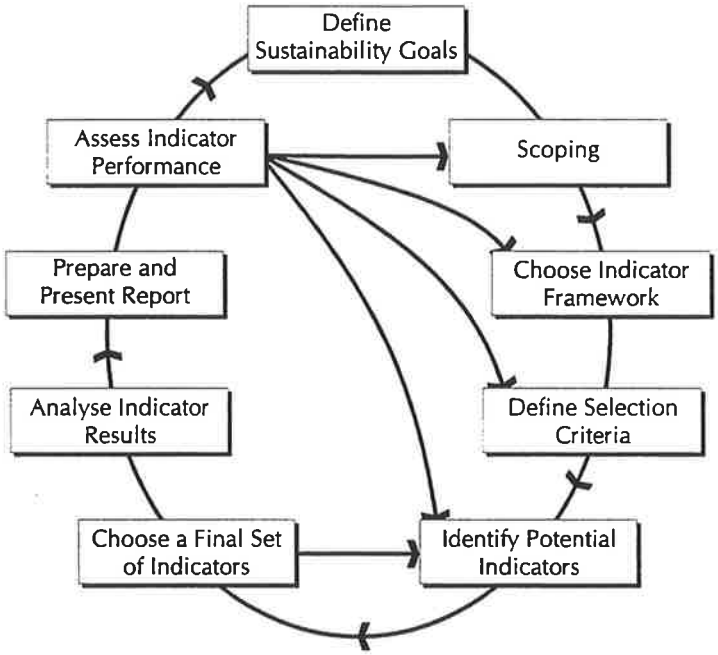


Figure 3.6
Process of Urban Sustainability Reporting

The steps in the process of developing an Urban Sustainability Report are illustrated in Figure 3.6 and briefly summarised below:

1. **Define the sustainability goals** for which indicators are needed: a community visioning technique can be a useful technique for articulating sustainability goals.

2. **Scoping**: of the report, target audience and the number, purpose, and spatial and temporal extent of the indicators.

3 The Human Development Index was developed by the United Nations Development Program (UNDP) for comparing human welfare levels in different countries. The index is an aggregation of four indicators: life expectancy at birth, adult literacy, average years of schooling, and GDP per capita. The UNDP publishes the index for all members of the United Nations in its annual *Human Development Report*.

3. **Choose an appropriate indicator framework**: six general frameworks can be used for developing sustainability indicators. The frameworks could be domain, goal, sector, issue, or cause based, or a combination of these. Examples of these frameworks are given in Figure 3.7.

Domain Based
• Environment
• Economy
• Society

Goal Based
• Carrying capacity
• Social well-being
• Economic prosperity
• Participation in governance
• ...

Sector Based
• Housing
• Welfare
• Recreation
• Transportation
• Environment
• Economic Development
• ...

Issue Based
• Urban sprawl
• Solid waste management
• Crime and safety
• Job creation
• Industrial pollution
• ...

Cause Based		
Conditions	**Stresses**	**Responses**
• Air quality	• Automobile use	• High occupancy vehicle lanes
• Unemployment	• Inadequate education	• Special training programs
• Human health	• Air quality	• Pollution warnings
• ...	• ...	• ...

Figure 3.7
A Typology of Frameworks for Sustainability Indicators Development
(after Maclaren, 1996)

4. **Define the indicator selection criteria**: a good set of indicators are often those that are scientifically valid; representative of a broad range of conditions; responsive to change; relevant tot he needs of potential users; based on accurate and accessible data that is available over time; understandable by potential users; cost effective to collect and use; attractive to the media; and unambiguous.

5. **Identify a set of potential indicators.**

6. **Evaluate the indicators and select a final set**: a key issue in performing the evaluation is the possible existence of conflicts amongst the general selection criteria identified in step 4 above. Decisions also have to be made about the relative importance of the criteria. Because of the nature of the value judgements involved, these decisions are probably best undertaken by means of a consensual multi-stakeholder consultation process. An evaluation matrix is a useful way of organising the information needed to evaluate urban sustainability indicators.

7. **Collect data and analyse indicator results.**

8. **Prepare and present the urban sustainability report.**

9. **Assess indicator performance**: the purpose of this step is to assess whether the indicators are performing adequately in measuring what they were meant to measure.

For a more complete description of the process, refer to Maclaren (1996).

3.4.5. Measuring Sustainability Using A Multiple Risk Approach

Professor Daniel Loucks of the Department of Civil and Environmental Engineering, Cornell University, New York has also recognised the need to measure or quantify, at least relatively, the extent to which sustainability is being achieved.

Loucks (1996) examines the subject of sustainability in the context of water resources management, and proposes the use of the commonly used measures of reliability, resilience and vulnerability as measures in changes of relative sustainability in systems over time. Sustainability indices are defined as separate or weighted combinations of these measures of various economic, environmental, ecological and social criteria. These criteria, once identified, must be able to be expressed quantitatively or at least linguistically (such as 'poor', 'good' and 'excellent') and be determine from time series data. The relative sustainability of the system with respect to each of the criteria is higher the greater the reliability and resilience, and the smaller the vulnerability. Loucks (1996) notes that there are often trade-offs between these three statistical measures of performance. Indeed, sustainability implicitly involves the notion of trade-offs over time. How to identify these trade-offs and their implications is the essence of the debate taking place regarding sustainable development.

The concept is illustrated by considering any selected criterion called C. Its time series of values are denoted as C_t, where the time periods t extent to some future time T. The values of C_t may vary over time, and could fall outside of some acceptable range that is particular to each criterion. The ranges may be scientifically defined or subjectively set. From the time series data for C_t it is possible to compute the sustainability measures as:

$$\text{Reliability of C} = \frac{\text{Number of } C_t \text{ values}}{\text{Total number of simulated periods, T}} \tag{3.3}$$

$$\text{Resilience of C} = \frac{\text{Number of times a satisfactory } C_{t+1} \text{ value follows an unsatisfactory } C_t \text{ value}}{\text{Number of unsatisfactory } C_t \text{ values}} \tag{3.4}$$

Reliability is the probability that any particular C_t value will be within the satisfactory range of values. Resilience is an indicator of the speed of recovery from an unsatisfactory condition.

Vulnerability is a statistical measure of the extent or duration of failure, should a failure (unsatisfactory value) occur. Loucks (1996) suggests a number of ways in which this can be defined. It can be based on the extent of failure of individual unsatisfactory values or the cumulative extent of failure of a continuous series of unsatisfactory values. In the latter case, each individual extent of failure is added together for the duration of each continuous failure sequence.

3.4.6. Discussion

Despite many efforts, no completely satisfactory alternative to cost-benefit analysis has yet been developed. In practice, it may be more appropriate to adopt a blend of features from the methods mentioned above to suit a particular problem. However, Hollick (1993) notes that it is always necessary to strike a balance on 5 issues:

- the cost of data collection and analysis versus the need for accurate evaluation;
- the need to simplify the decision problem through aggregation versus the need to take real-life complexity into account;
- the need to balance expert knowledge with community opinions and values;
- the role of qualitative versus quantitative information; and
- realistic incorporation of future uncertainties versus the need for clear-cut choices.

3.5. Summary

Quantitative analyses are a very powerful means of aggregating raw data into a few indices to facilitate choice, and hence it is desirable to make as much use of them as possible. There are however some practical limits to quantification.

Firstly, all factors must be measured in the same units if quantitative evaluation methods are to be used. Despite many attempts to devise environmental quality and other non-monetary indices, Hollick (1993) notes that none have been particularly successful, and the dollar has remained the common unit. Although dollars are a very useful common measure, many important factors have no market price because they are not bought and sold. These are what economists refer to as *intangibles*.

Data availability can be another problem for quantitative evaluation methods. Either there is insufficient data relative to the defined objectives, which can become an excuse for delaying making a decision. Alternatively, there can be too much data in which case the project planners must decide which data are relevant and collect only those. The distribution of costs and benefits over space and time and the associated equity considerations present another difficulty. The temporal distribution can often be dealt with by such methods discounting using cost-benefit analysis, but quantitative methods which produce a single index of project worth cannot take distributional effects into account. Common to all of these issues is the uncertainty associated with the data and evaluation process, which must be taken into account.

Governments can reduce many environmental problems by eliminating subsidies, which can be justified on both environmental and economic grounds. In instances when placing a monetary value on resources is not enough to prevent over-exploitation - it may be necessary to confine resource use to a sustainable level.

Ideally, CBA aims to put a monetary value on environmental damage, and more especially on the reduction in damage that may result from pursuing a particular abatement action (benefits). However, economic and cost-benefit analysis methods of addressing environmental issues are problematic. Too many problems and philosophical inconsistencies arise to plague its implementation.

Placing a high value on utilities enjoyed by future generations is contrary to the almost universal tendency of individuals to discount future goods. The traditional basis for valuing natural resources in the present (discounted) value of the annual income from their use in producing goods and services. Yet 50 years from now their value to that generation is likely to be much higher than the value we give to these natural resources today (Mikesell, 1992). It would therefore seem appropriate to develop and agree upon a simple and consistent scope and process of application of cost-benefit analysis, with concurrent development of complementary tools to address the problematic issues of intangibles and conversion to common scales for evaluation.

The EIA process should not be relied upon to deliver sustainable development, however. While it is likely that EIA will remain the primary environmental assessment tool for some time to come, there are many problems associated with the process and its application, including:

- the process is discretionary and reactive rather than necessary and proactive, and political pressure can be brought to bear to exempt particular proposals;
- they can be affected by personal or organisational bias;
- the quality and effectiveness of public involvement is significantly determined by the form of review process;
- public contributions can be neglected, distorted or misunderstood with little possibility of correction;
- costly delays and uncertainty are commonly associated with the process;
- EIA can be focussed on a legislative process rather than on outcomes;
- projects which raise environmentally significant issues of national or international importance may not be identified for assessment;
- EIA often fails to assess the cumulative impact of developments;
- few EIA procedures have made adequate provision for post development monitoring;
- there is a lack of scientific approach and data employed in EIA; and
- assessment of government policies, regulations and legislation is rare.

Inevitably, the success of any quantitative evaluation technique for selection from alternative projects is a function of the economic, legal and political stability of a society and the ability to gather and interpret scientific information. When these characteristics exist, decisions between technically feasible options are often made on the basis of economics with the objective of economic growth. However, there is no longer agreement on the goal of growth and it is becoming increasingly

apparent that the failure to incorporate environmental, social and political considerations into a project evaluation process has been a very limiting and degrading process. The result is a turmoil of conflicting values and pressures which make social, legal and political rationality high priorities (Mikesell, 1992).

In this situation, the 'best' choice of project depends on the relative importance assigned to each objective. Evaluation must therefore include an analysis and understanding of goals and values as well as quantitative technical and economic analyses.

Lindblom (1959) argues that in practice, decision makers 'muddle through' only making changes in an incremental way where alternatives differ only marginally from the status quo. In this way, there are a few well understood objectives and the role and context of evaluation is relatively simple. Unfortunately there are many examples of severe social and environmental problems that have resulted from this incremental approach that tends to entrench past practices. New evaluation methods must be developed which can integrate a broad range of criteria into both long- and short-term perspectives, and which will not eliminate new ideas because they fail to meet old evaluation criteria (Hollick, 1993).

The lack of appropriate tools to evaluate ESD is an area which must therefore be given the highest priority if the ESD concept is to progress as a basis for reconciling economic development with environmental constraints in Australia. Furthermore, sustainability requires additional goals for the economic process, to complement rather than replace the conventional ones. Ultimately, the principle of comparing social benefits with social costs must be adhered to in making decisions (Mikesell, 1992).

4

Matrix for Evaluation of Sustainability Achievement

4.1. Introduction

Most development decisions are multi-objective in nature, and involve economic, social, environmental and political issues. Yet this reality is often ignored. Most decisions are justified on economic grounds alone, with little or no consideration of other issues. To avoid development that benefits a few to the detriment of many, and for environmental protection, a more holistic review of development proposals is necessary.

Procedures for quantifying environmental and social impacts are often time consuming and occur late (if at all) in the process of planning. When they are considered, there are often conflicting objectives that cannot be expressed in commensurable units (Loucks, 1986). Attempts at expressing environmental, social and political impacts in monetary terms have been made, but with only very limited success (Ahmad, 1982).

The growing list of environmental problems has highlighted the inadequacy of the current decision making processes. There is now a greater realisation that parameters other than cost, many of which are essentially non-quantifiable in monetary terms, must be considered in the evaluation of alternatives. This increased awareness has resulted in the development of many methods to aid the often complex decision making task.

4.2. Multi-Objective Decision Making

Multi-objective decision making tools aid the identification of a preferred solution to a problem from a range of alternatives. Alternative solutions are compared with various performance criteria ranging from cost (a quantitative criterion) to aesthetics (a qualitative criterion). Many of the multi-objective methods have also been developed to facilitate the involvement and incorporate the views of interest groups and the public in the decision making process.

Goicoechea *et al* (1982) identify the shifting of societal values, relating to the use and management of natural resources, as a prime motivation in the development of multi-objective analysis.

There are now so many multi-objective decision making techniques available that methods have been developed to assist in the selection of the most suitable technique to employ in different circumstances (Gershon and Duckstein, 1984; Hobbs, 1986; Karni *et al*, 1990). The Nominal Group Technique (NGT), the Delphi Technique and the Iterative Open Planning Process (IOPP) are some of the more widely known multi-objective methods (Fleming, 1992).

4.2.1. Nominal Group Technique

The Nominal Group Technique (NGT) was developed by Professors Andrew Van de Ven and Andre Delbecq in 1968. It is designed to be used in situations where a small group (of up to 9 persons) is required make a decision on a complex, multi-faceted problem.

The NGT method involves the independent generation of ideas by each group member. These ideas are then offered to the group as a whole, and discussed. The ideas are consolidated to identify the main issues, and a preliminary vote of importance taken. Further discussion upon the results of the preliminary vote occurs, prior to a final vote. The final decision is based upon the aggregation of individual preferences, as a ranking of issues (Delbecq *et al*, 1975). The process is illustrated in Figure 4.1.

The NGT has the advantages of independent thought and idea generation by group members, and can generally be completed in under 2 hours. However it can be disadvantaged by poor selection of group members, argument over ideas, and lack of time for reflection or incorporation of new information. In addition, no information is provided by ranking of issues as to the relative importance of each issue.

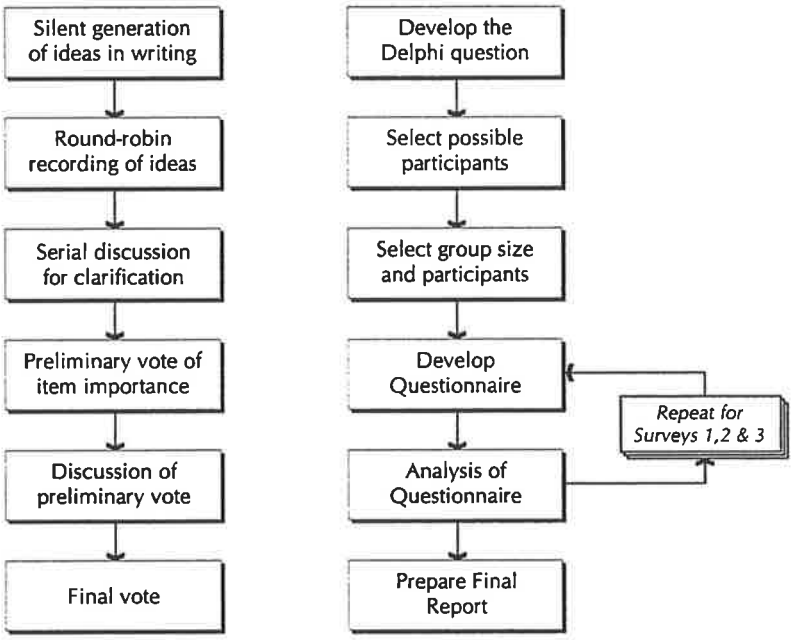
4.2.2. Delphi Method

The Delphi technique was developed by Dalkey (1967) at the Rand Corporation in 1950. Unlike NGT, it can be used by both small and large groups and does not require face-to-face contact. It relies upon written responses and so group members can be at widely dispersed geographic locations.

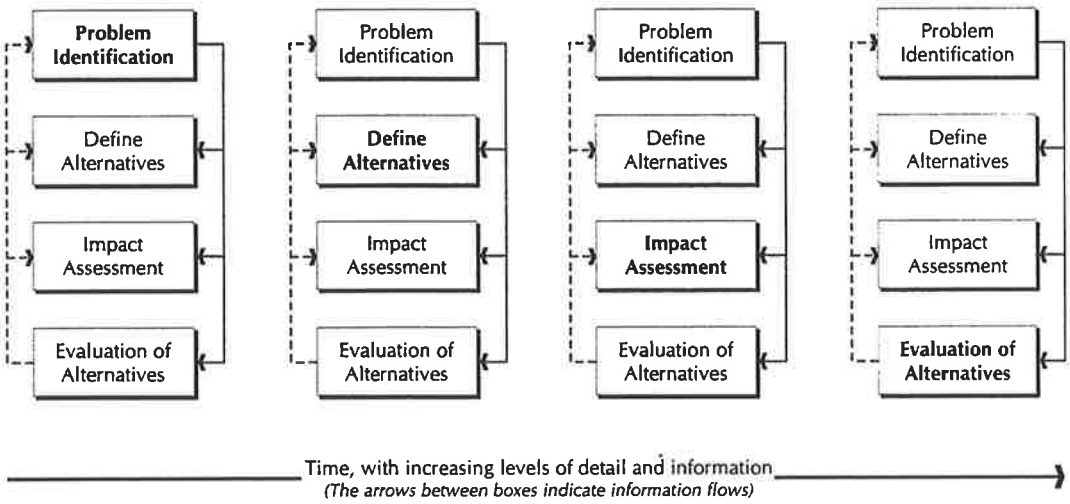
The Delphi method involves up to 3 surveys of respondents to identify and clarify the issues related to the main problem, as well as the assignment of preferences or importance to those issues. The process is illustrated in Figure 4.1.

A disadvantage can be that the whole process may take 6 or more weeks to complete. In addition, the development of the question is a critical step in the Delphi process (Goicoechea *et al*, 1982). As with any problem solving process, it is

essential to ask the right questions and define the correct problem, otherwise the whole process may ultimately prove a waste of time, effort and resources.



(a) The NGT Process (b) The Dephi Technique



(c) A Representation of the IOPP Technique

Figure 4.1
Multi-Objective Decision Making Techniques

4.2.3. The Iterative Open Planning Process

The iterative, open planning process (IOPP) was presented by Ortolano (1974) as a process that allowed the integration of public views at all stages of water resources planning.

IOPP employs the simultaneous, rather than sequential, undertaking of the activities of problem definition, identification of alternatives, impact analysis and alternative ranking. This is presented diagrammatically in Figure 4.1, where the size of the various boxes suggests the emphasis placed upon the four tasks at any point in the process. There is an open and continual interaction with the public involving institutions, scientific and technical organisations and the community at large.

A field test of IOPP found that the interactive and concurrent consideration of all four activities was consistent with the way participants thought through the issues (Goicoechea *et al*, 1982). Disadvantages are associated with the complexity of co-ordination of inputs, and the time required to carry out the process.

4.2.4. Multi-Objective Decision Making for Project Selection

The key to successful multi-objective decision making for project selection is to make assessments practicable for the decision makers, within the limits of information availability, technical personnel, and development schedule. Multi-objective methods should try to meet the following criteria:

- address the prediction of futures, both with and without the project;
- allow consideration of alternatives both separately and in combination;
- quantify the probabilistic nature of many of the economic, environmental and social impacts;
- be based on principles and assumptions that are valid and easily illustrated;
- employ qualitative and quantitative information in a methodologically sound way;
- make explicit subjective and value judgements;
- communicate the predicted impacts with respect to their spatial and temporal distribution;
- involve inter-agency coordination and public involvement to overcome the potential biases of a single proposing agency;
- yield results that are understandable to decision makers and the public;
- should be completed within a reasonable time frame; and
- require minimal expenditure for project evaluation (Loucks, 1986; Smith & Theberge, 1987).

Shafer & Davis (1989) consider that it is essential to incorporate all the perceived costs and benefits in project evaluation. This is because the future is shaped by the long-term planning priorities, decisions and activities undertaken today. For long-range planning to be effective, priority setting efforts must account for subjective judgement and contain formal, rigorous strategies to replace intuition. A method is needed that includes perceived quantitative and qualitative values, with a convenient method of scaling these values to evaluate trade-offs between money, environmental quality, health, happiness and social entities. Where decisions need to be made under conditions of risk and uncertainty, and when the dollar value of the benefits of items to be evaluated is unknown, simplifying assumptions simply to suit quantitative models must be avoided. The complex problem should be dealt with holistically.

Hipel (1992) supports this view and suggests that there is the need for a general methodological approach for solving simple *and* complex decision making problems. This approach would be supported by a tool box of useful modelling techniques that can be applied to specific problems.

Attention should also be given to issues of resource use efficiency, social benefit, siting, and even need for a project, as part of the project planning process. Environmental impact assessments (EIA) often fail in this regard, because they are normally implemented at the end of the planning process. In addition, EIAs are directed at identifying problems and developing strategies to mitigate the adverse environmental impacts of a particular development initiative. A tool is needed that enables relatively quick but holistic assessment of alternative projects in the planning phase, rather than following the selection of a 'preferred' project.

The Matrix for the Evaluation of Sustainability Achievement has been developed to meet these objectives.

4.3. Development of the MESA Matrix

The *Matrix for the Evaluation of Sustainability Achievement* (MESA) has been developed to address economic, environmental and social issues during the planning stages of development. The technique was established to indicate whether a project assisted or retarded the achievement of sustainability, and to ensure:

- public involvement in the establishment of priorities;
- concurrent evaluation of qualitative and quantitative information on costs and benefits;
- assessment and comparison of multiple projects or alternatives;
- consideration of the consequences of development relative to current conditions (ie. 'with' versus 'without' the project);
- combination of impact assessments in a methodologically sound way without resorting to estimated monetary values for intangible items; as well as
- a simple, logical technique that allows a relatively quick appraisal, and is inexpensive to conduct.

A matrix style of decision making tool was selected because it had shown to be a simple yet effective medium for surveying development consequences in environmental impact analysis (Biswas & Geping, 1987). A number of matrix styles and methods of presenting project performance or impact assessments were tested leading to the preparation of the proposed matrix.

Colour coding of the cells corresponding to a given criterion and project could indicate the severity of an impact, which could be compared across projects. However, no measure of the cumulative effect of the impact could be provided by this method, nor could the relative importance of the criteria be included. The decision process would be complicated further by the presence of numerous decision makers, each with their own preferences and opinions.

In an attempt to eliminate the need to place monetary values on costs and benefits, coupled with the desire to use the unavoidable subjective responses to some criteria, use of the theory of *fuzzy sets* seemed beneficial.

4.4. Decision Making Using Fuzzy Set Theory

Decision making in the real world takes place under circumstances where the goals, constraints and possible consequences of an action are imprecise. The concepts and techniques of probability and decision theory are often employed when dealing with such problems, and they assume that such imprecision is equivalent to randomness. However, this is a questionable assumption. Bellman & Zadeh (1970) contend that there is a need for differentiation between *randomness* and *fuzziness*. Essentially, randomness has to do with uncertainty of membership of an entity in a non-fuzzy or clearly defined set. Fuzziness on the other hand, has to do with classes in which there may be grades of membership intermediate between full membership and non-membership.

This presents one of the most difficult problems of decision making – when either the constraints or the goals are fuzzy or vague. While the human mind is capable of dealing with situations involving fuzziness, conventional quantitative methods are not equipped to deal with such decision problems.

In 1965, Zadeh laid the foundations for a theory that assists in the solution of such problems. He called his theory *fuzzy sets* (Yager & Basson, 1975). Zadeh (1973) stated that "as the complexity of a system increases, our ability to make precise yet significant statements about its behaviour diminishes, until a threshold is reached beyond which precision and significance become almost mutually exclusive characteristics."

The use of fuzzy sets enables many objectives and criteria that are often difficult to quantify, and are of varying degrees of importance, to be handled easily. One of the most useful aspects of fuzzy set theory is its ability to represent multi-objective decision problems involving vague or fuzzy objectives or constraints (Yager, 1977). This is certainly the case in most real decision situations.

Fuzzy sets allow the combination of quantitative and qualitative information by assigning to each criterion (for a given alternative) a number in the range [0,1], indicative of the satisfaction of that criterion. The number 0 indicates that the criterion is unachieved, while 1 indicates complete satisfaction of the objective. The relative importance of each criterion can also be included, and fuzzy set theory combined the individual criterion evaluations to obtain an indication of the value of the project as a whole.

A review of the literature has revealed some early attempts to include fuzzy set theory into engineering project decision making, most notably the works of Ragade *et al* (1976), Daniell (1978), Znotinas & Hipel (1979), and Alley *et al* (1979). The theory has also been applied to other varied situations, including ranking of alternatives (Baas & Kwakernaak, 1977: Buckley, 1985; Driankov, 1987; Zimmerman & Zysno, 1983), the determination of policies for regional development

(Kacprzyk & Straszak, 1980), and project site selection (Leung, 1980). After some of this early work, the application of fuzzy set theory went into a hiatus. Only in more recent times has fuzzy set theory re-emerged, with application in an increasing variety of fields. Examples include civil engineering applications, such as the design of construction strategies, analysis of structural failures, assessment of work performance, estimation of the consequences of failure, and water pollution and flood control (Ayyub, 1991; Eldukair & Ayyub, 1992; Esogbue et al, 1992). The natural and water resource management disciplines have also found use for fuzzy sets (Smith & Theberge, 1987; Fujita & Zhu,1993; Kannegieter, 1994; Yin & Hipel, 1994; Lee *et al*, 1994; Thomas & Sun, 1995; Xiang, 1996; Bender, 1996).

4.4.1. Basic Theory of Fuzzy Sets

This introduction to the basic theory of fuzzy sets and their application to decision making is based primarily on the work of Yager (1977) as well as Ragade *et al* (1976), Yager (1978), and Yager and Basson (1975). Further information on this basic theory, and more advanced topics can be found in many of the afore-mentioned sources, as well as Daniell (1978), Kacprzyk (1983), Wang & Chang (1980), and Zimmerman (1991).

Assume there is a set of *n* decision alternatives (or problem solutions) represented by the set **X**:

$$X = \{x_1, x_2, ..., x_n\} \tag{4.1}$$

A fuzzy subset called **A** in X is characterised by a membership function $\mu_A(X)$ which associates with every member of **X** a number in the interval [0,1] which indicates the grade of membership of x_i in A. **A** can be thought of as a goal or criteria, and can be written as:

$$A = \left\{ \frac{\mu_A(x_1)}{x_1}, \frac{\mu_A(x_2)}{x_2}, ..., \frac{\mu_A(x_n)}{x_n} \right\} \tag{4.2}$$

For example, **A** could be the set of membership values:

$$A = \left\{ \frac{0.8}{x_1}, \frac{0.2}{x_2}, ..., \frac{0.4}{x_5} \right\} \tag{4.3}$$

where the elements of **A** do not represent fractions, but (for example) indicate that the grade of membership of alternative x_1 is 0.8. The actual value of $\mu_A(x_i)$ is a subjective evaluation of the decision maker, however, the larger the value the stronger that value satisfies the conditions of that fuzzy set.

Now let **A** and **B** be two fuzzy subsets over **X**. The intersection operation, denoted $A \cap B$, is also a fuzzy set over **X**, and shall be called the set **C**. The membership function for **C** is:

$$\mu_C(x_i) = \min[\mu_A(x_i), \mu_B(x_i)] \tag{4.4}$$

for all x_i in **X**. This operation corresponds to the logical, linguistic connector of "and". The membership function of **C** indicates how well both conditions **A** *and* **B** are met.

Also let α be a scalar, such that $\alpha \geq 0$. The operation of raising **A** to the power α, denoted $\mathbf{A}^{\alpha}$ is defined as a fuzzy set over **X** with membership function:

$$\mu_A^{\alpha}(x_i) = [\mu_A(x_i)]^{\alpha} \quad (4.5)$$

The effect of raising **A** to the power α is to reduce the grade of membership of the x_is, but in such a manner that those that have large membership values are reduced much less than those that are small. Furthermore, the larger α is, the greater is the reduction in membership function. Zadeh (1973) associated the operation where $\alpha = 2$ with the linguistic modifier 'very'. An $\alpha < 1$ is equivalent to decreasing the stringency of the requirements of the fuzzy subset.

4.4.2. Optimisation Using Fuzzy Sets

Fuzzy set theory can be used to select an alternative x_i that best satisfies a range of criteria. Various goals or standards often describe the desirable characteristics of a solution to a particular problem. These goals or standards become the criteria for selecting a preferred solution from a range of alternatives. Where the criteria must be met simultaneously for a feasible solution to be defined, the problem can be defined as meeting:

$$C_1 \text{ and } C_2 \text{ and } C_3 \text{ and } \ldots C_n \quad (4.6)$$

where C_i is one of the selection criteria. The combination of the constraints (i.e. alternatives) and the goals (i.e. criteria) produces the decision framework for selecting appropriate strategies.

Associated with a criterion is a fuzzy subset, **C**, where the subset's elements correspond to the grade of membership of each of the potential solutions. Where there are a number of selection criteria, consider that C_i is a fuzzy subset of the set of potential solutions whose membership function indicates how well each of the solutions satisfies that particular criterion. The optimal solution **D** is therefore found by the combination or intersection of these criterion subsets:

$$D = C_1 \cap C_2 \cap C_3 \cap \ldots \cap C_n \quad (4.7)$$

The membership function of **D**, $\mu_D(x_i)$, indicates how well each of the candidates satisfies the set of criteria. Selecting the alternative with the highest grade of membership in **D** theoretically provides the best solution. This is shown diagrammatically in Figure 4.2. The range of alternatives in **X** satisfy the goals and constraints with varying effectiveness (represented by the grade of membership). The decision space is that region in which both the goals and constraints are met concurrently by the alternatives. The alternative that possesses the highest joint satisfaction (or grade of membership) is the best alternative in **X**.

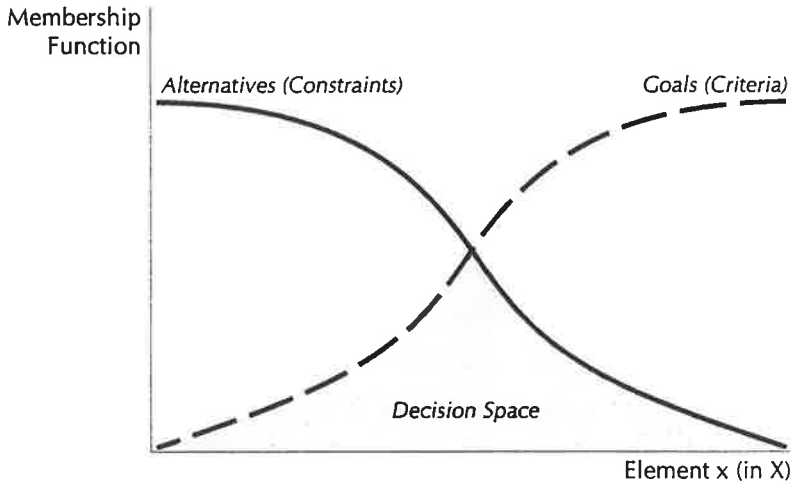


Figure 4.2
Elements of the Decision Making Environment

This method for selection of an optimal solution can be easily extended to cope with criteria of varying importance. If a particular objective or criterion is of greater importance, then it should have a higher membership in **D**. Conversely, objectives of low importance should have a low membership in **D**. Therefore, recalling the effects of using a power term α, if each objective is associated with an α (the more important the objective, the higher the α) then the decision becomes:

$$D = C_1^{\alpha_1} \cap C_2^{\alpha_2} \cap C_3^{\alpha_3} \cap \ldots \cap C_n^{\alpha_n} \tag{4.8}$$

where $\alpha \geq 0$ for $i = 1, \ldots, n$, such that:

$$\frac{1}{n}\sum_{n}^{1}\alpha_i = 1 \tag{4.9}$$

Therefore, this is a hierarchical system in that each alternative is first rated on its ability to satisfy each of the objectives and then the objectives are rated as to their respective importance. This procedure for selection of an optimal solution forms the basis of the MESA decision making methodology.

4.5. Undertaking the MESA Method

The MESA technique combines information on the current pre-development condition, the potential impacts of a range of developments and the importance attached to each evaluation criterion. This information is presented in a matrix, where the assessments of the pre-development condition and potential impacts are represented by numerical performance ratings in the fuzzy set style. An illustration of the matrix is provided as Figure 4.3, to be referenced in conjunction with the discussion of the following sections.

Figure 4.3
Example of a MESA Matrix with Numerical Details for Project Option 1

Project Assessment Criteria	Criterion Weights	Present Condition	Project Performance Rating			Fuzzy Set Combination		
			No Project	Project Option 1	Project Option 2	No Project	Project Option 1	Project Option 2
							0.174	
							0.271	
							0.008	
							0.024	
							0.578	
5. Improvement in surface water quality	0.39	0.50		0.70			**0.664**	
							0.644	
							0.705	
							0.845	
							0.669	
							0.573	
							0.751	
							0.705	
							0.179	
							0.254	
							0.096	
							0.874	
							0.536	
Minimal Aggregation			Minimum[$(PC_i \times PP_i)^{Wi}$]				**0.008**	
DOMINANCE MATRIX			No Project			-	11.5	
			Project Option 1	14.7		6.8	-	7.9
			Project Option 2				1.4	-
			Maximum Dominance	**44**			12.9	
			Dominance Factor			0.13	**0.19**	0.37
			Modified Fuzzy Minimal Aggregation			1.67	**1.52**	3.54
			Project Rank			**2**	**3**	**1**

Number representing the satisfaction of the assessment criterion by the existing or present conditions or state of development.

Product of the Performance Rating and Present Condition, modified according to the importance (weight) of the criterion, e.g. $(0.7 \times 0.5)^{0.39}$

The range of development objectives are translated into specific project assessment criteria and are listed here.

Importance or weight attached to the specific assessment criterion.

Likely change in the level of satisfaction of the assessment criterion under Project Option 1, i.e. indicator of whether surface water quality would be improved.

Minimum Aggregation (the smallest Fuzzy Set Combination number) indicates the lowest level of satisfaction associated with Option 1.

The column total indicates to what degree Option 1 is superior to other alternatives.

The row total indicates to what degree Option 1 is inferior to other alternatives.

The product of the Minimal Aggregation and Dominance Factor for Alternative 1.

The procedure for evaluation and selection of a preferred development proposal using the MESA method is illustrated in Figure 4.4 and includes:

1. Define the problem or opportunity that has initiated the development study, and outline the objectives that alternative solutions should meet.

2. Develop a number of alternative schemes to meet these objectives. The alternatives and their anticipated effects should be described in the context of the combined political, social, economic, and environmental values. The degree of generality of the description should be kept as uniform as possible.

3. Determine the criteria that are specific to the study and important in the selection of the best alternative. These are the *Sustainability Goals and Constraints*.

4. Assemble a multi-disciplinary team or *Assessment Panel* possessing knowledge and expertise in areas such as economics, engineering, the natural environment and social issues. Representatives from government agencies, social welfare and local interest groups should be considered. Assess the relative importance of each of the assessment criteria.

5. The members of the Assessment Panel should then assess the degree to which the present conditions satisfy the designated goals and constraints referred to in point 3. Each development alternative should then be similarly assessed.

6. The assessments are combined mathematically to provide an indication of the performance of each alternative relative to the criteria under consideration:

$$WP_{ij} = (PC_j \times PP_{ij})^{\alpha_j} \qquad (4.10)$$

where i = the development alternative,
j = the sustainability goal or objective,
α_j = weight attached to criteria j,
PC_j = Present Condition rating for criteria j,
PP_{ij} = Project Performance rating for alternative i and criterion j, and
WP_{ij} = Weighted Performance of alternative i relative to criterion j.

7. The Fuzzy Set Combination is the minimum WP_{ij} for each alternative; that is, the minimum value in the column corresponding to each alternative.

8. A Dominance Matrix is then constructed to examine the potential cumulative benefits of one alternative over another. The Dominance Factor is calculated as a measure of the effectiveness of an alternative relative to all other alternatives.

9. The product of the Weighted Performance and Dominance Factor (multiplied by 1000) determines the final ranking of alternatives. The closer the product is to 1000, the greater the satisfaction of the criteria and provision of benefits over other alternatives.

The various elements of this procedure are discussed in greater detail below.

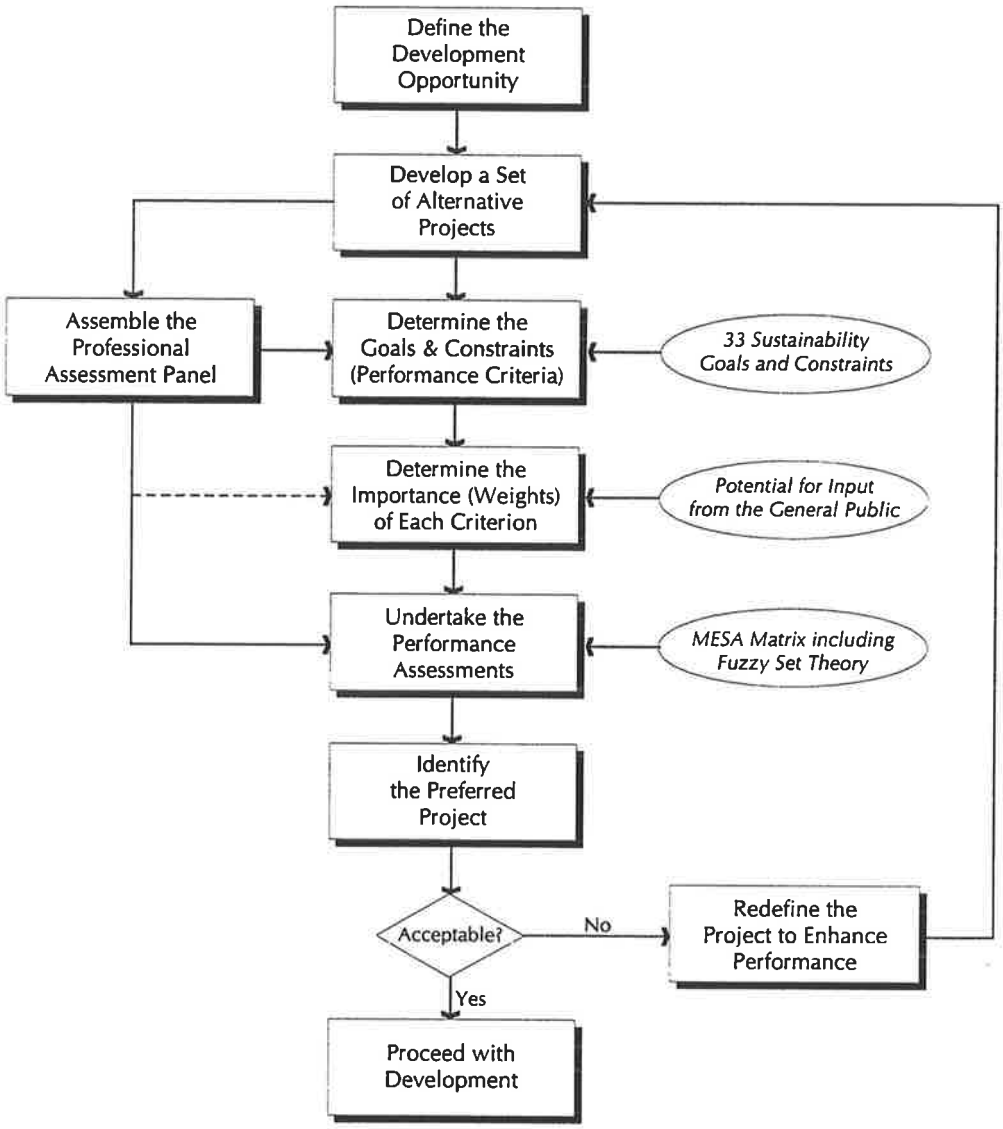


Figure 4.4
The Process of Undertaking the MESA Method

For this, and indeed any multi-objective analysis method to produce results of value, the identification of alternatives and the selection of analysts must be undertaken with care and thoroughness. A team should reflect the diversity of opinions and values of the broader community. The selection process should ensure that members are educated about the relevant issues and can present an informed opinion.

Perhaps the most important task is the specification of criteria against which alternatives are to be assessed. Deason & White (1984) note that despite the impressive growth in number of multi-objective methods, they are yet to enjoy wide success in solving actual problems. A possible explanation could be the apparent lack of emphasis on the specification of criteria, or the time required from busy people to complete them.

4.6. Selection of Criteria for Project Evaluation

The specification of an appropriate and operational set of objectives is as difficult as it is important. Thirty-three (33) goals and constraints have been developed as part of the MESA methodology, including criteria relating to the environmental, social and economic aspects of development. Considerable modification and adaptation of the criteria was required to achieve the final list presented.

The size, nature and complexity of a project largely determine the range of criteria that are appropriate, and against which its sustainability should be judged. Table 4.1 indicates the scale of impact that might typically be associated with a range of developments. A project such as the construction of a local playground or domestic dwelling, is usually of a small spatial size. Therefore, the project has, individually, little impact upon native habitat or other regional resources. The issues are local, and relate mainly to things such as energy efficiency, material usage, storm runoff and waste disposal.

Developments at a district or regional scale usually have a greater spatial size, demand greater initial and ongoing resource consumption, and often generate a wider range of concentrated and diffuse impacts. It is more likely that habitat, native plant and animal species could be adversely affected, while solid and gaseous waste disposal and storm runoff could have a more significant impact on their receiving environments. Consequently, assessment of such projects requires the inclusion of criteria reflecting the greater scale and diversity of impacts.

It has been observed that there are a number of fundamental issues that require consideration in almost all cases. These include:

- productive use of fertile soils;
- equitable distribution of the costs and benefits;
- increased employment opportunities;
- preservation of areas of landscape and amenity value;
- preservation of areas of cultural value;
- public acceptability; and
- capital cost funding capability.

Additional criteria that are particular to larger scale development are:

- maintenance of habitat and ecosystems;
- preservation of native plant and animal species; and
- local infrastructure compatibility.

The proposed Sustainability Evaluation Criteria are listed in Table 4.2. It is considered that the list comprises the objectives that are fundamental to the achievement of sustainability, while maintaining sufficient generality to be applicable to large development projects or strategies.

Table 4.1
Examples of Development with Differing Spatial Scales of Impact

Developments with impacts at the local scale
- Residential dwellings and estates
- Private hospitals
- Smaller retail and commercial premises
- Drive-in movie theatres
- Parks and playgrounds
- Horse stables, dog kennels
- Hotels and motels

Developments with impacts at the district scale
- Sports stadiums and sports fields
- Lakes, wetlands, retention basins, drainage facilities
- Airports (runways, fields, buildings)
- Hospitals and medical facilities
- Industrial facilities (chemical, petrochemical, cement, manufacturing)
- Large hotels and tourist resorts
- Large scale residential development
- Ports and harbours (wharfs, sea walls, barrages, channels, yards)
- Road network development (roads, tunnels, bridges)
- Shopping complexes
- Skyscrapers and city buildings

Developments with impacts at the regional scale
- Farming, agricultural and horticultural production
- Mining (processing facilities, open cut/underground, waste dumps, oil rigs)
- Power generation plants (hydro-electric, coal, gas, wind, solar)
- Railway and bus-ways (terminals, tracks, bridges, yards)
- Stormwater drainage (pipes, culverts, channels, basins, wetlands and other structures)
- Telecommunication facilities (towers and other structures)
- Water supply and sewerage systems (filtration plants, STWs, pipe networks, pumping stations, dams, reservoirs, weirs, groundwater extraction fields, sewage outfalls)

Some of the criteria in Table 4.2 would not be relevant to the evaluation of all major projects. The adopted criteria should therefore be tailored to the project under consideration. Where the criteria are not used directly, they can be modified to suit the project, so long as the principle and intent of each criterion is maintained. In addition, any project specific issues or objectives should also be included.

The MESA methodology is best suited to larger scale, more resource intensive development. The small scale, local development initiatives would not normally require evaluation by the MESA method.

4.7. Assigning the Relative Importance to Each Criterion

Just as the applicability of the criteria will vary from project to project, so to will the importance associated with each criterion. To ensure that the right emphasis is placed upon the development objectives and project selection process, it is desirable to ascertain the relative importance of each criterion.

Table 4.2
Sustainability Evaluation Criteria

Maintenance of habitat and ecosystems	Local infrastructure compatibility
Preservation of native plant species	Minimisation of greenhouse gas emission
Preservation of native animal species	Airborne disposal within assimilative capacity
Preservation of areas of landscape/amenity value	Use of renewable energy sources
Preservation of areas of cultural value	Energy efficiency
Reclamation & reuse of wastewaters	Public acceptability
Wastewater disposal within assimilative capacity	Involvement of the community
Groundwater extraction within sustainable yield	Improved recreational opportunities
Improvement in surface water quality	Improved access to public open spaces
Improvement in groundwater quality	Full cost recovery for good or service
Productive use of fertile soils	Annual equivalent cost-benefit ratio
Prevention of erosion	Costs borne by consumers
Application of clean technology	Equitable cost-benefit distribution
Waste recycling or use	Increased in employment opportunities
Material utilisation allowing recycling or reuse	Unit cost for good or service
Increased use of metal substitutes	Capital cost funding capability
Compatibility with existing operations or services	

Numerous different methods have been developed to determine the relative importance of different issues, criteria or objectives. These methods range from simple ordinal ranking to more sophisticated mathematical methods. The method proposed for use is that developed by Saaty (1972) and discussed by Yager (1977). This technique determines a ratio scale for the group of criteria or objectives, based upon a pair-wise comparison of the individual criterion.

Each member of the Assessment Panel (or alternatively community representatives) undertakes this pair-wise comparison process. The importance assigned to each criterion is calculated from each member's response. The weights determined for each member are then averaged across each criterion to produce a set of weights reflecting the combined importance of the individual criterion for the whole group.

Assume that a comparison is being made between criterion i and criterion j to determine which of these two criteria are more important. A value is assigned based upon the judgement of importance. These judgements are then combined to form an $n \times n$ matrix **A**, so that the following rules are satisfied:

1. if criterion i is more important than j, a number to a_{ij} from Table 4.3 is assigned;
2. $a_{ii} = 1$; and
3. $a_{ji} = 1/a_{ij}$.

Saaty (1977) showed that the eigenvector corresponding to the maximum eigenvalue of **A** is a ratio scale for the criteria compared. Having found this eigenvector, it is further modified to produce the vector **E**:

$$E = \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{pmatrix} = n.W = \begin{pmatrix} nw_1 \\ nw_2 \\ \vdots \\ nw_n \end{pmatrix} \quad (4.11)$$

where **W** is the unit eigenvector and n is the number of criteria, because the average importance should be equal to one (1). A FORTRAN program was written for use on IBM compatible personal computers for the computation of this maximum eigenvalue and corresponding eigenvector.

Table 4.3
Importance Scale and its Description

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over the other	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgements	When compromise is needed

This relative ranking process has the advantage that only 2 criterion be considered at any time. As the total number of criteria increase, the number of comparisons to be made can rise rapidly. Where there are *n* criteria, then the number of comparisons to be made can be calculated using the equation:

$$f = \frac{n(n-1)}{2} \quad (4.12)$$

It is usually recommended that the number of items for comparison be limited to between 7 and 12. The reasons include: (i) psychological research reveals that people have limited capacities concerning the number of conceptual units that can be effectively handled at one time; (ii) the time required from corporate or public sector decision makers should be limited; and (iii) the need to gather information for each alternative (Shepard, 1964; Shafer & Davis, 1989; Bouyssou, 1990; Nijkamp *et al*, 1990; Jannsen, 1992).

Where the number of criteria exceeds 10, say, then a hierarchical structure could be used to segregate the criteria into categories, thereby reducing the number of comparisons in any one group.

4.8. Assessing Criteria Satisfaction

The members of the Assessment Panel evaluate to what degree the project selection criteria are satisfied by the existing or pre-development conditions. The potential beneficial or adverse impacts of each development alternative are also assessed. Each member of the Assessment Panel undertakes the assessment for criteria relevant only to their field of expertise.

A value in the range of 0 to 1 is assigned to represent this level of satisfaction of a criterion, where 0 is analogous to no satisfaction, and 1 represents complete satisfaction. A value between 0 and 1 represents an intermediate condition. This value is also referred to as the *membership value*.

The relationship between the performance of a project relative to a specific criterion and the membership value could assume a variety of forms. The function may be linear, a polynomial, or have no specific mathematical description (such as the Transformation Curves from the Battelle Checklist described in Section 3.4.2), but rather be defined by the subjective judgement of the professional assessing the project.

Where quantitative information exists, such as water quality guidelines or details of a financial budget, this information can be used to establish the respective ends of the performance rating spectrum [0,1]. For example, assume that it has been predicted that the construction of a gas pipeline will cost around $10 million, but not more than $14 million. If a project alternative costs more than this amount, it can be considered to perform poorly, whereas an alternative that costs less than $10 million would perform well with respect to a criterion of cost effectiveness. Refer to Figure 4.5.

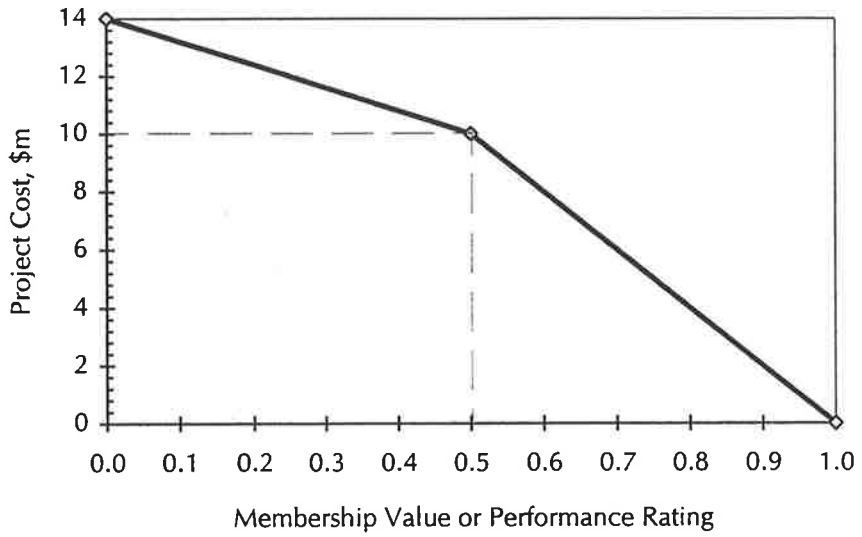


Figure 4.5
Example of a Performance Rating Function for Project Cost

However, sometimes only a subjective assessment can be made. In such cases, the value 0 is considered to correspond with the linguistic expression of 'very bad condition', whereas 1 corresponds to 'very good condition'. Refer to Figure 4.6.

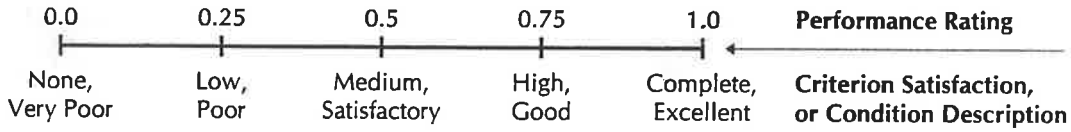


Figure 4.6
Linguistic Rating System

The membership values are then combined with the criteria weights to provide a preliminary indication of project worth. For each criterion, the membership value for a particular project is multiplied by that of the existing conditions. This corresponds to the linguistic "and" condition, and accounts for the impact that a project alternative may have with respect to the current circumstances. That is, this mathematical product effectively questions whether a project alternative would result in an adverse impact, and thereby compound an existing problem where the satisfaction of the criteria is already low?

Raising this product to the power of the criterion weight modifies the grade of membership in the fuzzy set for each alternative. For example, referring to Figure 4.3, the grade of membership of project Option 1 for Criterion 5 is:

$$\text{Overall Membership} = (0.35 \times 0.70)^{0.39} = 0.664 \qquad (4.13)$$

The cumulative satisfaction of all criteria for each alternative is determined to be the minimum membership value in each column. This reflects the minimum level of satisfaction of any criteria for each alternative. This is referred to as the *minimal aggregation* since it assumes that the worst evaluation of any feature for an alternative should be taken into consideration. Hence, the use of the minimal aggregation is a cautious approach to decision making, and tends to minimise the risks involved when attempting to find a reasonable solution. Fuzzy set theory suggests that the alternative corresponding to the largest of these minimum membership values is the best alternative.

The use of the criterion weight is therefore significant when following this approach to project selection. Consider the effect on the outcome of equation 4.13 if the criterion was considered to be much more important, and its weight was equal 2.0 instead of 0.39. Then:

$$\text{Overall Membership} = (0.35 \times 0.70)^{2} = 0.060 \qquad (4.13)$$

The change in the criterion weight has had the effect of reducing the overall membership value by an order of ten. By making this value much smaller, the importance of this outcome under the minimal aggregation approach to project selection becomes much more significant.

Using this approach, it is possible for a project to be superior in all respects but be rejected on the basis of poor performance against only one criterion. To temper this pessimistic approach, the use of a *Dominance Matrix* is proposed.

4.9. Dominance Matrix

The use of a Dominance Matrix was first suggested by Alley *et al* (1979), and was used to rank a set of alternative projects using a more basic approach. An alternative was defined to be superior to a second alternative if it dominates the second alternative in more features than the number of features in which the second dominates the first.

In order to display the dominance structure between all possible pairs of alternatives, a square matrix **D** of order *p* is used (where *p* is the number of alternatives or projects) and is called the Dominance Matrix. In the matrix used by Alley *et al* (1979) the element d_{ij} was the number of criteria for which the membership value of alternative *j* dominates or is greater than alternative *i*. A dash is entered for the diagonal elements. If the *k*th column is summed, the total number of dominances of alternative k over all other alternatives is obtained. Similarly, if the *k*th row is summed, the number of times the *k*th alternative is dominated by all the other alternatives is determined.

A modification to this technique is suggested. The situation existing with the original dominance matrix was that the dominance of one alternative over another for a low importance criterion possessed equal weight to that corresponding to a criterion of high importance. To enhance this approach, the element d_{ij} is redefined; d_{ij} becomes the sum of the weights corresponding to each criterion for which alternative *j* dominates alternative *i*. An example is shown in Figure 4.3.

The Dominance Factor, DF has been devised as an overall measure of the superiority of an alternative, and is defined as:

$$\text{Dominance Factor, } DF = \frac{MD - RT_k}{MD} \times \frac{CT_k}{MD} = \frac{(MD - RT_k).CT_k}{MD^2} \qquad (4.13)$$

$$\text{Maximum Dominance, } MD = n(p-1) \qquad (4.14)$$

where MD = the maximum possible dominance, which is equivalent to one alternative dominating all other alternatives in all criteria;
n = the number of criteria used in the assessment of alternatives;
p = the number of alternatives being considered;
RT_k = the row total for alternative k; and
CT_k = the column total for alternative k.

The more favourable alternatives have higher column sums and lower row sums, and this is reflected in the way the DF is formulated. A high column total and low row total will produce a DF close to 1. Similarly, a low column total and high row

total will produce a DF close to zero. Therefore, a DF near 1 indicates a favourable alternative while a DF near zero is a characteristic of a poor alternative.

In the case of the example provided in Figure 4.3, the Dominance Factor for Project Option 1 is:

$$DF = \frac{(44 - 14.7) \times 12.9}{44^2} \cong 0.19 \qquad (4.13)$$

Thus taking the product of the DF with the weighted performance measure, tempers the pessimistic aggregation produced using fuzzy set theory, to identify the alternative that most effectively meets all criteria, and is consistent with the priorities assigned via the allocation of weights.

The results should then be checked against the criteria weights and dominance matrix for consistency and errors, and to ensure that no unacceptable impacts exist with the preferred solution.

4.10. Benefits and Limitations of the MESA Method

The MESA technique provides a methodology for dealing with multi-objective development problems at the planning level. Furthermore, it possesses many of the features that characterise a good multi-objective decision making tool. The numerous advantages of the MESA technique are:

- The method is logically sound, standardised and repeatable.
- Quantitative and qualitative data can be incorporated into a common framework without resorting to estimated monetary values of costs and benefits. A broad range of development issues can thus be explored at the same time.
- Available quantitative data is valuable and easily incorporated into the technique. The data can be used to set limits of acceptability (such as the total available funds, or allowable levels of pollution) against which the performance of alternative projects can be assessed.
- It provides a decision making 'audit trail'. This is a result of the formal structure and the method of combining the evaluations of dissimilar criterion. Furthermore, this clarity of the decision making path invites investigation, discovery, and constructive criticism. It facilitates challenge and improvement through debate.
- The use of weights to reflect the importance of the assessment criteria, and the assignment of impact ratings through membership values, inherently reflects people's attitudes to risk and uncertainty.
- A major shortcoming of many forms of public participation in decision making is that the views of individuals and minority groups may be heard, rather than those of a balanced public cross-section (Kiely-Brocato *et al*, 1980). This method allows the preferences (criterion weights) of each group to be tested

individually, if required, to see how the decision outcome would be affected. The best solution would be a judicious selection of individuals that ensured a representative cross-section of the community, not dominated by but still including the views of minority groups.

- The use of pair-wise comparisons in the evaluation of criteria importance is a simple yet effective technique to compare a large number of criteria. Nijkamp *et al* (1990) found that more simple and less time consuming weight evaluation techniques perform as well as or better than complex methods.

- The use of fuzzy set theory and the pessimistic aggregation method ensures a risk averse selection of the 'best' alternative, which is supportive of the philosophy of sustainability.

- There is considerable flexibility and scope for sensitivity analysis, both in terms of the fuzziness of membership values and criteria weights. The potential impact of differing political viewpoints can be examined through the application of criteria weights offered by each individual or group.

- Some characteristics of the methodology are common to other multi-objective decision making methods, and therefore should be easily understood and accepted by decision makers.

- The numerical evaluation of alternatives and combination of assessments is mathematically simple.

- The method accommodates the selective comparison of dissimilar criteria and consideration of the potential trade-offs between alternatives.

- The spatial scale of alternative projects and the implications for sustainability can be tested relatively quickly, as membership values (of criteria such as cost, or use of fertile land) could be constructed as functions of spatial size.

- The method is inherently flexible and can be applied to essentially any multi-objective decision making problem.

There are obviously some limitations to the MESA method. These relate primarily to the problems of incorporating qualitative and subjective information. Some problems include:

- Results are dependent upon the subjective evaluations or approximation of social, economic, political and environmental values. However, approximations are innate to all complex problems and improvements can be made as better information comes available.

- Results reflect only the knowledge and judgement of the participants.

- The method is new and unfamiliar to decision makers.

- The issue of sustainability is the subject of ongoing debate and numerous interpretations. Therefore the criteria listed for evaluation of alternatives would receive mixed acceptance from various groups.

- There is a requirement that decision makers overlook their own short-term interests to the long-term best interest of the community as a whole. However, human preference attaches a higher priority to the immediate and tangible. The discount rate used in economic evaluation reflects this preference. This is a problem associated with all methods. It is therefore particularly useful that longer-term goals be evaluated using MESA. In part, the criteria to be evaluated assist this objective.

- The selection of members for the Assessment Panel could be biased by the views and nature of the assessment coordinator or agency, thereby influencing the results obtained. Furthermore, the assessment of project impacts can be subject to the personal biases of the analyst. However, these problems are characteristic of most other multi-objective decision making techniques.

- There can be a large number of comparisons to be made in the process of evaluating the importance of criteria. In most instances computer software would be required to combine and determine the criteria weights.

4.11. Conclusions

There is little doubt that the use of multi-objective decision making methods will continue to expand, to aid decisions on optimal resource use by an increasing population, while pursuing the goal of sustainable development (after Hipel, 1992). The assurance of an acceptable quality of life, and indeed the survival of the human race, will require an holistic and responsible approach to sustainable development decision making.

The MESA methodology attempts to encourage development that is sustainable. It accounts for subjective judgement and contains a formal rigorous decision strategy that takes the place of intuition when quantitative and qualitative values need to be addressed.

The MESA method is capable of incorporating public opinion, which has become and will continue to be a vital component in the development and assessment of environmental policy (Hzero & Hzero, 1984). Use of the multi-disciplinary approach enables public opinion to be combined with expert knowledge for the successful preparation and promotion of environmental policies and development plans.

The effectiveness of any multi-objective approach in practice will depend in part on how easy it is to understand, how well it addresses the appropriate issues or problems, and how adaptive it is to various dynamic institutional settings. It is considered that the MESA method satisfies the requirements for it to be a practical and useful planning aid, and can only improve the quality of decisions that are made. Hollick (1993) considers that when qualitative, subjective and value-laden

information must be considered in the evaluation, the process is as important as the quantitative analyses, and may be even more important. The MESA approach can incorporate all forms of data and does not eliminate subjectivity, but rather makes it explicit, explaining the basis of the judgement and facilitating discussion of that assessment.

Simplicity and practicality are also very important if project proponents and decision makers are to be encouraged to use a decision support tool. The initial response to environmental impact assessment is often to regard it as an additional obstacle to overcome which is separate from other aspects of project planning. However, some proponents are learning that it is advantageous to address all issues early in project planning in an integrated way (Hollick, 1993). MESA provides the means to simply integrate the planning and development issues, and a process that will enable greater comprehension of the problem for identification of the 'best' alternative.

5

Water Resources Management

5.1. The Origin and Nature of Water

Water is the most abundant substance on Earth, the principal component of all living things, is chemically unique, and a major force shaping the Earth's surface.

Life on Earth started in water and without water as we know it could not continue. Plants and animals alike have a fundamental dependence upon water, and the nutrients and chemicals it transports enable life in all its forms to continue. Water also moulds the surface of the Earth, eroding materials from some locations, transporting it and depositing it in others. Water is also the main greenhouse gas and the key to the global energy budget, helping redistribute heat from one part of the Earth to another (WRI, 1990; Rodda, 1992; Pickering & Owen, 1994; Young *et al*, 1994).

Water is found throughout the atmosphere, on the land and through the oceans, and below the Earth's surface for a few kilometres. In the atmosphere it is found as vapour, as liquid and as small ice particles. On the land surface, it is found as snow and ice, but primarily in liquid form. In the soil it is also found in all three forms, while in deeper aquifers it is usually found as a liquid under pressure.

The total volume of water is estimated to be 1.42 billion cubic kilometres (UNESCO 1978). If this amount of water was spread evenly over the Earth's surface, the layer of water would be nearly 3 km deep. Nearly 98 percent of this water comprises the salt water of the oceans, inland seas, and deep aquifers. The remaining 2 percent is fresh water, of which 87 percent is locked in ice caps and glaciers. Much of the remaining fresh water is stored in aquifers, in the soil and in living things. Animals themselves are made up of more than 70 percent water, with plants containing over 90 percent water by weight. Aside from lakes, only 2,000 km^3 (or 0.006% of all fresh water) is available to satisfy human needs, mostly from rivers.

Because water is so common, it may be considered a typical liquid like any other. However, virtually every physical and chemical property is unusual when compared with other liquids, and these differences are essential to life (Berner & Berner, 1987 in Masters 1991). Water has a relatively high boiling point, and is the only common substance that expands when it freezes. It also has its maximum density at 4°C, which means that for temperatures above and below this point, water continuously

becomes lighter and more buoyant; hence, ice floats. The unusual density characteristics also lead to thermal stratification of lakes, which can enhance eutrophication and degrade water quality.

The specific heat[1] of water is higher than it is for any other known liquid except ammonia, and is five times higher than the specific heat of most common heavy solids, such as rock and concrete. This means that water heats and cools more slowly than almost anything else. This helps to moderate climates near large bodies of water, and also serves the important function of protecting life from rapid thermal fluctuations, which are often lethal. The heat required to vaporise water is also one of the highest of all liquids, meaning that water vapour stores a large amount of energy which is released when it condenses. This property is important in distributing heat from one place on the globe to another and is a major factor affecting the earth's climate.

What is significant from a water quality perspective is that water dissolves more substances than any other common solvent. As a result, it serves as an effective medium for both transporting dissolved nutrients to tissues and organs in living things as well as eliminating their wastes. Water's ability to assimilate many substances is a primary reason for its extensive use throughout industry and daily life, and also the reason why its pollution can be so easily achieved.

Table 5.1
Estimated Quantities of the Global Water Resources(1)

Resource	Area (10^6 km^2)	Volume (km^3)	Percent of All Water	Percent of Fresh Water
Oceans	361.3	1,338,000,000	96.5	
Groundwater				
– Fresh	134.8	10,530,000	0.76	30.1
– Saline	134.8	12,870,000	0.93	
Soil Moisture	82.0	16,500	0.0012	0.05
Polar Ice	16.0	24,023,500	1.7	68.6
Other Ice and Snow	0.3	340,600	0.025	1.0
Lakes				
– Fresh	1.2	91,000	0.007	0.26
– Saline	0.8	85,400	0.006	
Marshes	2.7	11,470	0.0008	0.03
Rivers	148.8	2,120	0.0002	0.006
Biological Water	510.0	1,120	0.0001	0.003
Atmospheric Water	510.0	12,900	0.001	0.04
Total Water	510.0	1,385,984,610	100	
Total Fresh Water	148.8	35,029,210	2.5	100

(1) After UNESCO (1978) World Water Balance and Water Resources of the Earth, *in Chow, Maidment and Mays (1988)*

1 Specific heat is the amount of energy required to raise the temperature of a unit of mass of a substance by one degree Celsius.

Given the unique chemical nature of water, its fundamental role in sustaining life on earth, the ease with which it can be polluted, and the precious value of the available fresh water resources, it is extremely important that water be carefully managed. The importance of sustainable water resource management is heightened by the fact that freshwater resources are unequally distributed among and within the continents. With an expanding global population, the resources must be managed to satisfy both present and future human demands, as well as maintain the aquatic environment and the life it supports.

5.2. A Global Perspective on Water Resources

5.2.1. The Impacts of Development on Water Resources

Modern civilisation has been built on the availability of fresh water. During the past three centuries, the amount of water withdrawn by mankind from freshwater resources has increased by a factor of 35 or more. In the second half of the 20th Century, water withdrawals have been increasing at around 4-8 percent annually (Figure 5.1), with most growth in the developing countries.

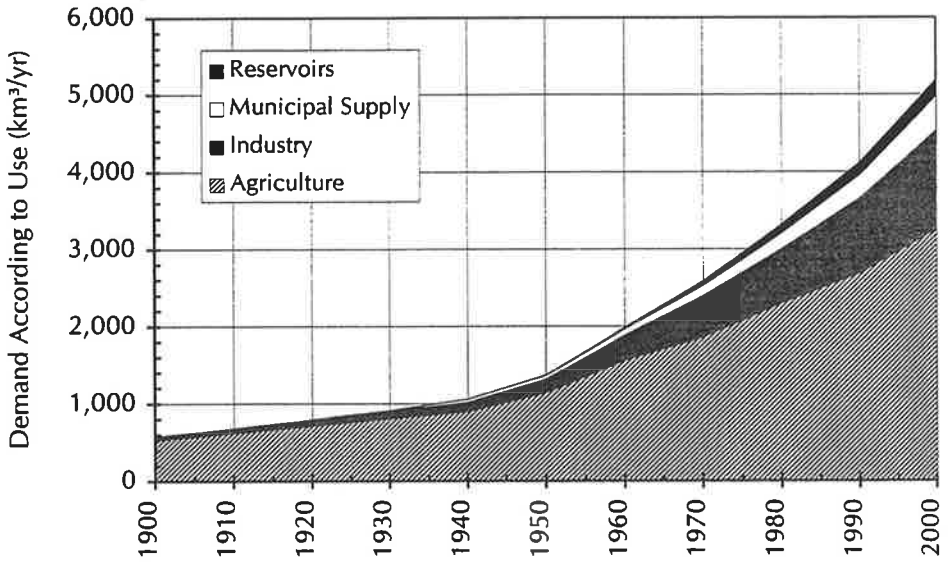


Figure 5.1
Approximate World Water Demand
(after Shiklomanov, 1991)

Apart from sustaining the life of communities, water is fundamental to almost every economic activity. Water is withdrawn from natural systems, from rivers and lakes on the surface and from underground aquifers for a variety of uses. Some 80 percent of the water withdrawn is used for irrigation (Young *et al*, 1994). Large quantities are also consumed for industrial use in manufacturing and power production, as well as for municipal uses. Much of the water that is withdrawn from natural systems is eventually returned, but it may be contaminated or thermally changed, making its reuse further down the natural pathway difficult or impossible.

There are three major sources of water pollution: domestic wastewater, industrial effluents, and land runoff, although leaching from mine tailings and solid waste dumps, and the atmospheric deposition of pollutants into water bodies, are of growing importance.

Much of this pollution finds its way into the oceans and seas, which have also acted as the dumping ground for human waste for many centuries. The problem of marine pollution has only become very serious in the industrialised world of the 20th Century as the assimilative capacity of these systems is exceeded. The wastes vary considerably, as do their persistence in the environment (refer to Figure 5.2).

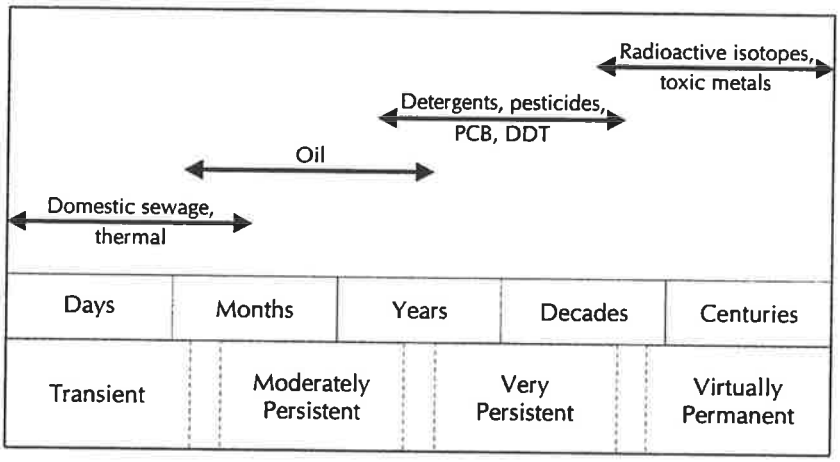


Figure 5.2
The Persistence of Pollutants in the Oceans
(after Smith and Warr, 1991 in Pickering & Owen, 1994)

In many parts of the developed world, water resources are under stress, often in terms of quantity as well as quality. Although essentially a renewable resource on a global scale, freshwater is being extracted from some river basins at rates approaching the rate of natural replenishment, and many groundwater systems are effectively being mined. The share of available water resources used by urban domestic and industrial consumers is also growing. At the same time, other aspects of human development are adversely affecting water resources, such as pollution by waste discharge or disposal.

California provides an excellent example of a technologically advanced and prosperous community, where there is a high degree of water regulation and importation using extensive infrastructure. Yet in California, a serious water supply crisis is looming. The feed to the state's water supply reservoirs is continuing to decline to its lowest level in history. In 1991, the state constructed its first desalination plant, and others have been proposed (Pickering & Owen, 1994).

In central and eastern Europe, the collapse of communist governments has revealed serious pollution problems resulting from years of rigid central planning, in which economic considerations to a large extent excluded ecological ones. Rehabilitation

of the environment, including water resources, will take many years. The greatest priorities in water resources management are improvements in water quality and the reliability of supply (Kindler, 1992).

The provision of basic water services is a major problem in the developing countries. According to the World Health Organisation, an estimated 1,200 million people lack a satisfactory or safe water supply (Pickering & Owen, 1994). In 1990, despite a decade of concentrated efforts, almost one third of the people in developing countries lacked safe drinking water. More lacked facilities for the hygienic disposal of body wastes. Clearly these conditions have serious implications for human health and the transmission of disease.

The degradation of the quality of water resources is a problem equally serious as that of supply. Issues of water availability and quality are likely to become critical and potential constraints to development. For many countries, the problem stems from the pursuit of industrialisation under conditions of a burgeoning population, and the concentration of the population in massive urban areas. Young *et al* (1994) indicate that early in the next century, more than half the world's population will be living in urban areas. By the year 2025, that proportion will have risen to 60 percent, comprising some 5 billion people. Rodda (1992) states that to meet the domestic, and particularly agricultural, demand for water to service these populations, that supply will need to double by the year 2050 to around 9,000 km^3 per year. This is equivalent to approximately one quarter of the combined flow of all the world's rivers. Such rapid urban and industrial growth will place severe strains on the water resources and the capacity of environmental systems.

As previously mentioned, where water resources are unable to meet demand, development can be severely constrained. This water scarcity is demonstrated to present itself in a number of different modes: two hydroclimatic – aridity, and recurrent droughts; and two man-induced – desiccation of the landscape, or unmanageably high population pressure on finite water availability. Falkenmark (1992a; 1992b) considers that water scarcity is still under-estimated as a factor complicating socio-economic development. She observes that the lowest income countries are concentrated in the zones of Africa, Asia and South America, correlating remarkably well with those areas where part of the year is dry and/or there are recurrent droughts, and where evaporation is particularly high.

Water can also be a hazard. Floods, avalanches and landslides at one end of the hydrological scale, and drought at the other, kill more people and damage more property than any other type of natural disaster (Kindler, 1992). These problems can be particularly devastating in less developed countries such as Bangladesh. Despite enormous preventative efforts and massive foreign aid, disastrous flooding remains a recurrent problem. The causes are population of the flood plains, compounded by deforestation, land reclamation, reservoir and road construction, and ironically, even the construction of anti-flood dykes (Solomon, 1992).

Irrigated agriculture can also be very destructive if poorly managed, while also being extremely water intensive. The potential effects of inappropriate irrigation practices are demonstrated by the Aral Sea; the Sea has lost 40 percent of its area, 60 percent of its volume, and virtually all of its once productive fishery since the early 1960s.

This has been the result of excessive water extraction for irrigation. Ensuing problems include desertification, salinisation and climate change, with disastrous consequences for the local economy and an alarming deterioration in the health of the local population (WRI, 1990; Perera, 1992). The wide application of fertilisers and pesticides has heavily polluted irrigation drainage water, presenting a significant threat to the aquatic environment. Poor land management and erosion causes the loss of an estimated 6-7 million hectares of agricultural land each year. An additional loss of productivity from water-logging, salinisation and alkalisation is estimated to occur at a rate of 1.5 million hectares per year (WRI, 1990).

Groundwater resources can be impacted as severely as those on the surface. Excessive and unsustainable groundwater mining is now evident in many parts of the world. Land subsidence caused by excessive groundwater withdrawal is well documented in many countries, including Thailand, Japan, China and Mexico. The city of Bangkok in Thailand was measured to be sinking at a rate 14 times faster than Venice, significant if only because the city is situated about one metre above sea level. Excessive pumping can also lead to salt water intrusion in coastal aquifers. This is now serious in many coastal areas of the Middle East, China and Pakistan. In Japan, 80 coastal districts are experiencing the effects of salt water intrusion (Tolba, 1988).

And so, under the difficult conditions imposed by an escalating global population it is a significant challenge to provide water for a need other than human sustenance or industrial growth – the environment. The increasing focus upon the natural environment and sustainability has lead to a recognition that ecosystems are genuine and necessary users of water for which provision must be made. The scientific knowledge of the functioning of many ecosystems is limited though. Thus, in many instances, it is unclear how much water must be maintained for, or allocated to, the environment. Without clear guidance, and in conditions of water scarcity, dismissal of environmental needs may be easy. Indeed, the competition for water can be so strong that it emerges as a threat to peace.

Problems of transboundary flows assume great importance in many of the basins of major rivers in Africa, the Middle East and in many Asian countries, in which water may be limited in supply and where demands on the resource are great and increasing. In basins such as the Nile and the Tigris-Euphrates, the scarcity of water and the splitting of its ownership and jurisdiction between several countries has been, and likely will be, the basis for international conflict. Lonergan *et al* (1992) note that continued increases in population, and industrial and agricultural output in the Middle East, will mean that demand for water will rise dramatically, exacerbating the current chronic problem of water scarcity. Long-term solutions must inevitably encompass regional water sharing agreements. The issue is clearly tied with cooperation, peace and security in this volatile region. Unfortunately, Young *et al* (1994) consider that 'water wars' are likely to be a more common occurrence in the future.

The Jordan basin has one of the most acute water problems in the Middle East. The waters are shared between three Arab countries – Jordan, Syria and Lebanon – and their traditional enemy, Israel (Pickering & Owen, 1994). In the 1960s, Jordan proposed to dam a tributary of the Jordan River, the Yarmuk, which rises in Syria

and flows along part of the border between these two countries, but also forms a border between Israel and Jordan. Without assurance of access to this water, Israel would not entertain the prospect, and in 1967 the Six Day War ensued. Israel occupied the Golan Heights and the site of the proposed dam, and the scheme was shelved. Jordan and Syria now have a new site for a dam and reservoir, but international funding has not been forthcoming in the absence of an agreement between all the parties (Pickering & Owen, 1994).

Conditions are particularly severe in the Nile basin where all the countries except Sudan will experience conditions of chronic water scarcity by 2025 (Falkenmark, 1992b). The potential exists for conflict over this precious water source. Damming of the Nile has also imposed adverse environmental effects, which are explored further below.

5.2.2. A Case Study: The Aswan High Dam

Around 96 percent of the land surface of Egypt is desolate, rocky desert. Yet Egypt has seen 7,000 years of continuous civilisation. The sole reason for the survival of the Egyptian population is the Nile River. The water of the Nile is the life blood of Egypt.

Typically once each year, the torrential rains falling on the highlands of central Africa runoff and make their way northward, through 9 nations, into the Nile River (refer to Figure 5.3). The flood flows carry a cargo of silt and mud, which would deposit over the flooded plains and delta of the Nile, replenishing the fertile soils which have supported agriculture for centuries.

A rising Egyptian population placed great demands upon the waters of the Nile, to the extent that Egypt's future development was severely restricted by the limited available water resources. In 1960, the Egyptian government undertook to construct one of the largest dams in the world - the Aswan High Dam. The dam is situated on the River Nile in the far south of the country, and resulted in the formation of Lake Nasser. The lake is some 500 km long, and is capable of storing 5,500 GL (Horsley, 1984). The dam provided a largely expanded water resource, and hydro-electricity for Egypt.

Cultivation and productivity increased by 30 percent, and traditional crops were replaced by higher value export crops such as sugar cane. Yet increased irrigation of the agricultural lands, coupled with a general rise in water table (because of the head provided by the dam), brought salts to the surface and resulted in the waterlogging of soils. In 1993, one third of the prime agricultural land had been rendered useless because of waterlogging or was ruined by salinity.

The Aswan High Dam had broken the cycle of flood and replenishment, but hydro-electricity provided the power for industry and the production of chemical fertilisers. Now, two thirds of Egyptian industry is tied to the River Nile by the need for water, and more than 180 industrial plants return untreated wastewaters back into the Nile (Smith, 1993).

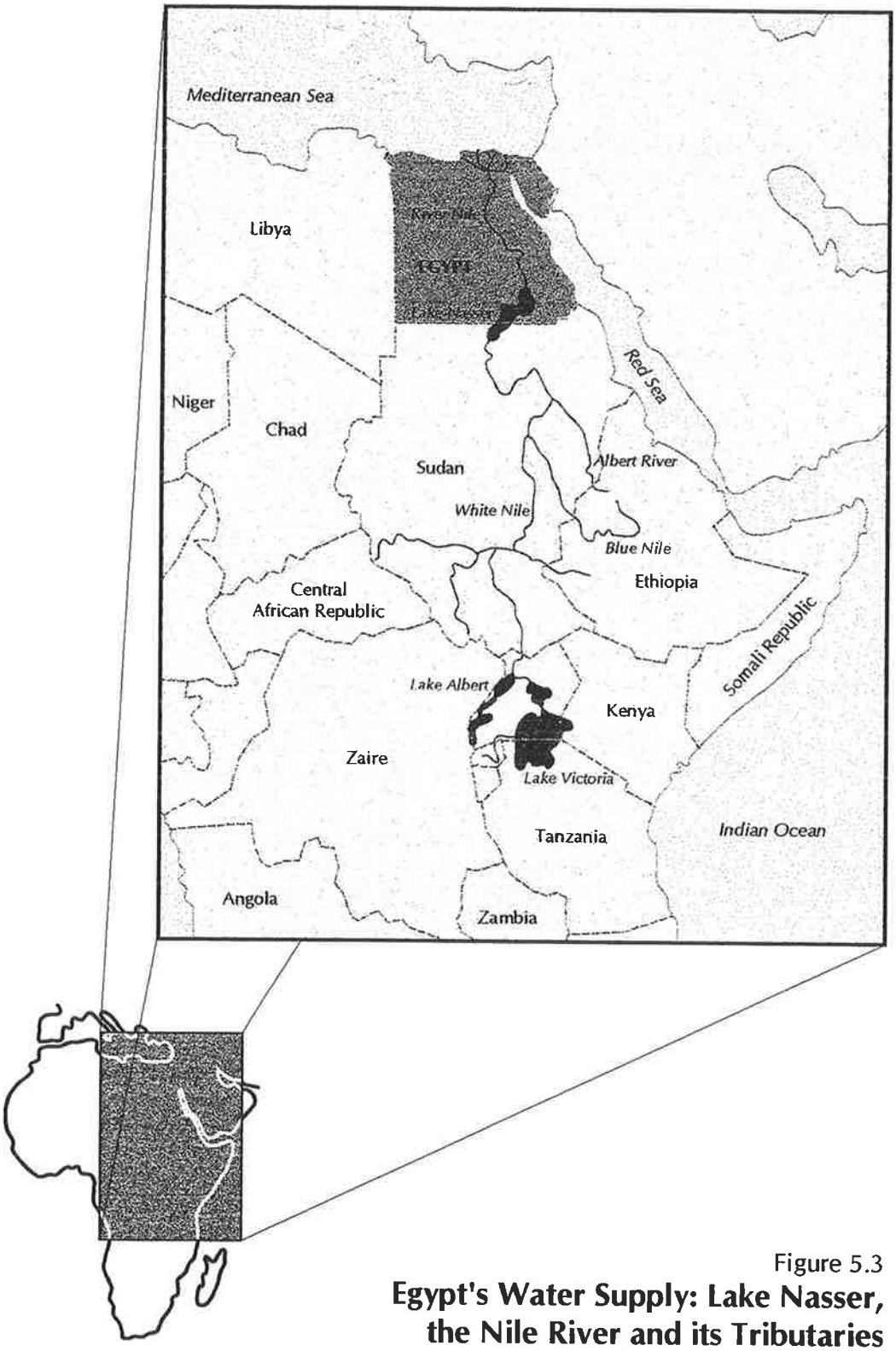


Figure 5.3
Egypt's Water Supply: Lake Nasser, the Nile River and its Tributaries

The security of water supply offered by the dam provided economic and social conditions that were conducive to a population explosion. The population is now more than four times larger than when the dam was constructed, and is expected to reach 75 million by the year 2000, and 100 million by 2025. The population increase consumed all the predicted growth in income by the time the dam was completed. The urban development that accompanied this population boom spread uncontrolled over the agricultural land lining the Nile at a rate of some 1,200 hectares per year. The government recognised the huge problems that such development would cause, and in 1984 enacted legislation to prevent any further building on agricultural lands. The restriction of the horizontal spread translated into vertical expansion, and urban centres are now characterised by a sea of high-rise buildings. People began to flock back to the cities; Cairo is now the largest city in Africa and the Middle East, with population densities in some suburbs exceeding 200,000 persons/km^2.

In response, the government undertook to move people back to where they had lived centuries before – in the deserts. The plan, initiated in the early 1990s, was to transform more than half a million hectares (5,000 km^2) of desert to urban and farming land by the year 1997. Examples already exist of sustainable, integrated farming in the desert. Where there was once only desert sands there are now fertile soils supporting a range of crops, established using holistic resource management and farming methods, with a careful use of water. All waste products are recycled, and returned to the soil as nutrients.

By the sea, the soil is being eroded by wave action because of the lack of new deposits of silt. Land is being lost to the sea, salinity and houses. The risk of a climate induced sea level rise and inundation has prompted proposals of a joint European venture to dam the Mediterranean and Red Seas near their inlets. At the present time, the response is to construct many sea walls in an attempt to prevent further erosion.

In addition, Egypt is not self sufficient in terms of feeding its population. The country relies upon tourism to produce sufficient revenue to purchase food from overseas. Yet tourism brings its own problems. In the country where paper was first produced, papyrus no longer grows wild; the Blue Lotus flower is rare; and many Nile animal species are extinct. The tourist dollar is feeding the growth of hotel developments along the Nile and at Aswan, in areas where some of the last remnants of native vegetation and biological heritage exist.

The silt that once revitalised the Nile flood plains now fills Lake Nasser. While provision was made to accommodate the silt load behind the dam, the sediment has not fallen in the designed location. Silt is dropping on the lake fringes, in volumes greater than predicted, producing a submerged mountain some 200 km long and 30 metres high. Evaporation rates have increased, and 20 percent of Lake Nasser's volume is lost annually to evaporation. It has been predicted by Egypt's engineers and scientists that there is only 10 to 20 years to resolve this problem (Smith, 1993).

The Nile and the Aswan High Dam are clearly crucial to the prosperity of Egypt. The dam's economic benefits were never in doubt and have been proven during the past. A seven year drought in northern and central Africa devastated Sudan and

Ethiopia, but Egypt was saved by the Aswan High Dam, although it was drained to critically low levels. In 1988, Egypt was also saved from the ravages of an abnormally high summer flood by the retention capacity of the dam.

Was the construction of the dam worthwhile? Biswas (1992) considers that an objective evaluation of the impact of the dam over more than 20 years of operation shows it has been overwhelmingly positive. He goes on to state that Egypt had no real choice but to build the dam, and that the environmental impacts must now be addressed. Yet the future economic benefits are now in question as well, while the environmental impacts have always been the subject of debate and criticism (Tolba, 1988). It is estimated that the currently unfavourable socio-economic conditions will worsen (Biswas, 1992) and by the year 2000, there will be less than one third of a bucket of water per person per day. The major constraint upon increasing agricultural production also remains the lack of water rather than of land. Environmental degradation through the loss of many Nile islands and associated biodiversity, the loss of replenishing silt, erosion of the coastal shoreline, salinity, waterlogging and reduced land productivity are being tackled by structural and chemical interventions, and at substantial cost.

The future of Egypt clearly depends on who 'owns' the waters of the Nile. All upstream countries are facing similar rapid population growth and accelerating demands for water, without the water infrastructure of Egypt. When these countries have proposed the construction of their own dams on the Nile, Egypt's government has made it very clear that they would not allow this to occur. Egypt cannot survive without the dam. The potential therefore exists for conflict over water.

5.2.3. Summary

Water is essential to all life on Earth. It is indispensable to humans, and the habitat of many animals, plants and other organisms. As a central component of socio-economic systems, an adequate supply of clean, fresh water is necessary for human health and welfare. Water is the basis for agriculture, is essential for many industries and for much energy production.

The massive growth of the global population during the 20th Century, and associated urbanisation and industrialisation, has placed enormous stress upon water resources in many parts of the world. There is ample evidence that urban growth is always accompanied by serious contamination of water resources in the urban areas and downstream. Population driven water scarcity can limit socio-economic development, and increase pollution of water bodies by domestic sewage and industrial effluents. At the same time, there is fierce competition for water use between the cities and irrigated agriculture. Inefficient water use in rural areas, while wasteful and economically harmful, can also degrade the environment and cause a long term decline in the productive capacity of the land. As damaging as water scarcity, leading to drought and famine, can be the over-abundance of water in the form of catastrophic floods. Unfortunately, there are communities that simultaneously experience both ends of this spectrum.

The simple message is that the world is facing an impending water crisis, largely a result of a massive and growing global population, and the associated forms of development and water use. Often, numerous land management, water quantity and quality problems are present together and are inter-linked. The challenge is to resolve these problems to sustain the health and welfare of human communities, while restoring the natural environment, a vital component of any sustainable development strategy.

Grover (1992) considers that it is possible to deliver adequate supply and sanitation services to this huge unserviced population, but that a new approach is required ("some for all, rather than more for some") and the mobilisation of more international aid. The most fundamental change is the acceptance that local communities must be the driving force in achieving sustainable systems. National governments must change their role, placing more emphasis on promotion and support, rather than on providing services. Kindler (1992) suggests that special attention should be paid to low cost technologies and cost recovery schemes, and all concerned should be convinced that such technology is not a second rate choice.

A greater recognition of the need for integrated land and water planning is emerging, with land capability and ecological capacity approaches being proposed for use to determine appropriate limits for water resource development. In the United States, integrated resource planning (IRP) is gaining widespread acceptance and demonstrating valuable benefits. IRP considers all types of resources equally and observes their interactions. Thus alternatives to new supply might include conservation, reuse, alternative rate structures, and other forms of demand management (Beecher, 1995). Other examples from the United States include Pizor *et al* (1984), Glasoe *et al* (1990) and the Pacific Institute (1995), and from Europe are Hengelveld & Geldof (1995) and Niemczynowicz (1995).

A greater degree of flexibility will be required in many systems so that they can respond to environmental shifts or discontinuities that may occur, potentially unexpectedly, due to the degrading effects of over population and urbanisation. The Greenhouse Effect is just one phenomenon that may require a creative approach to water management.

5.3. Impact of the Greenhouse Effect

The interaction of the water resources of the Earth with the atmosphere is exceedingly complex. As a consequence, much research has been required to enable the prediction of hydrologic events (such as rainfall, flood magnitudes, and catchment yield) for water resource development and management.

Projects involving the development of water resources are often large in scale, and can include irrigation, drainage and hydro-power schemes, land development for agriculture, structural and coastal engineering. Any decision to implement such a project raises important economic, social and environmental issues which can have long term implications. The reliability of hydrological and engineering investigations, and the data upon which they are based, is thus very important.

In most instances, hydrologic events can now be predicted with sufficient accuracy to establish water infrastructure and management facilities with an acceptable degree of reliability. Historic climatic and hydrologic data is typically used to provide a guide to future events, from which engineers can prepare the design of water infrastructure. Implicit is an assumption of 'stationarity' or constancy of key hydrologic variables such as average annual flow, annual variability of flow and seasonal distribution of flow (Williams, 1989; McMahon & Mein, 1986). To continue to assume that previous hydrologic records will be representative of future events may be incorrect, and could cause substantial dislocation and inefficiencies in water resources management in different climatic regions. Pittock (1989) believes that to improve these decisions the refinement of estimates of future climate conditions must be undertaken as a matter of urgency.

5.3.1. What is the Greenhouse Effect?

The Greenhouse Effect is actually one of the most well-established theories in atmospheric science. It is a natural phenomenon which refers to the effect of the warming of the planet through the presence of greenhouse gases.

Other than water vapour (H_2O), the greenhouses gases include carbon dioxide (CO_2) and methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFC), chlorinated hydrocarbons (HCFC), as well as ozone (O_3), nitric oxide (NO) and nitrogen dioxide (NO_2). The important greenhouse gases are listed in Table 5.2.

Table 5.2
Important Greenhouse Gases and Their Sources
(after Taylor, 1989)

Greenhouse Gas	Industrial / Biosphere	Major sources
Carbon dioxide, CO_2	80% / 20%	Industrial emissions, deforestation
Methane, CH_4	10% / 90%	Rice paddies, ruminants, termites, biomass burning, natural wetlands, coal mining, gas drilling, waste landfills
Nitrous oxide, N_2O	20% / 80%	Agricultural activities

The greenhouse gases, along with the clouds, act as a blanket to the earth, maintaining the global radiative energy balance of the earth-atmosphere system. Most of the sun's energy, which is mainly short wavelength radiation, passes through the atmosphere and warms the earth's surface. Long wavelength heat radiation is returned to the atmosphere, some of which escapes into space. Most of this radiation, however, is absorbed by the greenhouse gases, and is re-radiated in all directions, partly further warming the earth (Taylor, 1989).

Concern is therefore not with the existence of the Greenhouse Effect or the presence of greenhouse gases, but rather with the rate of increase of these gases and how much the Earth's surface temperature will rise (Schneider, 1989a; 1989b). Furthermore, because gases are mixed thoroughly in the atmosphere, the location of the source of pollutants is largely irrelevant, and therefore the reduction of

greenhouse gas emissions becomes a global challenge requiring a coordinated response. As previously discussed in Chapter 2, this is often very difficult to achieve.

5.3.2. Potential Changes of Climate

The effect of increasing concentrations of greenhouse gases on global climate has been simulated using General Circulation Models (GCMs). The models are currently in an early developmental stage and incorporate only a basic treatment of key biological and hydrological processes. Complex feedback processes, especially those involving increased water vapour and cloudiness in the atmosphere, make precise estimation of the degree of warming difficult. The picture is still very imprecise, especially when it comes to local changes in rainfall, cloudiness, tropical cyclone occurrence, frequency of extreme events and other phenomena which are of local economic importance. In addition, while GCMs can project seasonal distribution and annual variability, their resolution is too large to assess the impacts on key hydrologic parameters of a particular watershed (Williams, 1989; Pittock, 1989, Jakeman, 1990; Arora *et al*, 1997).

While there has been debate over the predictions made using GCMs, there is general consensus amongst atmospheric scientists that there will be an appreciable surface warming. Pittock (1989) has observed that changes in average air and sea-surface temperatures, and in global mean sea level, are consistent with the predicted changes. However, it can still be argued that recent variability in weather and climate, though strong, is just part of a cycle of natural variability.

Nevertheless, the best current consensus appears to be that temperatures would rise by 1.5-4.5°C within the next 50 to 100 years, with smaller increases in the tropics and larger increases at high altitudes (WRI, 1990). While there is uncertainty about the magnitude, timing and geographic distribution of climate change, and the prospective shift in temperatures may seem small, it is nearly comparable to the change between the extreme climate of the last ice age, 18,000 years ago, and today's climate (Schneider, 1988).

Consequently, the magnitude, seasonal and spatial distribution of temperature, precipitation and evaporation could be substantially altered. An increase in sea level is also predicted due to the expansion of the oceans that would occur with an increase in global temperatures.

Askew (1987) comments that while changes in mean values are important, increased or decreased dispersion and/or probabilities of extreme values are likely to be far more critical. A modest increase in variability could throw doubt on the viability of certain rain-fed crops or run-of-the-river hydropower schemes. Major reservoirs could be left empty or threatened by floods which are greater than those for which their spillways were designed. The security of supply of many systems will be reduced.

Furthermore, the time taken to plan and construct large-scale water resource systems is of the same order of magnitude as the time over which significant greenhouse-

induced climate changes are expected to occur. Thus, while detailed investigation of the regional impact of the Greenhouse Effect is subject to many uncertainties, it is prudent to anticipate its possible consequences now because of the long lead times required to plan for its amelioration (Nathan *et al*, 1989). Present climate change scenarios can therefore be useful as a basis for sensitivity studies to identify the potentially important practical effects of climate change, and to set in motion preliminary thinking and planning in how to cope with those effects which cannot be avoided.

The particularly arid nature of Australia and the tremendous variability in its climate provides a range of unique characteristics, problems and opportunities.

5.4. Water Management in Australia: Problems & Possibilities

Australia is the driest inhabited continent on earth. Not only does Australia have the lowest precipitation and runoff in proportion to its area, but also the lowest percentage of runoff to rainfall. Average runoff for the continent as a whole is only 57 mm, and less than 5 percent of Australia exceeds 250 mm (AWRC, 1976).

In terms of per capita runoff, however, Australia is well endowed with water compared with other countries (ESDWGC, 1992). The average figures used to describe Australia's water resources are misleading though, because of marked irregularities in space and time of the availability of water. When median annual rainfalls are examined, it can be seen that over two thirds of Australia can be classified as desert, or at least semi-arid. Apart from the northern and southern extremities of the continent, rainfall deficiency is a frequently recurring hazard. This is related to Australia's latitudinal position, as well as its shape and general lack of topographical relief.

A further distinguishing feature of the precipitation pattern is its unpredictability and unreliability. The seasonal distribution of rainfall varies greatly over the continent with the most obvious feature being a clearly defined summer maximum in the monsoon region of northern Australia and a marked winter maximum in the south-west and south-east. Australia is also subject to adverse climatic conditions and prolonged droughts, that are now being linked to the global climatic phenomenon known as the El Niño-South Oscillation (Piechota *et al*, 1997). This temporal and spatial variability of rainfall results in a variable streamflow, and is a major factor in the need for large regulatory works, and poses problems for their design and operation. Ratios for annual variations in maximum and minimum flows range from 300:1 to 1,000:1 for Australian rivers, compared with a range from 3:1 to 10:1 for most European rivers and 3:1 to 5:1 for North American rivers (Perrens, 1982).

Surface water sources meet around 76 percent of Australia's total consumptive water requirements, the rest being supplied by groundwater. The major proportion of water used is for agricultural purposes (77%); Australia has one of the highest ratios of irrigated land per capita in the world (WRI, 1990). Domestic, industrial and commercial applications consume the remaining 23 percent (AWRC, 1987a).

Groundwater is widespread in Australia and major sedimentary basins extend under 60 percent of the continent. Historically, the availability of groundwater facilitated the spread of settlement inland. Even today, over much of the arid interior, it is a more important resource than the sparse and unreliable surface water, and is less susceptible to evaporation.

The Great Artesian Basin is Australia's most expansive groundwater resource, extending from the mid-north of South Australia to the east coast to the top of the Gulf of Carpentaria in Queensland (Figure 5.4). The basin underlies 22 percent of the continent and its deep sandstone aquifers provide the only reliable and continuous supply of water for stock and domestic purposes for much of the arid zone (Pigram, 1986). This resource has developed over hundreds of thousands of years, but is now being depleted due to uncontrolled extraction from bores. About 20 percent of the bores in south-west Queensland have ceased to flow because of declining water pressure in the basin. A program of capping bores to conserve groundwater is under way, but will take years to complete (CSIRO, 1996).

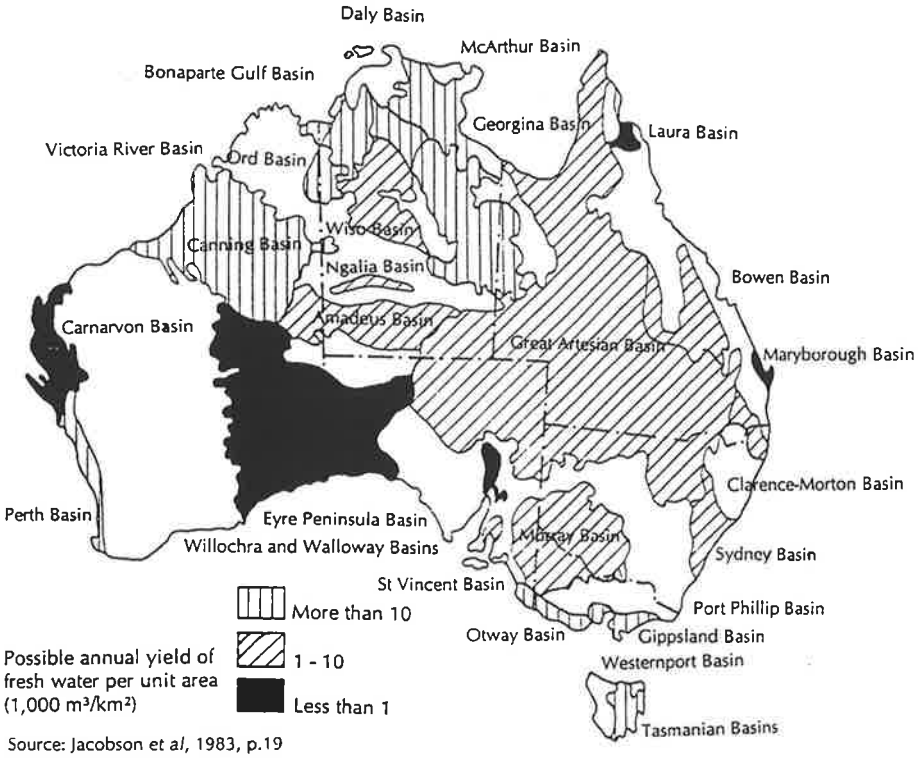


Figure 5.4
Groundwater Resource Potential of the Large Sedimentary Basins
(after Pigram, 1986)

Indeed, there has been a general decline in the availability and quality of Australia's water resources. Rivers, lakes, groundwater and flood plains have all been degraded as a result of major changes in their catchments, and regulation of river flows. These changes are a consequence of Australia's economic development over the past 200 years (AWRC, 1991), and threaten the country's future prosperity and

environmental quality. To improve the condition of the water resources requires fundamental changes to the current management philosophies, and adoption of the principles of sustainable development.

While communities in the arid regions of Australia have for many years recognised the importance and value of conserving their water resources, most town and city dwellers have taken the provision of potable water for granted, with unfortunate consequences. An alternative approach to the management of water and wastewaters could ensure that many Australian towns and cities would rarely face water shortages. Selection and use of water of a quality suited to the intended application, coupled with the treatment and reuse of wastewaters, has the potential to significantly reduce demand for potable mains water, with many flow-on benefits.

Clark & Desmier (1991) undertook preliminary investigations into the feasibility of a small scale, localised and integrated approach to the provision of water services in Adelaide. Roof runoff, stormwater and recycled sewage effluent were the sources of supply. It was found that this alternative approach to water supply, which was far less dependent upon mains supply, could provide a significantly less saline water supply, would largely overcome marine pollution problems, would reduce drainage and flood damage costs, and potentially provide an extensive range of additional marketable benefits. These benefits have also been recognised by practitioners including Fisher & Clark (1989), Clark (1990), McIntosh & Pugh (1991), Schrale *et al* (1991), EWS (1992a), Newman & Mouritz (1992; 1996), Pavelic *et al* (1992), CEPA (1993), Hopkins & Argue (1993), and Thwaites (1997). The potential of integrated urban water management has since been demonstrated through modelling and design studies (Thomas *et al*, 1994; Law, 1996; Mitchell *et al*, 1997; Fleming & Daniell, 1997).

However, Australian organisational structures and institutional attitudes to managing land and water resources have tended to prevent the adoption of such an integrated approach. Water authorities have traditionally been concerned with the provision and development of resources for supply. This focus has changed little, even in the current era of greater environmental awareness, largely due to the corporatisation of water authorities, and the separation of responsibilities for water supply and resource management.

While water availability and management remains important, the issue of water quality is also attracting increasing interest. The (mis)management of water resources over the past 200 years has failed to maintain the quality of water sources; how long it will take to restore their quality to an acceptable standard is unknown. In 1991, Cullen identified three reasons why successful water quality management had not been achieved in Australia:

- there had been no successful attempt to establish and implement national water quality guidelines;
- interventions attempting to improve water quality were unsuccessful because of a lack of understanding of how natural systems respond to various actions; and
- there was uncritical acceptance of proposed solutions where the problem was never fully understood.

Fortunately, these conditions are changing. A range of initiatives are providing new guidance on the management of water resources for water quality improvement and maintenance, as well as the productive reuse of wastewaters.

Commonwealth, state and territory governments have made good progress in the development of a National Water Quality Management Strategy (NWQMS), a part of the national program for ecologically sustainable development (ESD). The aim is to deliver a nationally consistent approach to water quality management 'to achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development' (AWRC, 1992i).

The NWQMS provides the basis upon which the States can establish water quality planning and environmental policy tools to achieve the desired goals. The strategy addresses issues of policies and process, provides water quality benchmarks as well as guidelines for diffuse and point sources. A mix of regulatory and market based approaches are proposed to ensure preservation of water quality and the prudent disposal of wastes. Numerous detailed documents have been released for public comment which discuss topics such as drinking water quality; sewerage systems and industrial wastes; groundwater protection; rural water quality management; reuse of reclaimed water; and provide details of basic strategic requirements, resource management principles, and proposed acceptance criteria (AWRC, 1992a–1992i).

A cornerstone of the NWQMS is the *Australian Water Quality Guidelines for Fresh and Marine Waters* (ANZECC, 1992). This document describes the quality of raw water sources required for protection of aquatic ecosystems, or for different passive, active and productive uses. The condition of a particular water resource is assessed by measuring a set of water quality indicators and comparing these with the criteria established to protect a certain designated environmental value. The criteria are currently being reviewed, with the release of a working document planned for late 1997 (Davis, 1997).

Hart (1991) predicted that management of inland waterways and coastal marine waters would increasingly take on an ecologically based focus. Fulfilling the prediction, the revised ANZECC guidelines will expand the concept of biological indicators, address sediment quality and add aquaculture as an environmental value. Major changes are also being made to the ecosystem, agriculture and salinity sections of the document.

In recent years, environmental agencies have also attempted to introduce indicators that better reflect the biological condition of the river or stream. In conjunction with details on the physical and chemical conditions of the riparian zone, the biological indicators enable a description of the 'health' of a watercourse. Since the early 1990s, the Victorian EPA has taken surveys of macro-invertebrate communities as an indicator of the biological condition of that state's streams. A national program of biological stream surveys, the National River Health Program, was initiated by the Federal Government in 1992 and continues, but under the new name of the Australian River Health Assessment Scheme (AUSRIVAS). This work will result in more than 2,000 sites being surveyed, and constitutes the first assessment of river health to be conducted at a continental scale anywhere in the world (Markwort, 1997; Goonan, 1997). Measures of river health are now emerging as instruments,

along with hydrological and water quality parameters, for the establishment of water resource management and allocation plans (Burgess & Thoms, 1997; Deen & Ragavan, 1997; Pyle, 1997).

The Federal Government has also initiated and supported research and development activities, in collaboration with CSIRO and industry, through the establishment of the Cooperative Research Centres (CRC). The CRC for Catchment Hydrology, and CRC for Freshwater Ecology, have their primary focus upon the management and restoration of Australia's water sources.

It can be said that these initiatives are in broad recognition of the poor condition of Australia's water resources, both in quality and quantity, and the dire necessity for their restoration. The following sections further examine the nature of the water resource problems, and identifies potential solutions.

5.4.1. Impacts of Agriculture on Water Resources

The hydrological impact of agricultural developments on water resources has been profound (AWRC, 1991). Water balances have been altered: water yields, flood flows and groundwater recharge have all been increased.

Poor cropping and stock grazing practices, and the excessive use of fertilisers and chemicals on crops, has caused pollution of streams and water courses. Productive topsoil is eroded, and the turbidity of streams is increased, as is the oxygen demand and nutrient load. The result is the death of fish and other organisms and the cultivation of nuisance algae (which are harmful to humans and animals).

Furthermore, aquatic plants and animals in Australia are adapted to irregular flows. Yet the transformation of many rivers from intermittent to permanent flows by the construction of weirs and dams has altered their indigenous habitat and resulted in the death of plants and animals.

Table 5.3
Salt Damaged Areas of South Australia (Turner, 1993)

Region	Hectares	Percentage
Eyre Peninsula	60,000	17.0
York Peninsula	10,000	2.8
Kangaroo Island	8,000	2.3
Northern Agricultural	8,000	2.3
Murray Mallee and Plains	16,000	4.5
South East	250,000	70.6
Mt. Lofty Ranges	2,500	0.7
Total	354,000	100.0

Salinisation as a result of land clearing and irrigation practices has emerged as the most pressing problem of land and water resource management in Australia

(Jacobson & Lau, 1989). Removal of native vegetation and replacement with shallow rooted annual vegetation has resulted in decreased interception and evapotranspiration, increased infiltration to groundwater and a gradual rise in the water table (NCWE, 1991). As saline water tables approach the surface and invade the root zone, salt intolerant species die and soil erosion increases. The soil is bared and ceases to support plant life. It has been shown that over 350,000 hectares of South Australian agricultural land has been severely damaged by salinity (Table 5.3), and it was estimated that this cost the state $50 million per year.

Within the Murray-Darling Basin the salinity of river water has been steadily increasing, and it is recognised that stream salinities will continue to increase for several decades. Much of the southern portion of the Murray-Darling Basin is affected by land salinisation, with water of high salinity being returned through irrigation drainage and as a result of enhanced groundwater flows. Jolly *et al* (1997) report that the eastern portion of the Basin now appears to be under threat of the same effects of dryland salinity.

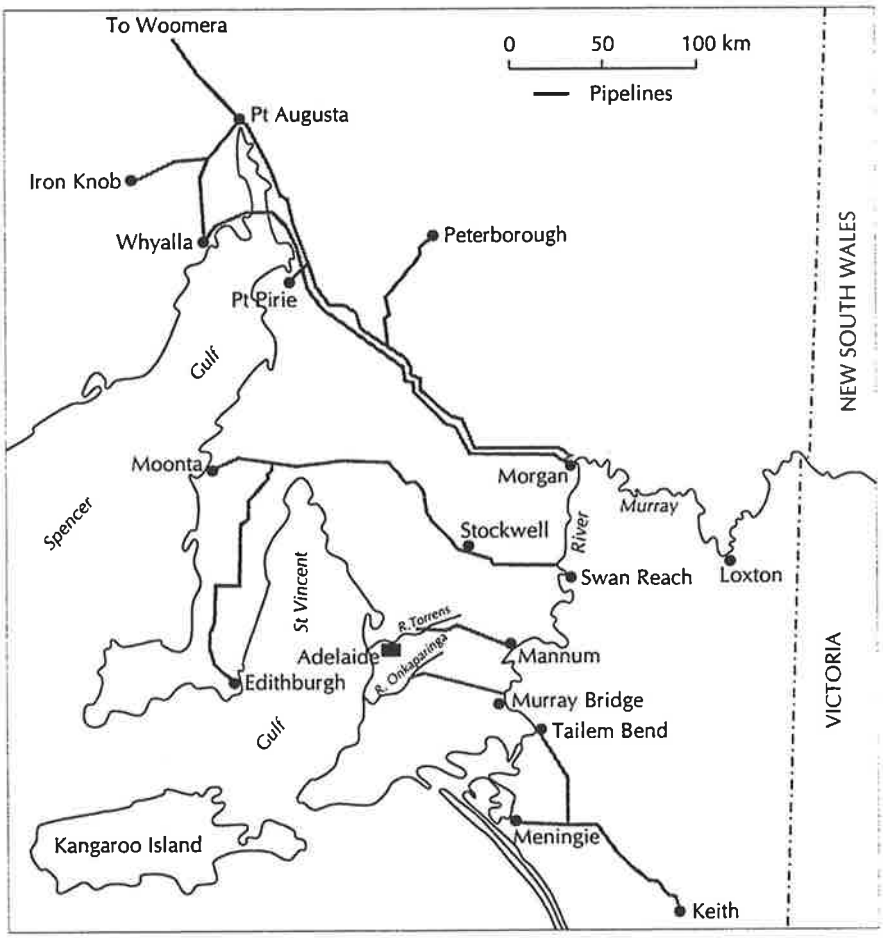


Figure 5.5
Cities and Towns Served by River Murray Water (after EWS, 1991a)

Maier & Dandy (1993) have undertaken research into the affects of salinity to aid the prediction of River Murray salinities and to establish schedules for pumping water to

Adelaide. Increased salinity of the domestic water supply affects palatability; increases the hardness of the water, thereby requiring the use of more soaps and detergents; and causes scaling and corrosion of pipes, fittings and water heaters. Saline water used for industrial purposes causes corrosion, scaling and poor steam quality, resulting in increased energy and chemical treatment costs. Many of the agricultural consumers along the River and pipelines (refer to Figure 5.5) are potentially affected by the reduced permeability of clay soils, reduced crop yields and a limited choice of crops that can be grown, which could ultimately lead to the dislocation of farming communities. Saline water can also kill native vegetation, resulting in the loss of habitat and biodiversity. The EWS (1991b) previously estimated that the total cost to domestic, industrial and agricultural users was A$82,000 per year for every EC unit of change in average annual salinity at Morgan on the River Murray. This work is currently under review (Wellington, 1997) and will incorporate costs to the environmental and agricultural water users, in addition to industrial and domestic impacts.

5.4.2. Impacts of Urbanisation on Water Resources

While the adverse impacts of agricultural activities upon water sources and natural systems has been significant, McPherson (1974) considers that the affects of urbanisation upon the hydrological cycle are more serious than any other of man's activities. Some of the hydrological affects of urbanisation due to population increase include:

- Rising demands for water which often exceed the available resources in the area of urbanisation. During an average year, the Mount Lofty Ranges catchments supply only 60 percent of the annual water requirements of metropolitan Adelaide, which is typically 185,000 ML (refer to Figure 5.6). However, in dry years up to 90 percent of Adelaide's water requirements are provided by pumping from the River Murray (EWS, 1989a; DENR, 1995).

- An increasing burden upon lakes and rivers and their ecology to accept waste waters. A number of Adelaide's urban water courses and lakes, such as the Patawalonga, Torrens Lake and West Lakes, have been degraded by the pollutants and rubbish contained in urban storm runoff.

- An increase in the peak rate of storm runoff, and a reduction in the time of concentration of runoff. Numerous investigations into urban hydrology and storm runoff have been conducted in Australia, and all have found that (i) the urban catchment has an almost continual baseflow, contrasting with virtual absence of baseflow on a rural catchment, (ii) average runoff from an urban catchment is many times greater than from the natural catchment, (iii) the runoff attenuation affect is much lower than that of the rural catchment, and (iv) the urban flood magnitude is much greater (Cordery, 1976; Laurenson *et al*, 1985; Boughton, 1986; Mein & Goyen, 1988). Figure 5.7 shows the effects of urbanisation on flood timing and magnitude, by comparison of storm runoff from adjacent rural and urban catchments in the Australian Capital Territory.

- Although there is normally a reduction in infiltration into the soil due to an increase in impervious area, and subsequently recharge to natural groundwater decreases, the baseflow in streams has been observed to increase. This is due to leaks from water mains and irrigation runoff using imported water (Boughton, 1986).

- Lowering of the water table due to extensive groundwater withdrawal, affecting agriculture; causing land subsidence; and potentially diminishing the base flows of streams.

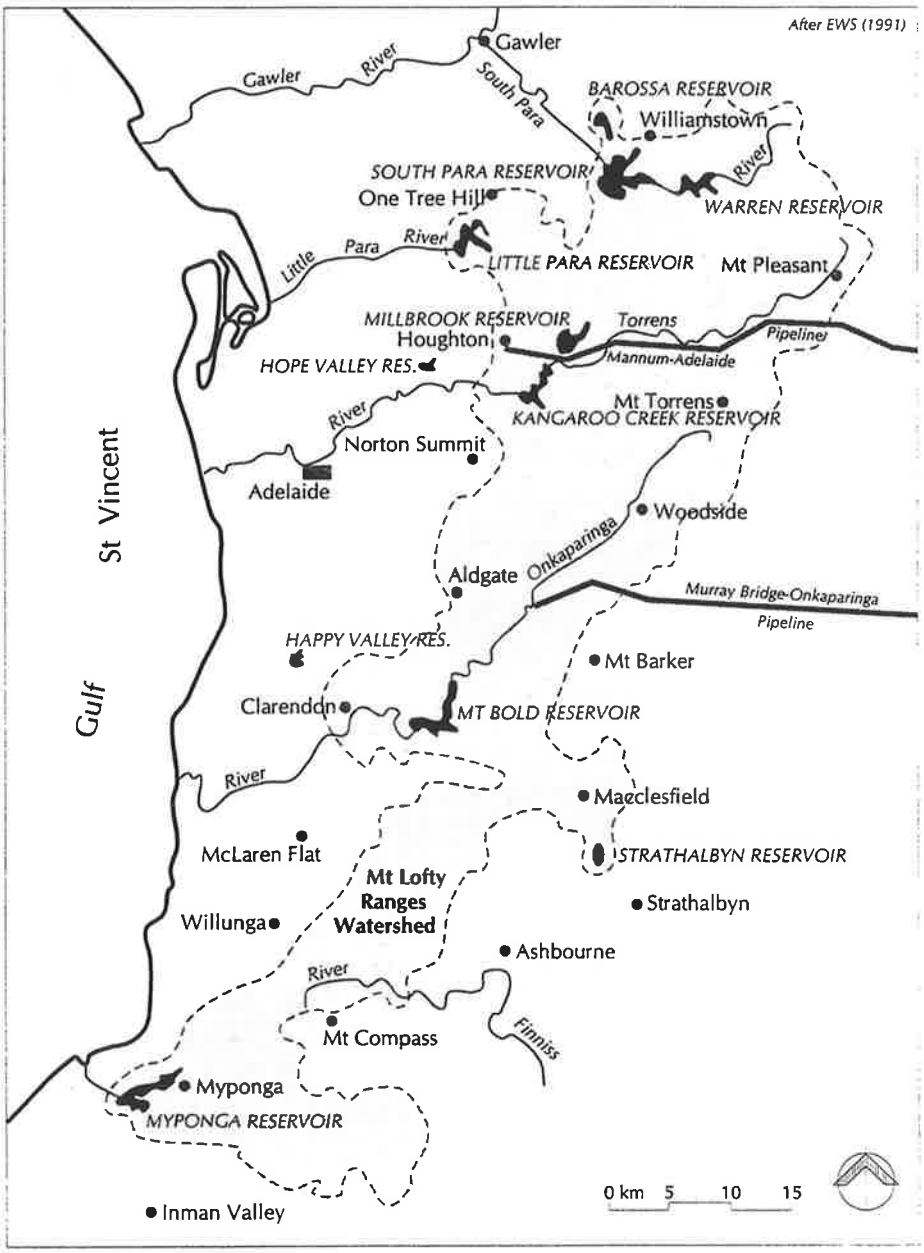


Figure 5.6
Water Supplies for Adelaide – the Mount Lofty Ranges Watershed and Water from the River Murray (after EWS, 1992b)

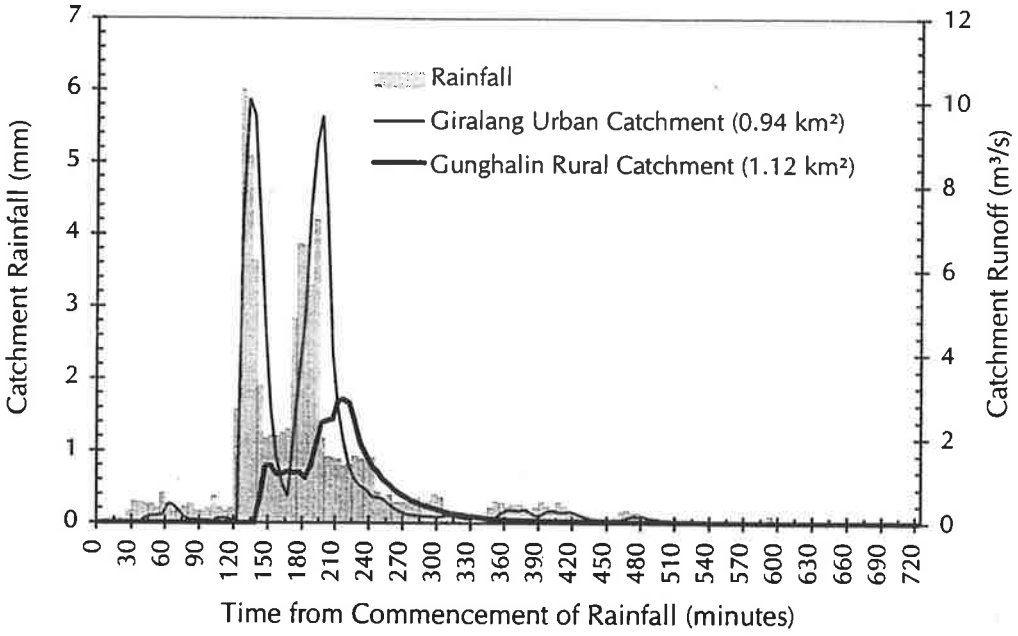


Figure 5.7
Runoff Hydrographs for the Adjacent Giralang and Gunghalin Catchments Resulting from the Same Total Rainfall, 5 February 1981

Runoff from urban catchments often highly degrades the receiving waters because of the pollutants it carries. The higher flood flows wash off and transport many times more solid materials into receiving waters. Faster flows are more likely to scour and erode the bed of natural channels. Increased flows also transport many more contaminants (such as nutrients, oxygen-demanding materials, micro-organisms, toxic organics, toxic trace metals, oils and pesticides). These wastes and chemicals originate as fertilisers and sprays used on gardens and as heavy metals, oils and litter from roads or rubbish dumped illegally into stormwater drains. They then accumulate by deposition in the receiving water body. Pollution of water bodies is also associated with point discharges of effluent from manufacturing enterprises and energy generation.

Stormwater and sewage effluent are suspected to have contributed to a decline in sea-grasses and marine ecosystems in the Gulf St. Vincent, which in turn, may be associated with adverse impacts on fisheries, nuisance seaweed, algal blooms, bacterial contamination of water and shellfish, and coastal erosion (EWS, 1989b; 1990; DA Lord & Assoc., 1996). In addition, the recreational amenity of beaches, creeks and waterbodies has been affected.

5.4.3. Climate Change in Australia

Australia's great diversity of environments, extensive coastline and location of urban centres makes it particularly vulnerable to the impacts of climate change. It has been postulated that an increase in severe storms, floods and droughts could occur. Urban flood magnitudes have been predicted to increase with summer rainfall, and in coastal districts, will be exacerbated by sea level rise. The changes can also be

expected to bring significant variation in water supply and demand. Biodiversity, agricultural industries, general industry and social infrastructure, as well as human health are also at direct risk. Indirect effects could include an increase in the range and spread of tropical diseases and pests (ICESD, 1997).

The anticipated climatic and hydrological changes are described further below.

5.4.3.1. Temperature

It is predicted that there will be a southerly shift in weather systems in response to a build-up in greenhouse gases. Therefore, regions presently characterised by temperature or Mediterranean climates will experience more tropical activity and an increase in mean temperature.

The CSIRO Division of Atmospheric Research (1989) states that a rise of 2-3°C in the annual mean temperature is likely to occur before 2030 AD. The greatest warming would occur in the south and in winter, and least warming in the north. Some regional variations in this picture can be expected due to change in cloudiness and air-sea temperature differences.

5.4.3.2. Rainfall

Tropical depressions penetrating further south are expected to increase summer rainfall by 20-30 percent (even up to 50 percent). Mid latitude low pressure systems will adopt a more southerly track, thus as a consequence winter rainfall may be reduced by around 20 percent (Rolls, 1989a; CSIRO, 1989; Pittock, 1989).

Increases in rainfall and its variability can have many effects on the flow and transport of water through the hydrological cycle. The predicted climate change and consequent changes in precipitation could result in an increase in stream flow, urban runoff, flooding, channel erosion, fluvial sediment transport, reservoir siltation, recharge to aquifers, rise in water table levels, water-logging and salinisation.

5.4.3.3. Sea Level

An increase in sea level of 200-1,400 mm over the next 50 years has been forecast, although this has been the subject of much debate (Rolls, 1989a; CSIRO, 1989). A likely scenario for South Australia is an increase of 120-400 mm (in addition to any measured local tendency due to land subsidence).

The direct effects of marine inundation from a rising sea-level will be limited, certainly within a time span of 30-50 years. However, most researchers agree that climatic change will lead to an increased frequency and intensity of storm surges which would produce the major impacts along the coastline.

5.4.3.4. Catchment Yield

In the southern regions of Australia, where most rainfall occurs during winter months, catchment yield may be expected to decrease. Traditional water sources would be threatened, extreme flood events could become more severe, and

adaptability would be required if some environmentally sensitive water dependent ecosystems are to survive (McIntosh & Fisher, 1989).

Relatively small changes in rainfall can markedly affect what can be harvested on a sustainable basis. Soil moisture, water runoff available for urban and rural water supplies, river flow and flooding arise from an often delicate balance between rainfall and evaporation.

Streamflow is a relatively small fraction of total rainfall; if rainfall increases in summer when temperatures are high there may be no increase in streamflow or groundwater storage, unless the increased rainfall is very intense (Rolls, 1989a). Wind speeds might be expected to be slightly reduced, due to the reduced north-south differences in temperature, but higher temperatures may still lead to a general increase in evaporation (Pittock, 1989). Therefore, reduced rainfall on drier catchments, with increased evaporation may actually reduce catchment yield.

A preliminary assessment of the Onkaparinga catchment in the Adelaide Hills revealed that a reduction in yield of 40 percent is possible; Adelaide derives 60 percent of its water from this catchment (Rolls, 1989a). Therefore, as the volume available from catchments and groundwater basins fed from local rainfall would fall, metropolitan Adelaide and other regional centres may become far more reliant upon the River Murray as a source of supply. Fortunately, the River Murray should become an even more reliable water resource for South Australia (Rolls, 1989a), but with a higher cost to the public due to increased pumping.

Analysis of rainfall records for the Murray River basin and its tributaries (from 1913) indicated a substantial increase in rainfall, corresponding with global climate models for this area. Estimates of increased river flow of 25 percent indicate that Adelaide will not suffer a loss of reliability of water supply. Projection of existing rainfall and streamflow trends, which are analogous to those predicted by global climatic models, suggests that the flow to South Australia will increase, and that salinity would decrease (Rolls, 1989b).

5.4.4. Discussion

Water authorities have succeeded in developing hydraulically efficient water reticulation and wastewater treatment and disposal systems to urban centres. The demands for irrigation water from a large agricultural industry have also been met through the construction of dams and diversion systems. However, past methods of meeting supply requirements and treating wastes has caused widespread harm to the water sources and natural environment.

Since water and land are basic components of the hydrological cycle, and very much determinants of a region's development potential, their conjunctive use and management requires greater consideration in planning. The quality of water is determined by its treatment and use within its catchment area. Therefore, integrated water management and land use practices are extremely important to the effective utilisation of these natural resources.

Increasing populations, ageing infrastructure and general financial burdens combine with environmental problems to necessitate a review of traditional water management practices. The position may soon be reached where increased investment in technological innovation based upon existing basic processes provides diminishing returns. A more promising direction for the attainment of cost effective and environmentally superior wastewater management may come from alternative or totally new configurations of wastewater handling systems.

In addition, the effects of climate change could be severe because of the uniqueness of the Australian hydrology and the extreme sensitivity of natural and farming ecosystems to change. Additional buffering storage will be required to maintain the reliability of surface reservoirs, while water and land management practices will be needed to conserve the quality and quantity of water even if only the most conservative greenhouse predictions are realised. For these reasons, Jakeman (1990) considers that water resources planning must be dynamic in general, flexible and responsive, ingenious and information sensitive in particular.

An alternative approach might involve the replacement of 'conveyance' systems with smaller scale water resource management systems that are integrated into local communities.

These issues were identified by the Ecologically Sustainable Development (ESD) Working Groups in the draft ESD Intersectoral Issues Report (Mouritz & Newman, 1991):

> *The water industry in common with its overseas counterparts, has identified our degrading water supply and sewerage treatment infrastructure as a major issue over the coming decades, both in urban and irrigated areas. This is likely to represent a multibillion dollar investment. The current mix of investment (85 percent for the distribution network and 15 percent for treatment) may not be the most appropriate, nor the most efficient and effective means of meeting demands.*

With increasing deregulation of the provision of water supply and sewerage infrastructure and moves toward greater 'pay for use', Clark & Desmier (1991) envisage a situation where the role of the public service will be to establish and steer imaginative strategies, policies and regulations, and private enterprise is responsible for providing the water services. The present monolithic systems would be broken up and replaced with lower cost components which provide a wider array of customer services, with the assets transferred to private ownership. There would also be matching of the quality of water demanded to the local availability of water sources. Furthermore, Clark (1990) notes that the cost bulge in the replacement schedule for South Australian water and sewerage assets expected in the early part of the next century will coincide with the opportunity to provide a fundamental review of the performance of the existing systems against revised criteria.

Such reviews of water management strategies have commenced in Australia. Numerous studies have been discussed and are presented in Chapter 8, which examine the potential for reuse of sewage effluent and the harvesting and reuse of urban stormwater.

The problems of infrastructure management and the need to repair or replace assets should be seen as an opportunity rather than a problem – an opportunity to restructure the water industry and eliminate unsustainable water management practices. To make this transition successful will also require changes in land planning strategies and community attitudes, and the adoption of 'appropriate' technologies.

The challenge for the next century in terms of the provision of urban water services will therefore be to introduce innovative water technologies, management systems and institutional arrangements which are able to meet simultaneously, the multiple objectives of equity, environmental integrity and economic efficiency, while maintaining a high level of water services for urban dwellers (Newman & Mouritz, 1992).

5.5. Ecologically Sustainable Development and Water Management

Traditional practices in water management have yielded many environmental and economic problems. To improve and maintain the quality, availability and ecological value of Australia's water resources will necessarily involve a change in attitudes to land and water management.

Careful thought is necessary to identify a course for change that might deliver the most beneficial and sustainable outcomes. The entire range of important technical and social issues should be addressed, rather than focussing upon one issue in isolation from all others. For example, might the exclusive promotion of efficient water management require the unsustainable use of other resources? If so, would the resulting unsustainable resource consumption be an acceptable sacrifice? For example, would a new interbasin transfer of water by pipeline, and the resulting demand for energy for pumping, be unsustainable? Or, is the depletion of groundwater resources acceptable, on the presumption that cheap and clean technologies will be available in the future for sea-water desalination? A broader perspective is therefore required for the issues of sustainability and resource management.

Unfortunately, the policy objective outlined by the Australia and New Zealand Environment and Conservation Council, and the Australian Water Resources Council (AWRC, 1992f) does not explicitly recognise the broader resource management requirement. The stated policy aim is:

> *... to achieve sustainable use of the nation's water resources by protecting and enhancing their quality, while maintaining economic and social development.*

To determine the key issues for holistic management of water resources, it is useful then to examine the goals of ecologically sustainable development, the problems currently facing the water industry, and the needs and desires of the community in terms of the management of their water resources. These three subjects are outlined in Tables 5.6, 5.7 and 5.8, respectively.

A more appropriate aim for water resource management is considered to be:

... to provide water services in a manner that ensures the social, environmental and financial needs of present and future communities are met equitably, guided by a development process which integrates management of all resources and ecosystems.

Table 5.4
Characteristics of Sustainable Development, Common to All Major Interpretations
(after Sadler *et al*, 1991)

Objectives of sustainable development:

- providing for inter-generational equity in use of resources;
- providing for socio-economic growth which will, however, be less material and more sensitive to the environment;
- conserving the environmental resource base, with particular emphasis on maintaining the diversity/robustness of ecological systems; and
- maintaining the vital life supporting roles of the key elements of air, soil and water.

Key issues identified in most interpretations of sustainable development are:

- merging economics and environment in decision making to ensure environmental and economic sustainability;
- recognising the global, national and regional dimension of resource systems;
- enhancing intersectoral co-operation and achieving appropriate institutional change;
- being cautious with risk and irreversibility; and
- re-orienting technology to be more attentive and innovative in regard to the environment.

With this aim in mind, it is clear that current approaches to urban and rural land development must be modified, with ongoing review and adaptation of methods as new knowledge becomes available.

A basic goal should be the preservation and maintenance of unaffected natural water-bodies, and the restoration to a productive state of those that have been degraded (where this is possible). Water resources should not be used over a prolonged period at a rate that exceeds the sustainable yield, especially in the case of groundwater resources. Any development aimed at increasing the yield of catchments (e.g. dams and reservoirs) or increase of supply (e.g. interbasin transfer via pipelines, seawater desalination) should be implemented in a manner which prevents significant environmental impacts, or loss of important habitat or biological diversity.

There are an array of initiatives which, in combination, could lead to the achievement of these goals and sustainability of water use. Some are being investigated, trialed or have been adopted for use in Australia, and include:

- recovering, recycling and reuse of wastewaters and effluents;
- treatment of wastewaters for disposal to a standard within the assimilative capacity of the receiving water body;
- rehabilitation of degraded waterways and the associated catchment environment;
- establishment of consistent national guidelines on water quality;
- application of 'appropriate' and 'clean' technology;

- development of a better understanding of the functioning of ecosystems;
- adoption of demand management and conservation strategies;
- true valuation of the water resource;
- revision of the roles of government and private enterprise in the provision of water supply and wastewater treatment services; and
- legislative reforms to protect the environment.

Perhaps most importantly of all, what is required is:

- integrated land use planning;
- education of the community about sustainable water use practices; and
- community participation in decision making and policy implementation.

Environmental issues, and water issues in particular, should not be considered in isolation. To be properly appreciated they must be viewed in as broad a context as possible. This means that water must be examined not only in its role as essential to all life systems on the plant Earth, but also in its role as indispensable to most human activity and thus to socio-economic development. A holistic approach to management of resources and to development issues is regarded as essential (Young *et al*, 1994).

In addition, the support and commitment of the community is essential, because significant results will only be achieved in the long term, and will be expensive.

Table 5.5
Traditional Community Expectations in Provision of Water Services

Services that water agencies are currently required to provide are:

- clean water to cities, for industrial, commercial, domestic and recreational applications,
- water for environmental, irrigation, hydroelectric and navigational uses,
- sewerage and drainage services for waste control,
- minimisation of the impacts of droughts and floods;

while always addressing issues of:

- health and safety,
- preservation of natural ecosystems,
- preservation of aspects of scientific and cultural significance,
- provision of information on supply, quality and quantity issues, and
- community involvement in decision making processes.

Table 5.6
Current Water Resource Management Problems

Impacts of urbanisation
- Degradation of streams and water bodies due to polluted stormwater
- Pollution of receiving water bodies by domestic and industrial wastewaters
- Increased storm runoff and flooding due to changed catchment land use
- Changing of estuarine environments, flow regimes and ecology
- Decrease in groundwater levels

Impacts of rural land use practices
- Increased flood flows
- Raising of water table through excessive irrigation
- Increased groundwater salinity
- Soil and channel erosion
- Siltation of water courses and reservoirs
- Pollution of water bodies by fertiliser nutrients and agricultural chemicals
- Destruction of natural drainage paths

Sewage Treatment and Disposal
- Increasing population placing stress upon existing facilities
- Pollution of marine and estuarine environments from discharge of nutrient and heavy metal rich effluents
- Decline in sea grasses and marine ecosystems, impacting on fisheries and coastal erosion
- Environmental concerns relating to existing treatment technologies
- Pollution of groundwaters from land disposal of effluent and sludges
- High costs of sewage treatment, increasing with higher community expectations

Stormwater Management
- Adverse impact of polluted runoff (sediment, litter, chemicals, oils, nutrients, heavy metals etc.) on receiving water environments
- Development on flood plains
- Potential for injury or financial loss from flooding
- Reduced recreational amenity of creeks, rivers, beaches and other water bodies

Ageing Infrastructure
- Most accessible resources have been fully developed
- Need for water supply or sewerage system rehabilitation or replacement
- Water agency income insufficient to cover asset maintenance requirements
- Significant scope to improve operational efficiency

Groundwater Resources
- Extraction rates exceeding natural sustainable yield
- Increasing pumping costs from depleted aquifers
- Loss of natural wetlands with decline in water table levels
- Contamination by industrial and sewage effluent, and landfill leachate
- Coastal saline groundwater intrusion into freshwater aquifers
- Discharge of saline groundwater into streams

Water Quality Management
- Unsuccessful development and implementation of national guidelines
- Lack of understanding of natural water resource systems
- Uncritical acceptance of suggested solutions
- Required improved control of non-point source pollution
- Need to incorporate ecosystem protection as a 'beneficial use' in planning

5.5.1. Conservation and Demand Management

With increasing populations and often increasing per capita consumption, implementation of demand management and conservation strategies is essential. Successfully reducing the per capita consumption of water will provide significant cost savings in the provision of new water supply and sewerage facilities, as well as delaying the replacement of old infrastructure and new water development.

Government under-charging and cross-subsidisation (with other sources of income) for water and wastewater disposal has been a major contributor to many water related environmental problems. The establishment of an equitable pricing structure to charge the full cost of water service provision to consumers is seen to be a key component of future management strategies in Australia. The true value of water resources, while necessarily represented in economic terms, must also take into account their social and environmental value.

Transferable water entitlements (TWE) are another means of combining efficiency gains with more sustainable water use. TWEs are useful in mature water economies where few new water supply options are available and there is increasing competition for existing supplies. Each consumer (or property holder) may be entitled to an allocation of water, which can be bought or sold in the 'water market', without the necessity of buying and selling the land. Water will therefore tend to be used more for higher value purposes (WAWRC, 1989):

- increased allocation to higher value crops;
- decreased use on land which is poorly suited to irrigation; and
- increased adoption of water saving technologies (because saved water can be sold).

Transferable water entitlements ensure that available supplies are used in the way that maximises the benefits to the community, providing greater certainty to purchasers, and allowing formal water allocations for environmental purposes.

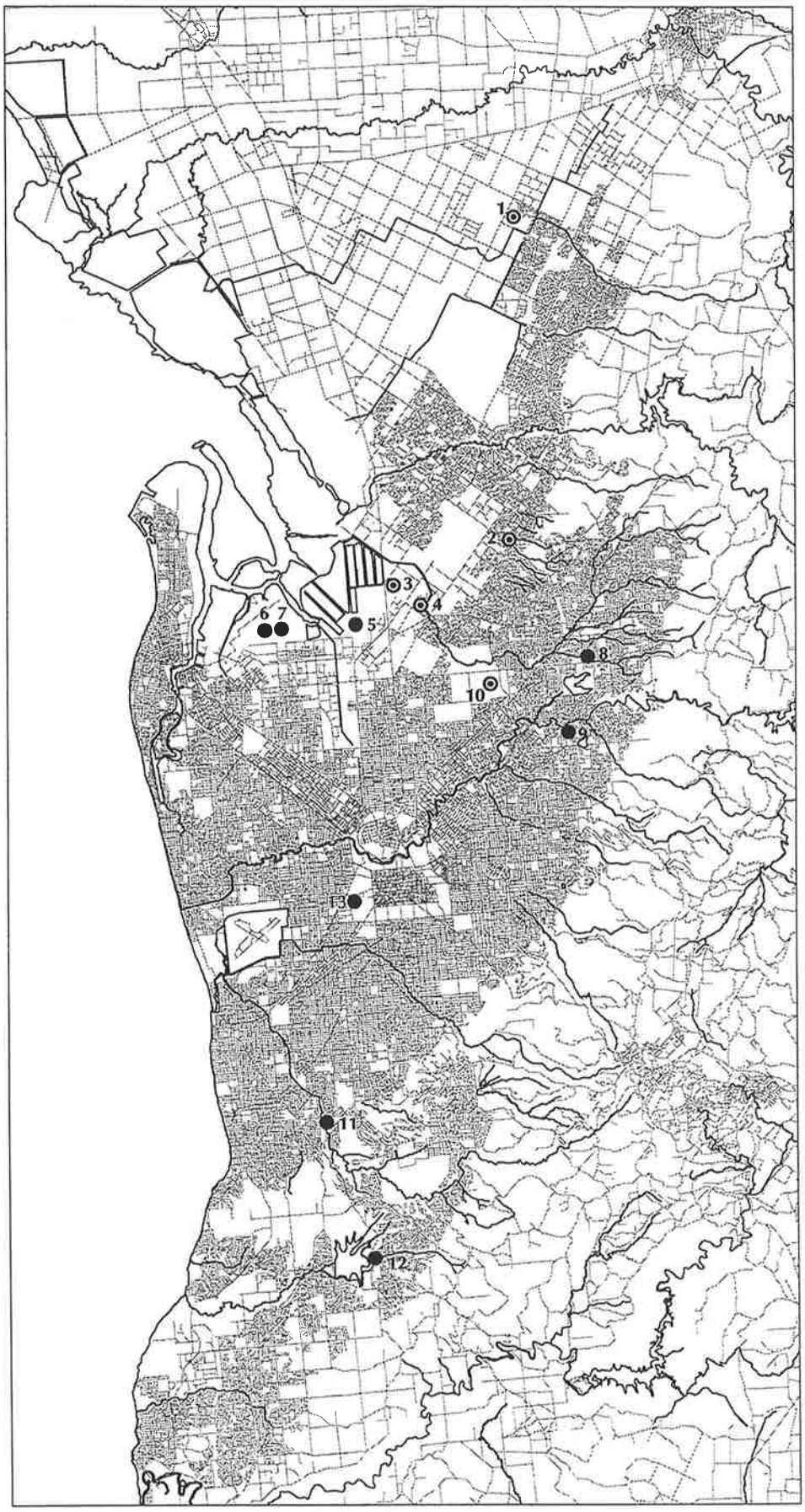
Adoption of the 'polluter-pays' and 'user-pays' principles in pricing water services, and the use of 'transferable water entitlements' should ensure a more conservative, economically and environmentally efficient allocation of available resources. The use of wastewater, treated to a quality fit for its intended purpose, can also substantially reduce potable water demand, with many flow-on benefits.

5.5.2. Wastewater Reuse for Environmental Protection

Wastewater recovery and reuse schemes can include the harvesting of stormwater, or the use of treated sewage effluent for irrigation of parks, golf courses and crops; establishment of urban lake and wetland systems, improving stormwater quality and urban amenity; use in industry as cooling water; domestic use for toilet flushing and garden watering; or even for potable uses with appropriate treatment. Sewage sludge can be a valuable fertiliser component, but could also be used in many varied applications such as compost or soil manufacture, fuel source in clay brick manufacture, or in fuel oil production (EWS, 1992a).

Wetland Names

1 Andrews Farm
2 The Paddocks
3 Greenfields
4 Mawson Lakes
5 Barker Inlet
6 Dean Wetlands
7 Rifle Range Wetlands
8 Tea Tree Gully
9 Dernancourt
10 Regent Gardens
11 Warriparinga
12 Minkara
13 West Park Lands



● *Constructed wetland* ⊙ *Wetland with Aquifer Storage and Recovery facilities*

Figure 5.8
Constructed Wetlands in Metropolitan Adelaide, South Australia

Where release of wastewaters to receiving water bodies must continue (such as treated sewage effluent, or industrial waste to sewers), the wastewater should be treated prior to discharge to a standard that is within the assimilative capacity of the receiving water environment. (The use of the assimilative capacity concept in water management requires caution, since ideas on the assimilative capacity of river systems are changing as more knowledge of the ecosystems is gained.)

Gross pollutant traps, sedimentation basins, detention ponds and wetlands can be introduced in stormwater systems to remove a large component of the pollution load, minimising the impact on the receiving watercourse. This will aid the rehabilitation of water bodies, allowing the native vegetation to re-establish and wildlife and aquatic species to multiply or be reintroduced.

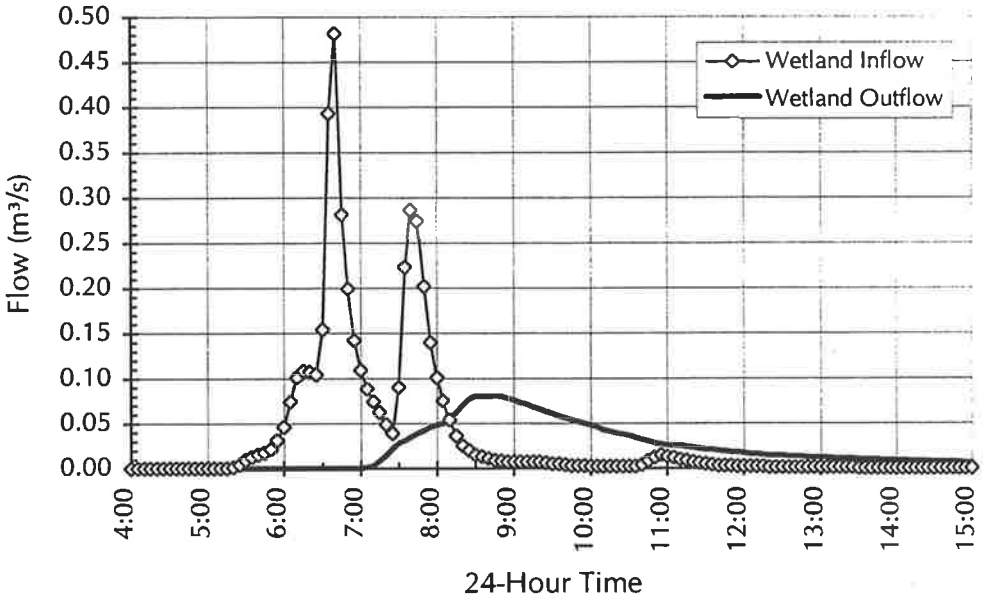
Figure 5.8 illustrates the distribution of wetlands in metropolitan Adelaide, which have been established to remove pollutants from urban stormwater. The Paddocks wetland has been monitored to examine the effectiveness of wetlands in removing suspended solids and other pollutants. Figure 5.9 demonstrates the suspended solids removal capabilities exhibited by this wetland.

5.5.3. Integrated Catchment Management

Catchments are naturally occurring units of landscape, which contain a complex array of inter-linked and interdependent resources and activities, irrespective of political or administrative boundaries. Irwin & Williams (1986) argue that the catchment is a logical planning unit, with readily identifiable boundaries and characteristic patterns of water movement, and is therefore ideally suited as the spatial unit for coordinated planning and management.

Integrated land use planning is essential to sustainable water use. Many of the factors adversely affecting water quality and the water environment occur as a result of activities and land uses which are outside the control of water authorities. Integrated catchment management is therefore broader than efficient water management that involves conservation, demand management and wastewater utilisation. It means the simultaneous and inter-related management of land, water vegetation and other physical resources within a catchment, to ensure minimal degradation and erosion of soils, minimal impact on water yield and quality, and on other features of the environment (after Cunningham, 1986).

An important component of any attempt to implement integrated catchment management is a detailed strategic plan for the catchment, river basin or defined bioregion. Young *et al* (1994) are unequivocal in their position on the matter, stating that the holistic management of water as a finite and vulnerable resource, and the integration of sectoral water plans and programmes within the framework of national economic and social policy, are of paramount importance for action in the 1990s and beyond.



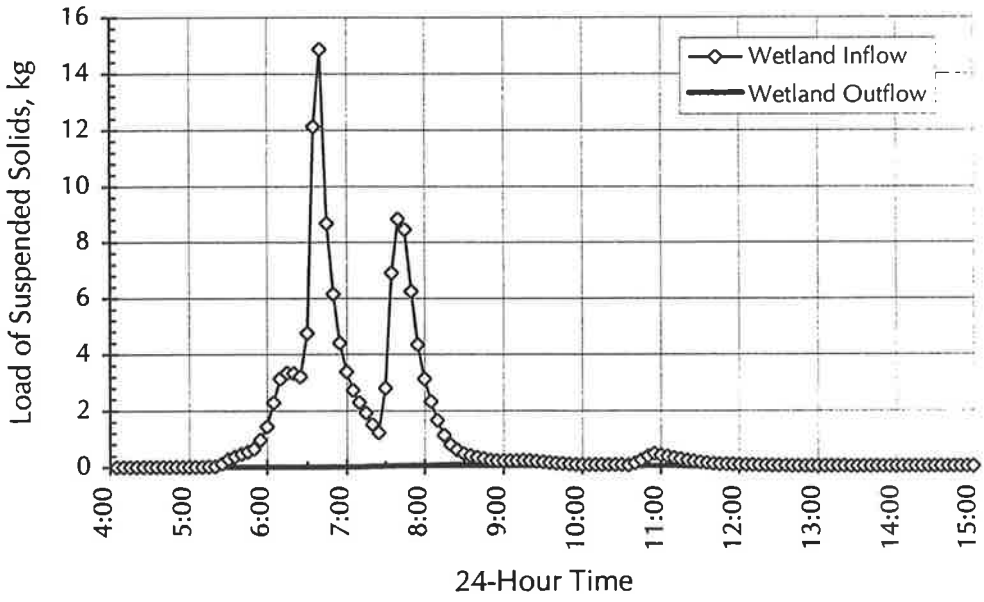


Figure 5.9
Removal of the Suspended Solids Load by The Paddocks Wetland

An integrated catchment management plan should be based upon detailed technical studies and strategic land use planning. It provides an holistic framework to direct and link projects undertaken at local level and by independent organisations. In doing so, all incremental actions can contribute to the achievement of the defined strategy. The South Australian *Water Management Action 1997* aims to facilitate this type of planning according to the principles of ecologically sustainable development (DENR, 1996). The Act provides for the formation of Catchment Water Management Boards, charged with the responsibility for water resource management, allocation and licensing (as required). While a very positive step has been made toward sustainable resource management, truly integrated land and water planning is yet to emerge in any mature form.

The support and involvement of local government, industry, and the broader community is vital to the successful realisation of these strategic plans. Leadership by government is critical, yet government agencies must also be educated to the needs of the environment and community. The process of sustainable development is as much a social and political issue, as one of technological development.

5.5.4. The Role of Government and Private Enterprise

The role of government in providing water supply, sewerage and drainage services will also need revision. The operation and maintenance functions of Australian water authorities have been largely transferred to the private sector, operating according to contracts with output-driven performance measures. The question of privatisation of the provision of water services has been particularly contentious. The economic rationalists argue, possibly quite correctly, that private enterprise can deliver water services in a manner that is more economically efficient. Yet ultimately, it is the effective management of catchments, rivers and other water-bodies, and the potential conflict of multiple objectives when managed by one authority, that should come into question.

Clark (1990) argues that greater emphasis on full cost recovery and economic efficiency, or privatisation of water agencies, can provide more rapid achievement of smaller, more responsive and efficient systems. However, such a move would require that stronger regulations were introduced to ensure that social and environmental objectives were achieved at the same time as corporate goals.

A model for the delivery of water services therefore involves government in the role of strategist and regulator, with private enterprise providing an economically efficient service to meet the defined objectives.

To develop appropriate strategies and legislation, the government must be served by skilled scientists, engineers, planners, solicitors and administrators. The trend in Australia, and many other countries, is toward a substantial reduction in the number of people in public employment, precisely at the time when informed leadership is required. In terms of hydrological and environmental conditions, Rodda (1992) argues that careful and ongoing monitoring is required, so that changes can be determined and trends identified in relation to baselines and thresholds. Yet he confirms that in recent years, most national hydrological and related services have

experienced cutbacks in funding, staff and training. As a result, the understanding of the availability and quality of water resources has generally decreased, nationally and globally, precisely at a time when new forecasts, planning methods and management techniques are required to cope with increasing uncertainties and risks (Tolba, 1988).

While the depletion of technical skills cannot be understated, water management issues are also highly political, social and legal. The adaptability of responsible institutions is thus equally crucial to the achievement of good outcomes (Clark, 1990). Synnott (1991) agrees, and states that sustainability must mean the transmission of institutional structures into the future, as well as actual resources.

5.5.5. Evolution and the Application of TQM to Water Resource Management

Attempts to implement sustainable resource management are often based upon strategies that embody a 'static' view of the world. The intention is to maintain the existing ecosystems as they are, or to return them to a state that was believed to exist at some time in the past. Brown *et al* (1987) have identified that definitions of sustainability often contain a number of common themes that entrench this static view. These include the maintenance of biological and agricultural systems; stable human populations; limited growth economics; an emphasis on small scale and self reliance; and preservation of existing environmental systems.

Although many definitions acknowledge the reality of change, it is unusual for sustainable development strategies to recognise evolutionary or self-organising systems. Hollick (1991) considers that this situation exists because of the fear of limited resources, the absence of opportunities, and the risks of change.

Every element of natural ecosystems continues to adapt and evolve in response to external influences. The nature of these external influences in the future, such as climate and other environmental factors, is inherently unknowable. Technocratic control in the sense of management based on scientific prediction of system behaviour is therefore impossible (after Hollick, 1991). 'He who thinks that he is managing the evolution of a complex system is likely to be only managing the microscopic fluctuations – the incremental changes – optimising the details and neglecting to anticipate possible qualitative changes. Then comes the surprise: a staggering realisation that the old order no longer works' (after Gryzbowski & Slocombe, 1988).

Technocratic control can be counter productive, because it is generally aimed at reducing natural fluctuations and moving a system toward equilibrium and away from evolutionary change points. The use of weirs to control the flow in the River Murray is an example of a control placed on nature, for which there are many examples of environmental degradation with social and economic consequences. The effect in the long term may be infrequent but large system discontinuities rather than more frequent but smaller adjustments.

Given that the future is unknowable, and that (possibly major) system shifts are inevitable, resource management techniques must be flexible and adaptable.

However, hierarchical command structures such as bureaucracies tend to protect existing institutions and values, thus reducing the openness to change. By comparison, heterarchy[2] is both more flexible and better able to cope with complex situations.

Hollick (1991) argues that the aim of planning and management should thus be to enhance the capacity of man-made and natural systems for self management. Active intervention should be used only to steer the system away from large discontinuities, not to achieve or maintain an 'optimal' equilibrium state, however that may be defined. To this end, it is useful for water managers to:

- view water resources as part of a larger sociobiophysical system which may be the source of external stimuli with the capacity to trigger system changes;
- view themselves as part of the system they manage, and other participants in the system as managers as well; and
- recognise and cultivate the capacity of the systems they manage for self organisation rather than trying to control them entirely.

Adoption of a flexible and responsive approach will be important in the pursuit of sustainability. While the goals of sustainability are easily identified, the purely practical means of achieving sustainability is unknown. It would seem that any serious attempt to manage our resources sustainably requires the adoption of the best available technologies (subject to social and economic constraints), integrated planning, the active involvement of the community, recognition of uncertainty and the inevitability of change, and a commitment to continual review and improvement. These ideas align closely with the philosophy of Total Quality Management (TQM) or continuous improvement.

TQM has traditionally been applied to the improvement of corporate management and operational techniques. It was the concept of TQM, preached to the Japanese by the Americans named Deming and Juran, that lead to Japan's staggering economic development (Kanji, 1990).

The objective is to achieve ongoing improvement in processes and outcomes, through planning, implementation, review and adaptation. Involvement is sought from every person in an organisation, to seek out and collectively remedy problems. The TQM approach requires leadership by management, to encourage company-wide participation and to transfer responsibility for, and the ability to implement, improvement in outcomes. The philosophy emphasises prevention of faults and mistakes, with the training of people within the organisation an important element. People drive the system, rather than the system driving the people (Blakemore, 1989), ensuring satisfaction and enthusiasm in the process.

Within the (traditionally conservative) water industry, the principles of TQM are slowly being embraced. Much of the impetus for adoption of the adaptive approach has come from the need to address environmental issues, rather than those of an

[2] A multi-facted, non-hierarchical system of classification or order.

engineering or economic nature. The nature and ethos of the water authority or related organisation has therefore largely determined the extent to which this more modern approach has been accepted. This reality has been recognised by the Water Services Association of Australia (WSAA, 1995), who stated that "environmental management in the industry has, in the past, best been seen as a legislative compliance driven 'add on' to the real business at hand or, at worst, a nuisance to be paid lip service. While these attitudes are by no means extinct, an ethos is gaining ground based on widespread recognition that the benefits of taking a proactive approach will outweigh the costs."

In terms of the management of water resources, the continuous improvement approach has also begun to emerge. Early efforts have used computer simulation or gaming tools to examine various management alternatives, often aided by local knowledge from members of the community as well as the expertise of scientists. Doolan *et al* (1993) adopted this approach to the management of water quality in the Latrobe River in the Gippsland region of Victoria, using the method of Adaptive Environmental Assessment and Management (AEAM) developed by Holling in the mid 1970s (Holling, 1978).

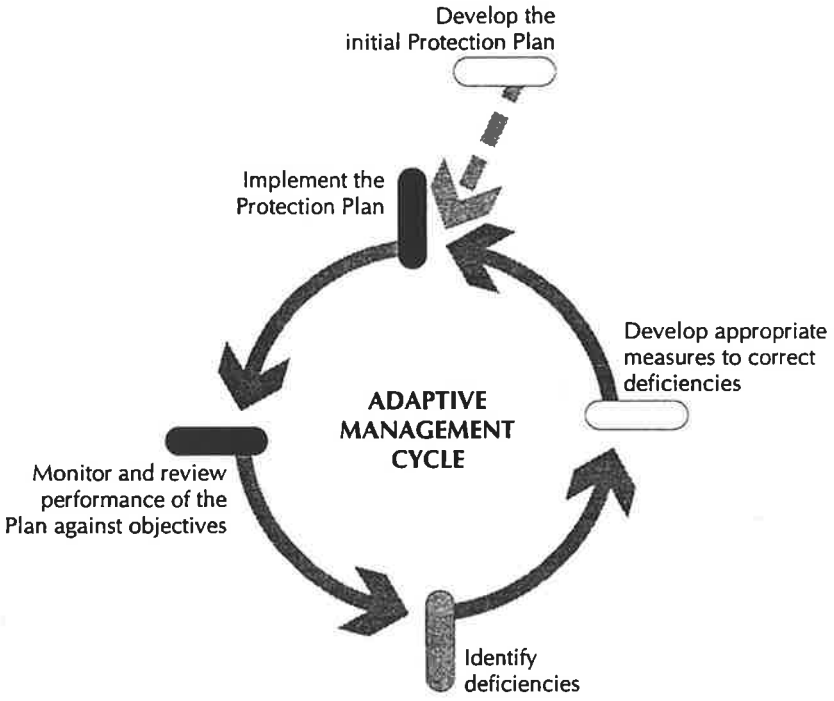


Figure 5.10
Adaptive Management Approach to Groundwater Protection (AWRC, 1992a)

A continuous improvement approach is required in implementation and operation as well as during the planning stages. The Australian Water Resources Council recognised this need in the *Draft Guidelines for Groundwater Protection*, one of the first documents released under the National Water Quality Management Strategy. In conjunction with Figure 5.10, the AWRC stated that "a groundwater protection plan is not a static event. It must evolve with the information base and changes in society and land use. This requires an adaptive management approach, with regular review

of strategies, their priorities, effectiveness, direction and focus, and the evolution of adapted or different strategies in order to continually meet protection objectives" (AWRC, 1992a).

Strategy and policy documents developed by various levels of government with regard to the environmental and natural resource management have incorporated monitoring and review mechanisms since the early 1990s in particular. However, mention of continuous improvement or similar terminology has been curiously missing, particularly from the associated legislation. Only recently have such measures begun to be incorporated. The South Australian *Water Resources Act 1997* requires that all comprehensive catchment water management plans be reviewed at least once in every 5 years to ensure that they 'remain relevant and appropriate' and are consistent with the State Water Plan (the over-arching strategic plan) and other resource management plans (DENR, 1996). There is no particular requirement for similar review of the State Water Plan though.

The only known model of continuous improvement relating specifically to the achievement of sustainability has been developed by Fleming & Daniell (1993), and extended by Fleming (1996). The inherent uncertainty associated with any move toward sustainability is a result of inadequate knowledge, and would most appropriately be handled using the plan, do, check and act cycle which typifies TQM. The need to adopt a 'predict and prevent', as well as 'react and cure' precautionary approach makes this approach a sensible foundation upon which to base new resource management strategies.

The process of continuous improvement forms only one part of a larger picture though. The 'whirlwind' in Figure 5.11 provides the broader context, and illustrates the various paths that can be taken in pursuit of sustainability.

In order to check on progress, performance indicators are required. These indicators need to reflect the integrated approach required for sustainable development, where a balance between economic, social and environmental goals is struck. The nature of the performance indicators, and the decisions made within the 'check' and 'act' stages of the improvement cycle, are often subject to political rather than purely scientific processes. Ideally, a clear direction for future development should be formed through the collaboration of all levels of government, private enterprise and broader community. Without shared values and clear direction, the path to sustainability is longer and less effective. The measure or degree of sustainability achieved is dependent also upon the state of knowledge and management decisions, and therefore upon the evolution of appropriate technology. These concepts are illustrated by Figure 5.11.

It can be seen that a cycle of continuous improvement is followed over time. The envelope which describes the degree of sustainability achievable is determined by the state of technology. A longer and less sustainable path is followed when a balanced approach to economic, environmental and social issues is not adopted. The direction or path taken is dependent upon decisions made in the political arena. Governments therefore have a responsibility to 'get the balance right' through appropriate economic, legislative and policy levers.

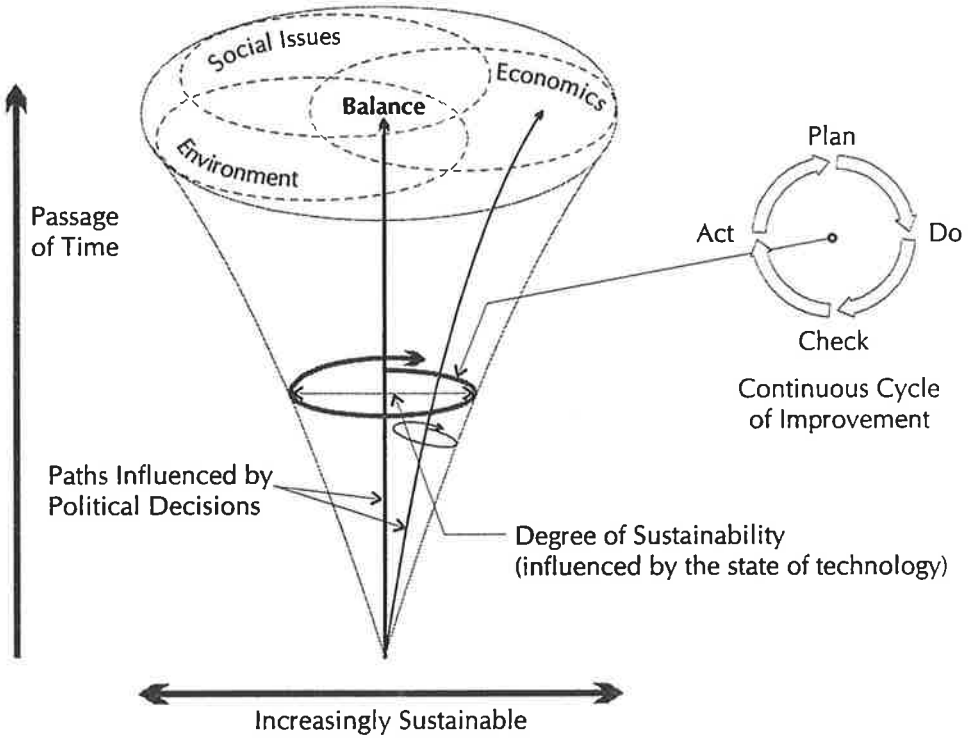


Figure 5.11
The Sustainability Whirlwind

Furthermore, this model demonstrates the vital importance of undertaking strategic planning and the provision of integrated development frameworks to coordinate activities. Without these, development can be fragmented and support conflicting goals. Progress can be achieved in the most efficient and effective manner, through a clear consensual direction and periodic review.

5.6. Conclusions and Recommendations

While all environmental issues are of concern, there is a growing realisation that water is the most important common element in environment and development issues. It is not only essential for life, it is the cornerstone of economic development, and the limiting factor on growth. But water is also a finite resource, unevenly distributed over time and space. In some areas, water scarcity already causes hunger, disease and poverty. Development and management of water resources on the scale of river basins is necessary to avoid conflict and promote sustainable living conditions (after Veltrop, 1996).

The question is no longer 'how much water is available?' but 'how do we use it?'. What is traditionally considered as a water problem handled by water specialists within the water sector, expands to all human activities and water becomes a key factor in human-Nature relationships (Niemczynowicz, 1992). It is somewhat ironic that many societies, in particular indigenous societies in developing countries, have had a long standing tradition of viewing themselves as part of nature and of realising

that sustainability in development requires caring for the land on which they live. This ethos has been lost almost entirely – so called civilisation has swept away many of the concepts and ethics on which these societies were based and has nullified the application of their philosophies (Young *et al*, 1994). To regain an understanding of humanity's place in Nature, and the application of tribal knowledge in a modern way, is of critical importance.

The achievement of sustainability in water resources must therefore focus on the integrated use of land and water resources, with the aim of ensuring a high level of water quality; use of water within the sustainable yield of the resource; and maintenance of biological diversity. The major initiatives in achievement of these goals should therefore be:

- development of a better understanding of ecosystems and their functioning, with recognition of the environment as a genuine user of water;
- adoption of total catchment management for integrated land and resource use planning;
- adoption of demand management and conservation strategies, with the controlled allocation of water resources where necessary;
- recovering, recycling and reuse of wastewaters and effluents;
- application of 'appropriate' and 'clean' technology that are adaptive to changing conditions;
- revision of the roles of government and private enterprise in the provision of water supply and wastewater treatment services, with associated legislative reform;
- community participation with all levels of government and private enterprise in the decision making and policy implementation processes;
- establish a new long-term commitment to data collection, with improvement in the data collection systems, as well as the availability of information; and
- adoption of the Total Quality Management (TQM) philosophy.

6

A Profile of the Northern Adelaide Plains

6.1. Introduction

The Northern Adelaide Plains is an important horticultural region on the outskirts of metropolitan Adelaide, basically comprising the council areas of Salisbury, Elizabeth and Munno Para, and the town of Gawler. The region is bounded in the east by the Mount Lofty Ranges, the coast to the west, Gawler River to the north and the middle metropolitan suburbs of Adelaide to the south.

In socio-economic terms, the northern metropolitan region may be described as a young but maturing section of Adelaide's outer metropolitan area. Although Salisbury and Gawler originated as small service centres for a predominantly rural community, those functions have long since been overtaken by planned urban and industrial development. Post World War II development was rapid, and although some parts are now approaching full development, the region will continue as a major metropolitan growth area until the end of the century and beyond (Gaston, 1987).

Arterial roadways form the main transport corridors through the region. The northern plains are of linear form and have acted as a corridor for movement to the northern areas of the state since colonisation. Inland from the plains the country is increasingly rugged is less accessible and has, therefore, caused the concentration of traffic on the plains. The Little Para River which cuts across the plain further defined traffic movement by limiting access along the corridor to 3 main crossings located at Salisbury town centre, Main North Road and Port Wakefield Road.

The Northern Adelaide Plains is a significant production district with agricultural production valued in excess of $130 million. It produces horticultural products worth an estimated $50 million per annum, with the main product groups being vegetables, fruit, cut flowers and some wine grape production. The region also contains approximately 25 percent of the State's intensive animal industries. The mix of good soils, mild climate, good quality ground-water and proximity to the Adelaide market reinforced by a skilled workforce and extensive established infrastructure makes the area arguably Australia's best horticultural region (DHUD,

1994). Long term planning of resource use is essential if these important contributions to state wealth are to be maintained (Philp, 1993).

The region's coastal areas are low lying, ecologically significant and sensitive to change, while supporting valuable economic activities, such as fishing and salt extraction.

The main problem experienced on the Northern Adelaide Plains (NAP) and by the horticultural industry generally is the shortage of water, not other adversities such as the incidence of frost. While around 3,500 ha is currently cropped within the area known as the Virginia Vegetable Triangle (VVT), a further 8,000 ha to the north as far as Port Gawler Road could become productive if not for the shortage of good quality irrigation water resources (Curd, 1996).

6.2. The Study Area

The area commonly referred to and defined as the Northern Adelaide Plains is more strictly known as the Northern Adelaide Plains Proclaimed Region (NAPPR), an area formally defined under State Government legislation for the purpose of groundwater management.

To appropriately address all water resource management and urban development issues of the NAP, land beyond the Proclaimed Region must be included. The study area has therefore been extended eastward to the top of the Mount Lofty Ranges so as to incorporate all of the catchment areas having an impact upon the plains and to enable whole-of-catchment issues to be addressed.

The study area covers approximately 651 km² as illustrated in Figure 6.1. The northern boundary is defined by Sharpe Road and Parkers Road (both formerly part of Middle Beach Rd), running roughly parallel and some 6 kilometres north of the Gawler River. From the town of Gawler, the boundary extends the south along the Gawler–One Tree Hill Rd, Black Top Road and then along the hills face and catchment boundary to the east of Main North and Bridge Roads. The southern boundary of the Salisbury council area roughly defines the southern edge of the study area, which terminates at the North Arm of the Port Adelaide River. The coastline of the Barker Inlet and Gulf St Vincent define the western extremities.

The discussion that follows provides an overview of the history of the region, the natural and physical character of the northern Adelaide plains, and how its present form emerged.

6.3. The Natural Environment

6.3.1. Climate

The climate is typically Mediterranean, with hot and dry summers and cool, wet winters. General climatic data is presented in Table 6.1. The mild winter climate enables year-round production of most vegetable crops. Irrigation is necessary for

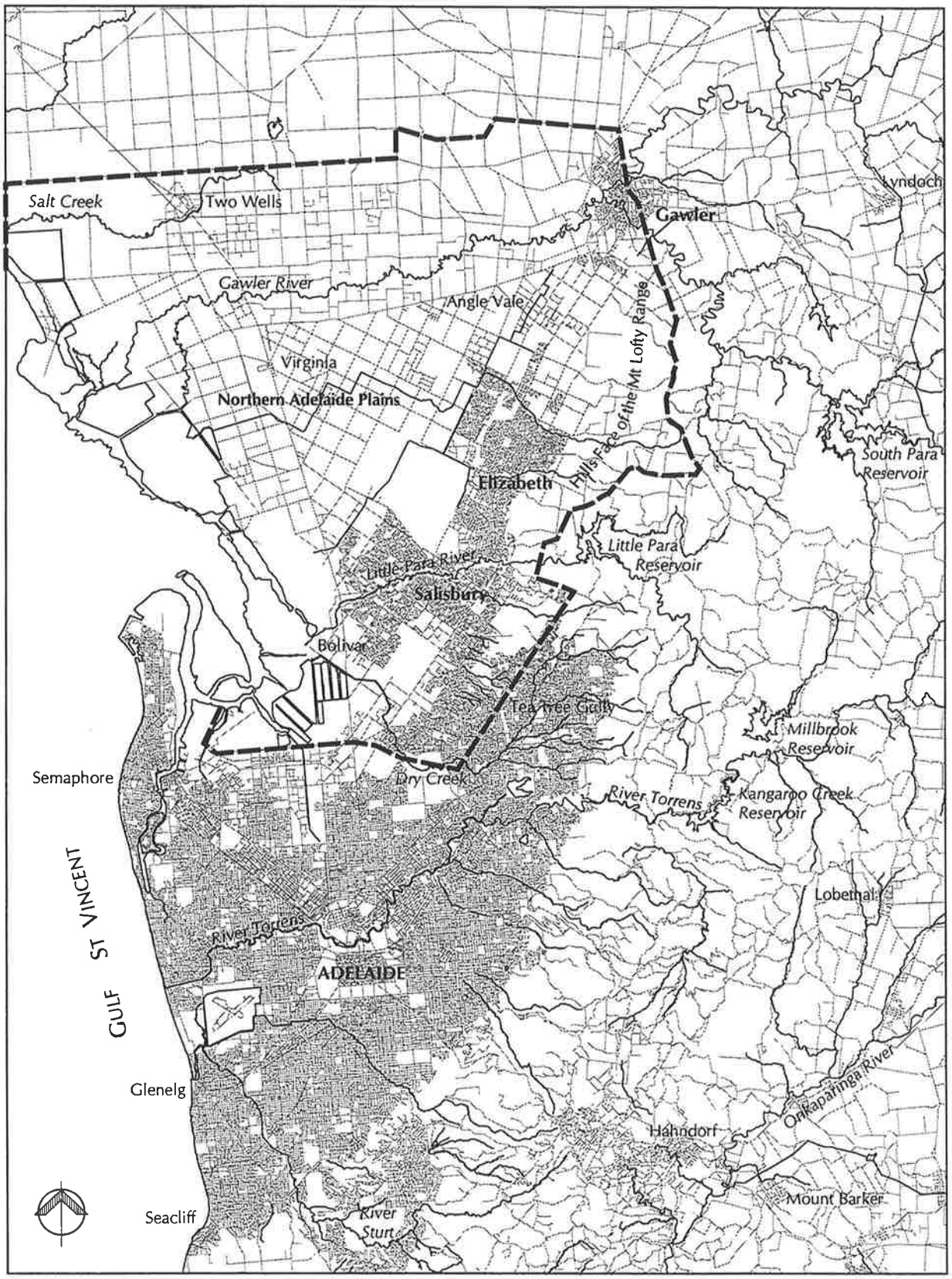


Figure 6.1

Study Area Including the Northern Adelaide Plains

all crops during the dry summer, and supplementary irrigation is sometimes necessary for winter crops.

A maritime influence ensures that the incidence of frosts is relatively low, with an average of eleven frosts each winter. Occasional heavy hailstorms have created problems for the glasshouse industry and damaged field vegetable crops, although only three major hailstorms have occurred in the last forty years.

The study area is in the drier portion of the greater Adelaide area. The mean average rainfall varies little over much of the plains, ranging from 395 mm at Two Wells to around 490 mm at Pooraka. At the northern extremity of the horticultural triangle annual rainfall is typically only 400 mm, with the general tendency for reduction in mean annual rainfall towards the north-west. About 67% of the rainfall occurs during the months May through October, with the remainder occurring in irregular, occasionally heavy falls during the summer months. 1889 was the wettest year on record with 1992 being the third wettest on record. Further information is provided in Chapter 7.

Table 6.1
General Climatic Data for Northern Adelaide Plains

Month	Rainfall, mm[1]	Number of Rain Days[1]	Evaporation, mm[2]	Temperature, °C Minimum[3]	Temperature, °C Maximum[3]	Frost Incidence[3]
January	20	6	281	16.3	29.4	0
February	17	5	261	16.5	29.7	0
March	22	7	189	14.4	26.5	0
April	38	11	126	11.8	22.3	0
May	53	16	97	9.1	18.8	2
June	57	17	70	6.5	15.6	3
July	57	20	65	6.2	15.6	3
August	54	20	77	6.7	16.4	2
September	45	16	99	8.2	18.2	1
October	41	14	166	10.4	21.2	0
November	27	10	232	12.4	24.9	0
December	23	8	250	15.0	28.2	0
Year	454	150	1,914	11.1	22.2	11

(1) Regional mean determined from historical data over the period of available record
(2) Mean monthly evaporation based on data collected at Bolivar STW
(3) After Eco Management Services (1994), Table 3.1, p. 4

Annual average evaporation is near 1,920 mm over the study area, which is a ratio of more than 4:1 over annual rainfall. This ratio compares with about 2:1 in the well vegetated areas of Victoria or the near 1:1 ratio of the heavily vegetated areas of the east coast of Australia (PPK, 1992). The study area is therefore comparatively dry.

The most frequent and strongest winds come from the south-west to north-west quarter, in the afternoon. Most winter rains also come from this quarter. The winds

in the morning are predominantly from the north and north-east direction, particularly during winter. The area is very exposed to winds because of its features and general lack of tree cover.

6.3.2. Physiography

The area is of low relief with surface elevations ranging from sea level to around 290 metres. From the Mount Lofty Ranges on the east of the plains the land surface slopes gently down to the coast at a gradient normally less than 1 in 250. Dunes of red quartz sand, 5 to 6 metres high trending north-west occur at quarter to half mile intervals in an area of high ground north-east of Two Wells. South of the Gawler River the sand dunes are rare, apart from scattered low dunes in the coastal area and few eroded remnants further inland. The flat and low lying coastal area is only a metre or so above sea level and is used extensively for evaporation pans for the production of salt from sea water.

The eastern margin of the plains is a fault line escarpment; the Para Fault block further east rises to elevations of up to 310 metres above sea level. Numerous escarpment consequent streams (streams formed after the fault uplift) are present. These are short, steep watercourses along which water flows for only one to two days following heavy rain. Most of their channels disappear in the outwash fans bordering the foothills, but the largest, those of Smith Creek and Cobbler Creek, persist for 3 and 1 kilometres respectively onto the plain.

The area is traversed also by three antecedent streams (which existed before the fault uplift). These are the Gawler and Little Para Rivers and Dry Creek. The two rivers follow almost parallel courses, slightly south of west. They have changed courses a number of times, and previous channels can be seen as elongated and usually arcuate depressions. Natural levee banks occur along the lower reaches of the rivers. Dry Creek enters the plain in the southern part of the are and drains north-westerly through Pooraka (Eco Management Services, 1994).

6.3.3. Geology and Soils

Most soils on the Adelaide Plains are red sandy loams over a permeable clay subsoil. The depth of sandy loam topsoil varies from 10 to over 35 cm. Most irrigation is concentrated on soils with over 25 cm of topsoil, with shallower soils being generally poor for horticulture. Good drainage and a close to neutral pH makes these soils suitable for winter vegetable production.

Some heavy black soils are located adjacent to the Gawler and Little Para Rivers. While satisfactory for vegetable production, they are not favoured for winter production and are flood prone. Saline soils unsuitable for irrigation are located adjacent to the coast.

Growers in the district are very conscious of soil structure as it can influence their ability to harvest or planting of crops during wet conditions. Green manure crops, gypsum and deep ripping are used widely to maintain soils in a friable, well drained condition (Philp, 1993).

Soils with a long history of vegetable production (particularly glass houses) have high levels of phosphorous and potassium. More accurate fertiliser management will reduce growing costs and avoid development of toxic P and K levels.

Soils between the Gawler and Light Rivers can be broadly divided into 4 groups. A coast strip of dune and swale brown calcareous sands. These are shallow with poor water holding capacity. An area between Mallala and Dublin has shallow grey calcareous sands. The main soil type east of Mallala is gently undulating to float loamy mallee or red-brown earth soils graduating into sandy ridges between Gawler River and Roseworthy. The red-brown earth soils are highly suitable for a wide variety of cereal and grain legume crops along with pasture production for livestock production.

6.3.3.1. Stratigraphy

There is a considerable thickness of tertiary sediments, as much as 80 to 100 m in places, consisting chiefly of fine-grained red-brown clays and sandy clays with occasional thin bands of sand and gravel marking old stream channels. At the surface there are chiefly reddish clays and sandy-clays (Miles, 1952).

The area is broadly composed of:

- St Kilda formation on the western margin with light-grey shelly strand beach ridge deposits and shelly silts and sands overlain by modern intertidal and swamp deposits.

- Pooraka formation over the remainder with pale red-brown sandy clay containing carbonate in Loveday soil. Small outcrops of older calcrete and younger undifferentiated sands and silts occur. Hindmarsh clay underlies much of the area.

6.3.3.2. Soil Features

There is little published information on the soil of the Northern Adelaide Plains. Northcote (1960) surveyed the area in very broad detail. A soil map and brief soil description of the land adjacent to the main irrigation areas south of the Gawler River was published in 1967 (Anon., 1967). In addition, two large tracts of land were mapped between the Gawler and Light Rivers. Wells (1966) published a composite map of the soil of metropolitan Adelaide that overlaps the surveyed area.

The soil of the surveyed area falls into two distinct groups. The flats adjacent to the rivers but restricted to a distance of 1-2 kilometres from them, consists of deep, fine textured alluvium suitable for most crops in the area.

The greater part of the land between the Gawler and Little Para Rivers consists of sandy duplex soil with varying depths of sandy loam or loamy sand surface soil over clay, clay loam or occasionally nodular or sheet calcrete. All crops grown on the area can be produced on the sandy duplex soil where the surface soil exceeds 250 mm.

There are limited occurrences of saline soil north-west and south-west of Virginia.

6.3.3.3. Soil Mapping (after Matheson, 1975)

As part of an investigation into the viability of the reuse of Bolivar effluent for irrigation on the NAP, the State Government commissioned a study in 1971 which placed a strong focus upon the suitability of the soils in the area for irrigation with effluent. Some 11,000 hectares were mapped, extending north from Bolivar to the Gawler River and north-east to Angle Vale (refer to Figure 6.1). Most of the land used for market gardening in the Northern Adelaide Plains is included in this survey.

Salinity largely determines if the effluent is suitable for irrigation, and therefore for the purpose of the soil mapping it was assumed that the Bolivar effluent could be treated simply as saline irrigation water. No special soil characteristics had therefore to be considered in assessing the suitability of the soil for irrigation with effluent. Other important characteristics of the soil were determined via a survey of growers and included:

- depth of topsoil (preferably 250-300 mm);
- presence of stone (or lack thereof); and
- soil texture, particularly as it relates to drainage and ease of working.

Using these criteria, five units were differentiated based on their suitability for irrigation. An additional two units were described to cover soils not used for irrigation, as outlined in Table 6.2.

Table 6.2
Soil Mapping Units for the NAP

Map Unit	Soil Characteristics
Unit 1	More than 350 mm of sandy topsoil over permeable clay or clay loam subsoil.
Unit 2	Between 250 – 350 mm of sandy topsoil over permeable clay or clay loam subsoil.
Unit 3	Between 150 – 250 mm of sandy topsoil over permeable clay or clay loam subsoil.
Unit 4	Between 100 mm – 150 mm of sandy topsoil over: a) impermeable clay subsoil, or b) dense nodular calcrete.
Unit 5	About 500 mm friable clay loam topsoil over perm. clay or clay loam subsoil.
Unit 6	About 100 mm of sandy topsoil over dense nodular or sheet calcrete.
Unit 7	Saline soil.

The results of the soil mapping are presented graphically in Figure 6.2.

6.3.4. Water Resources

As previously mentioned, the northern Adelaide plains does not typically receive a high annual rainfall. The runoff that does occur from the Mt Lofty Ranges is generally small and spasmodic and does not constitute a source of reliable water supply.

After Matheson & Lobban, 1975

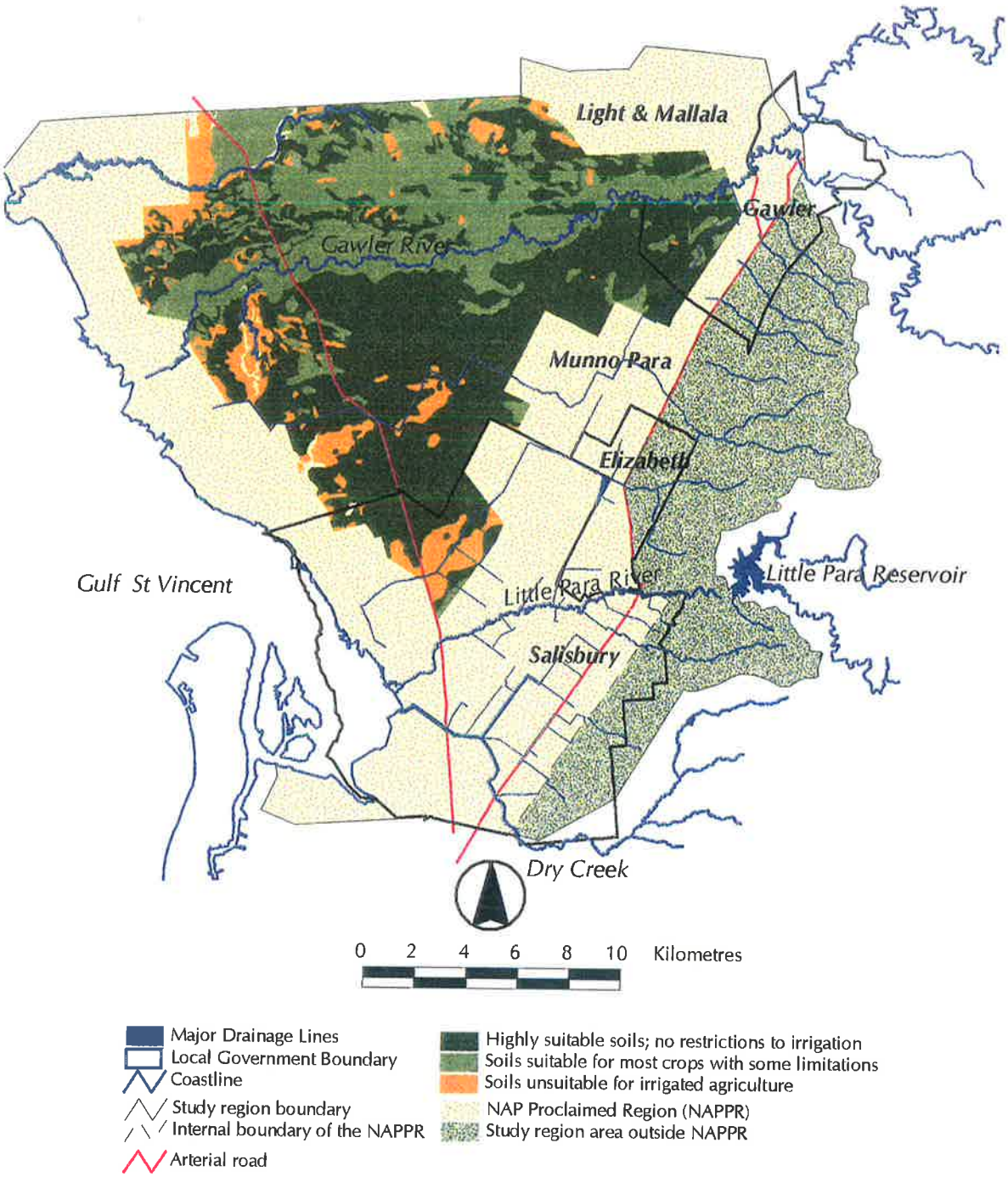


Figure 6.2
Suitability of Soils for Irrigated Agriculture

The Little Para River has been dammed upstream of where it emerges into the plains. The Little Para Reservoir acts more as a holding storage for water pumped from the River Murray than for storage of natural runoff from the associated catchment, since the Little Para River was a naturally ephemeral stream. Flow from the Little Para Reservoir is more consistent than natural flows due to programmed releases of water from the reservoir for the purpose of groundwater recharge. However, these releases have little effect upon the downstream reaches of the River as they are largely diverted to the aquifer systems at the Para Fault, or lost in the dry river bed.

While the Gawler River experiences some flow more regularly than the Little Para River, the River does not present a reliable water source, and water is typically only extracted to surface storages during times of flood. The natural flow regime of the Gawler River may have been more favourable to development for water supply (for irrigation, say), however the upstream reaches of the South Para and North Para Rivers have been extensively regulated through the construction of the South Para and Warren Reservoirs, and many farm dams.

The most important water resource for the northern Adelaide plains is clearly groundwater. The upper Quaternary aquifers are typically too saline and low yielding for productive use, however the deeper Tertiary aquifers are of good quality and provide greater yield. Unfortunately the groundwater has been used at a rate which far exceeds the rate of natural replenishment, threatening the sustainability of the resource and the horticultural industry on which it is dependent.

The harvesting of stormwater, and recycling of treated sewage effluent from the Bolivar Sewage Treatment Works may prove viable options for expanding the water resources available to the NAP and solving the groundwater resource problems.

Further detailed discussion is provided in Chapter 7.

6.3.5. Native Flora and Fauna

Over the past century and a half, European settlement and the development it has brought, has transformed the physical environment. Tree-felling, quarrying, farming, land clearing, waste disposal, pesticides and the introduction of exotic flora and fauna wrought many changes. The state has been extensively cleared and sown to crops or exotic pastures so that little remains of the natural vegetation of the Adelaide plains (refer to Figure 6.3). Most of the agricultural area has been intensively developed since the time of European settlement to a point where the desirability of further clearance of native vegetation has become a widely debated and contentious issue.

In the early years, native mammals were hunted for food, but the impact on population levels was small compared with the effects of land clearance and hunting for trade (EPC, 1988).

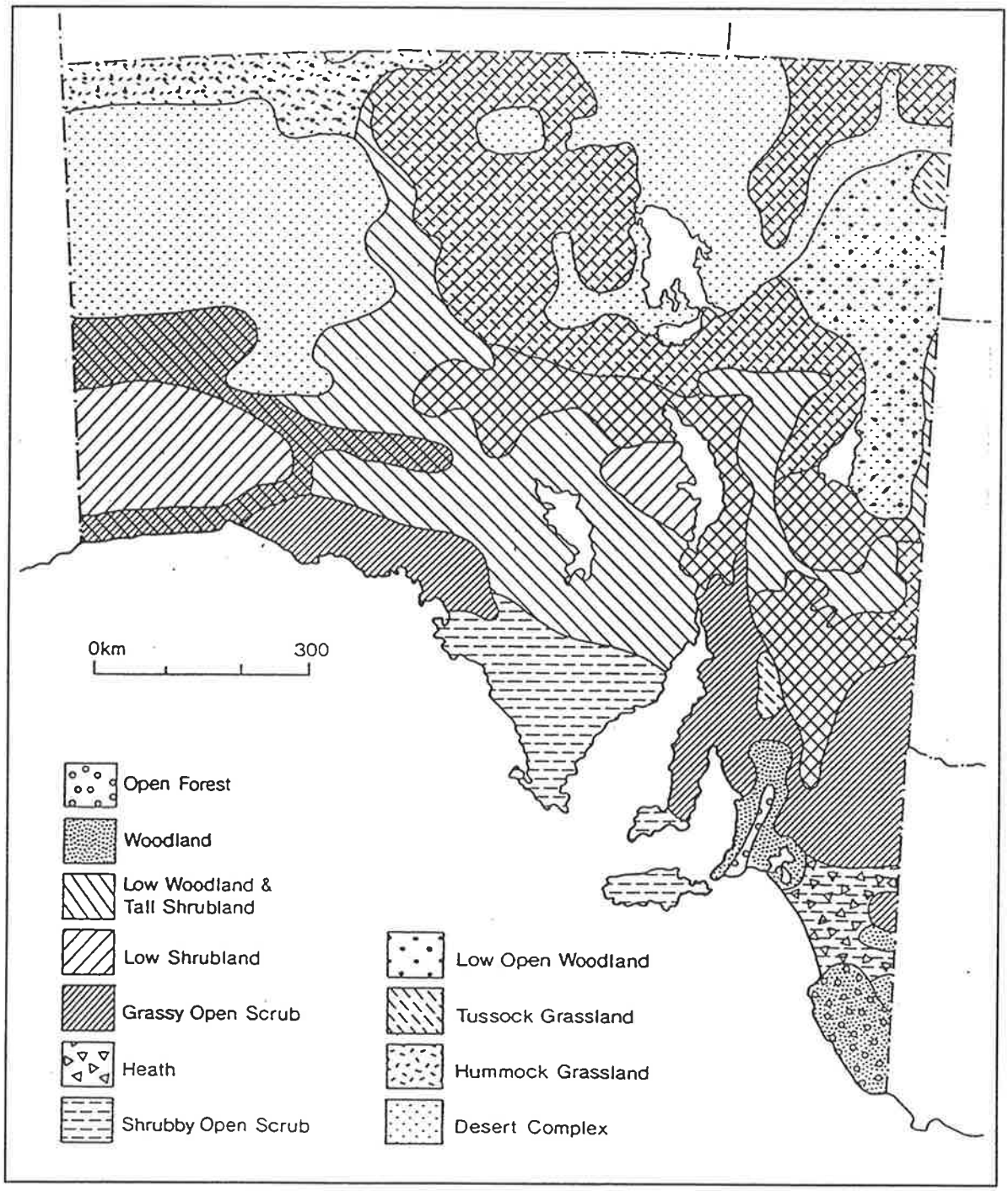


Figure 6.3
The Natural Vegetation Units in South Australia
(after Specht, 1970)

Most vegetation clearance occurred within the first few years of European settlement (Williams, 1974). The settlers stripped the plains of native vegetation with such thoroughness that as early as November 1875 the *Garden and Field* periodical commented (Whitelock, 1989):

> 'We can conceive nothing more dreary than a treeless country – especially where it is level and the climate is hot. Such as one, for instances, as that between Adelaide and Gawler. At one time the weary traveller could take shelter from the fearful heat of the summer sun beneath the shade of the trees which were then plentiful; now he may travel mile after mile along a straight road without even seeing any shrub as tall as a walking stick ... Timber, even for firewood, is already dreadfully scarce in many districts ... where, a few years back, the trees grew in vast numbers, and were cut down into heaps to get rid of them.'

Further north, the Gawler Scrub has almost completely gone. The last time a native turkey was seen in the Mallala district was 1916 (Whitelock, 1989). While a few introduced species have had *some* aesthetic or recreational benefits (e.g. trout in the North Para River, willows by the creeks, and the song of blackbirds), the majority of exotics have had severely detrimental effects. The introduction of foxes, grey and black rats, house mice, sparrows, thistles, soursobs, Salvation Jane, starlings, European pigeons, and the proliferating rabbits have had an enormously destructive effect upon the native environment.

Table 6.3
Extent of Native Vegetation Clearance in South Australia's Agricultural Areas (after Greenwood & Gum, c.1987)

Region	Total Area (ha)	Area Cleared (ha)	% Loss
Lower South East	1,037,552	999,154	96.3
Upper South East	2,049,160	1,630,066	79.5
Murray Mallee and Plains	2,787,037	2,453,296	88.0
Kangaroo Island	405,274	237,443	58.6
Mt Lofty Ranges and Adelaide Plains	1,015,264	961,995	94.9
Mid and Upper North	2,522,005	1,925,701	76.4
Yorke Peninsula	907,205	833,370	91.9
Eyre Peninsula	3,011,129	1,966,381	65.3
West Coast	1,782,375	1,097,156	61.6
Total	15,517,001	12,104,562	78.0

The red-tailed kangaroos (once plentiful on the plains), native cats and kingfishers are now extinct in the region, and many more such as wallabies and kangaroos only survive in forest reserves and conservation parks (Whitelock, 1989).

The northern Adelaide plains were originally covered in grassy open scrub, backed by the woodlands of the Mt Lofty Ranges; refer to Figure 6.4. The eastern portions of the plains were originally covered by a Mallee Box (*Eucalyptus porosa*) woodland

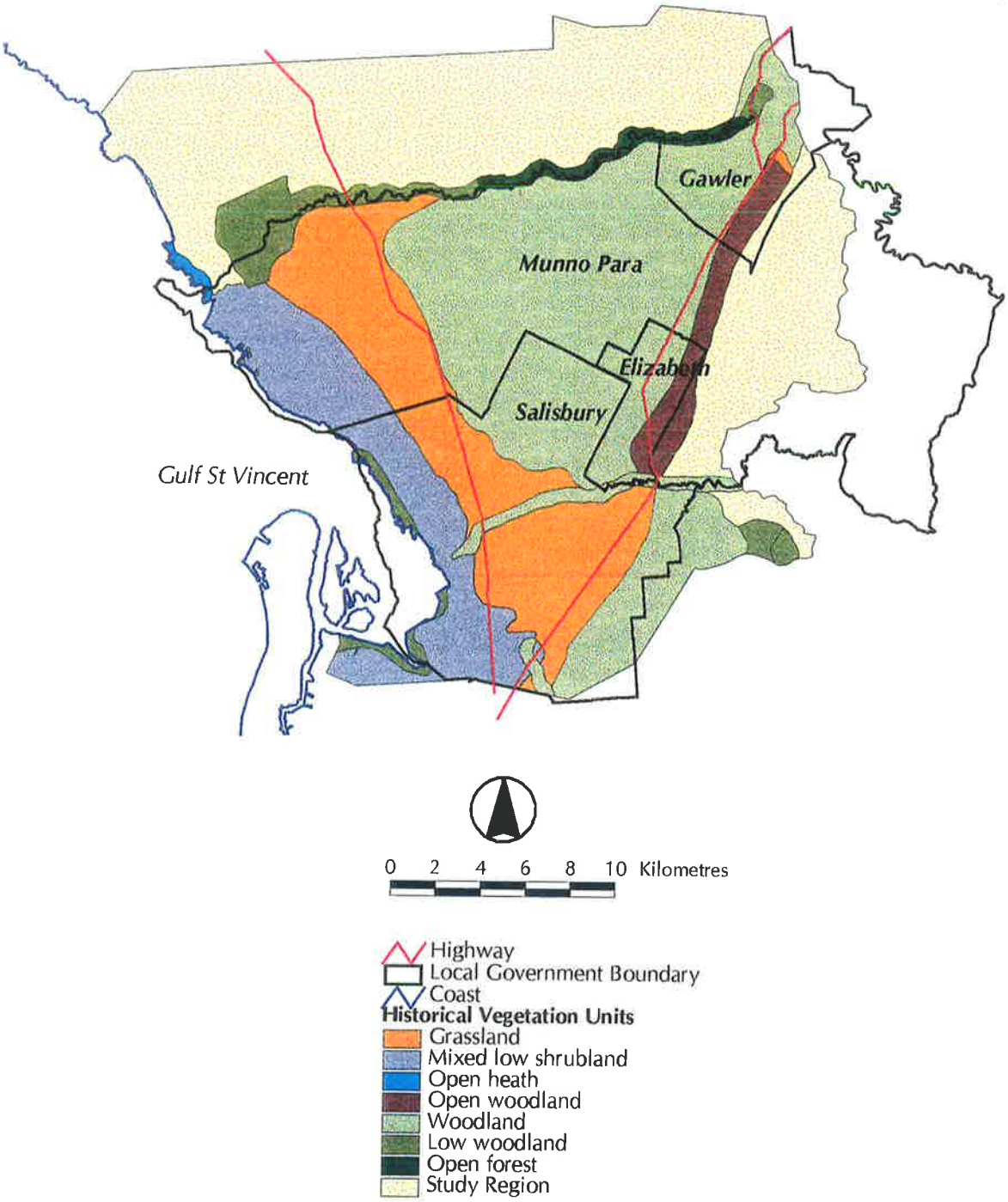


Figure 6.4
Original Native Vegetation of the Northern Adelaide Region

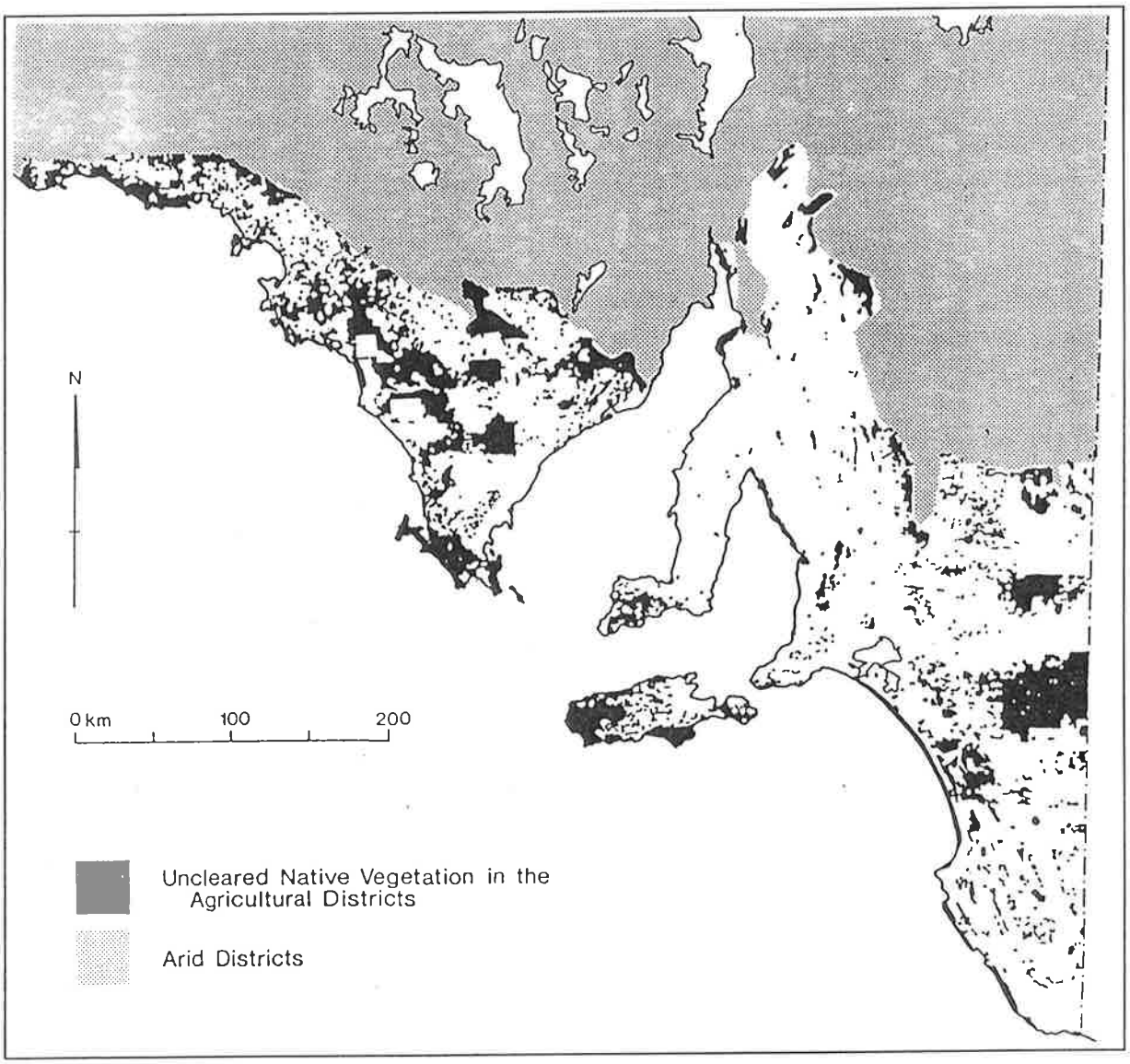


Figure 6.5
Vegetation Clearance in Agricultural Regions of South Australia
(SA Dept for the Environment, 1980)

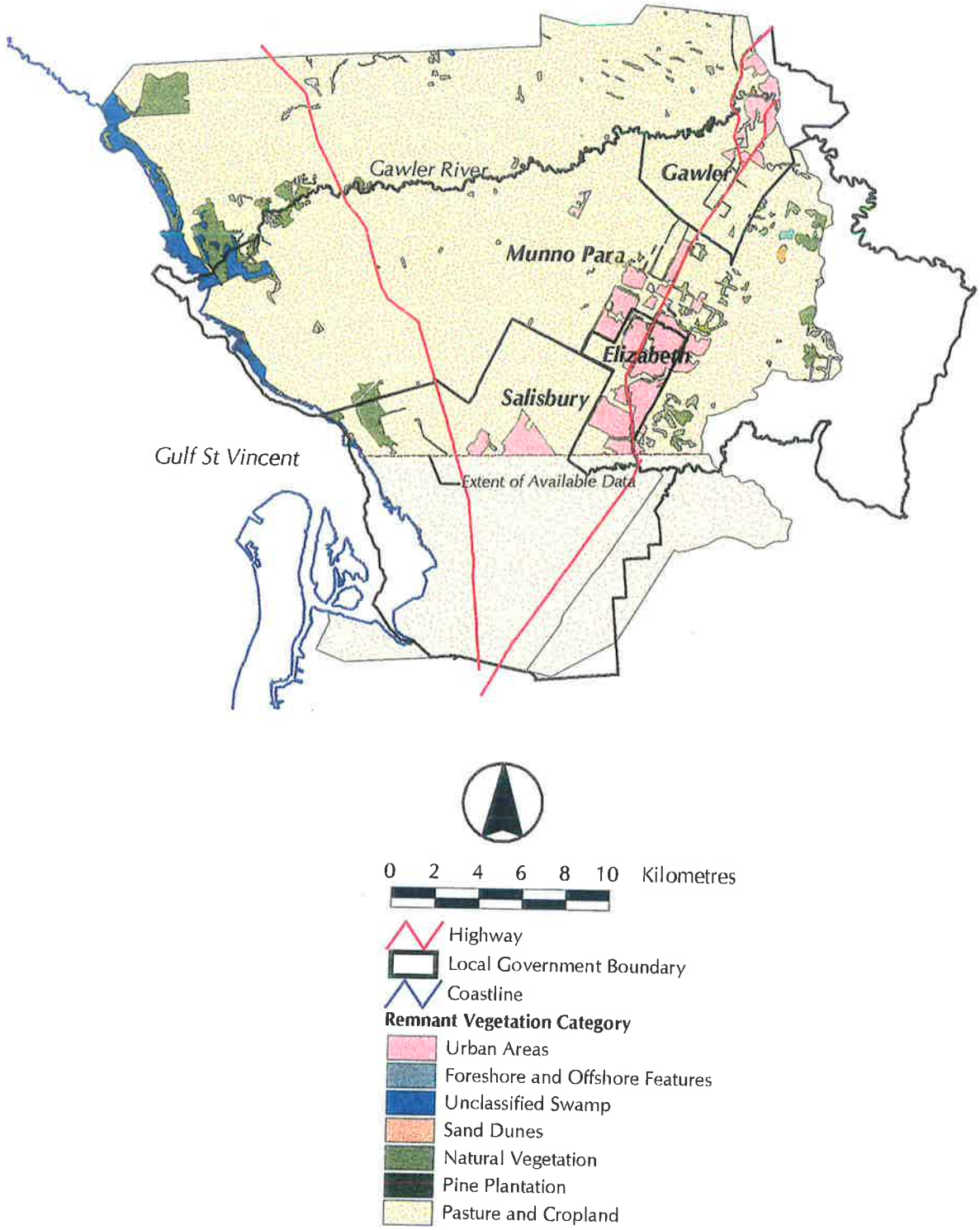


Figure 6.6
Locations of Remnant Vegetation on the NAP

and interspersed with open glades. Other tall shrubs and small trees were present. Many shrubs were present in the woodland's understorey, as well as many grass species such as Wallaby and Spear grasses. River red gums are present along the courses of the Little Para and Gawler rivers. There are some remnants of the native vegetation of the region present in the Cobblers Creek Recreation Park.

The western portion of the study area was dominated by coastal vegetation. The coastal landscape is a complex of tidal flats, dunes, swamps and sandy beaches, backed by a gently sloping plain that once held a low shrubland and grass cover (Laut *et al*, 1977). Mangroves still line the coast and are of high conservation value, not only because they are some of the only remnant vegetation but also due to the fact that they provide important spawning grounds for fish. Samphires formed a 2 kilometre band inland. Grassland was thought to have provided a transition zone between the coastal vegetation and the woodlands.

The sheltered conditions of the Barker Inlet and Port River system has resulted in extensive mangroves and seagrass meadows, and it has an important role in the overall Gulf ecosystem (Jones, 1984). Seagrasses provide important sites for spawning, breeding and shelter for many species of fish and crustaceans. They provide habitat, shelter and food for organisms which are used by fish and other secondary consumers. They also trap sediments and stabilise shorelines by reducing the energy of waves that would otherwise erode the beaches.

The mangrove forests of the Barker Inlet and adjacent coast consists of the Grey Mangrove. They grow in the inter-tidal zone in the carbonate rich shoreline sediments. The ecological importance of mangrove communities is well documented, due to their role in sediment stabilisation, nutrient cycling and primary productivity, and as shelter and feeding habitat for fish and crustacea (Edyvane, 1991a).

Off the metropolitan coast, stormwater, sewage effluent and sludge have been directly implicated in the lost since 1935 of some 4,000 ha or 22 percent of the total seagrass area (Steffenson *et al*, 1989; Shepard *et al*, 1989; Edyvane, 1991b). Since the discharge of sewage effluent from the Bolivar STW commenced in 1967, there has been extensive loss of ecologically important sea grasses in the Barker Inlet and northern waters of the Gulf around Adelaide. Furthermore, large losses of mangroves and the death of mangrove seedlings have been observed, at rates far exceeding the natural morbidity (Edyvane, 1991a). These conditions are expected to have detrimental and serious effects on fish populations and other marine life.

Over the past two decades there has been a growing awareness of the ecological value of estuaries and tidal swamps, which are now recognised as supporting diverse and abundant vegetation, invertebrate, fish and bird communities, and providing importing breeding, nursery and feeding habitat for many species of fauna (PPK, 1992).

The conservation significance of the estuary and mangroves is well documented and has been recognised by the establishment of the Barker Inlet–St Kilda Aquatic Reserve and the Torrens Island Conservation Park (Kinhill Delfin, 1991).

So great tracts of land in South Australia have been cleared of native vegetation (Figures 6.3 and 6.5), and in many parts of the State, roadside vegetation is the only remaining example of a region's original vegetation (EPC, 1988). There is very little of the native vegetation remaining with the exception of the coastal mangroves and the traces in the Cobblers Creek Recreation Park. Only approximately 1 percent of the native vegetation remains on the northern plains, as illustrated in Figure 6.6.

6.4. The Urban and Rural Form

The urban development of Adelaide has mirrored the patterns of many large to medium cities, with the central business district (CBD) remaining very much the hub of employment opportunity, and the expansion of the population being catered for in increasingly distant dormitory suburbs. Of course, there is a scattering of economic activity right throughout the metropolitan area, particularly with pockets of manufacturing. However, what has emerged are significant job surplus areas – with many more jobs than residents (mainly the CBD) – and many job deficit areas (Robertson *et al*, 1992).

The northern plains can be considered to be comprised of three quite distinct units: a horticultural triangle in the north-west; a residential band running north-east from Adelaide to Gawler; and the rural and natural environment of the Hills Face and Mt Lofty Ranges in the east. Industry is largely restricted to the southern and central areas. Refer to Figure 6.7.

The location of natural resources, the patterns of early settlement, and natural barriers (such as the hills face and rivers traversing the plains) are significant factors which have affected this pattern of urban and rural development. These issues and the history of the region are explored further below.

6.4.1. History of the Northern Adelaide Region

Dutch, British and French explorers had sailed the coasts of South Australia before Matthew Flinders and Joseph Banks joined forces to circumnavigate the continent of Australia and chart the coast in detail. During the period of these voyages, sealers and runaway convicts were visiting Kangaroo Island, where from 1804 onwards, settlements were founded. Pressure of population in England, along with assurances that South Australia offered land fit for agriculture, led to decisions about it being a suitable place for a colony (SA Govt, 1982).

While the original European explorer of the area had been Captain Collett Barker in 1831, it was Colonel Light who undertook preliminary exploration of alternative sites for the future city. He surveyed the area in 1832 and laid out the plan of Adelaide next to the River Torrens, 10 kilometres inland from its port. The *South Australian Colonisation Act* was assented to in August 1834, and the city of Adelaide was founded in 1836 and named after Queen Adelaide, wife of King William IV.

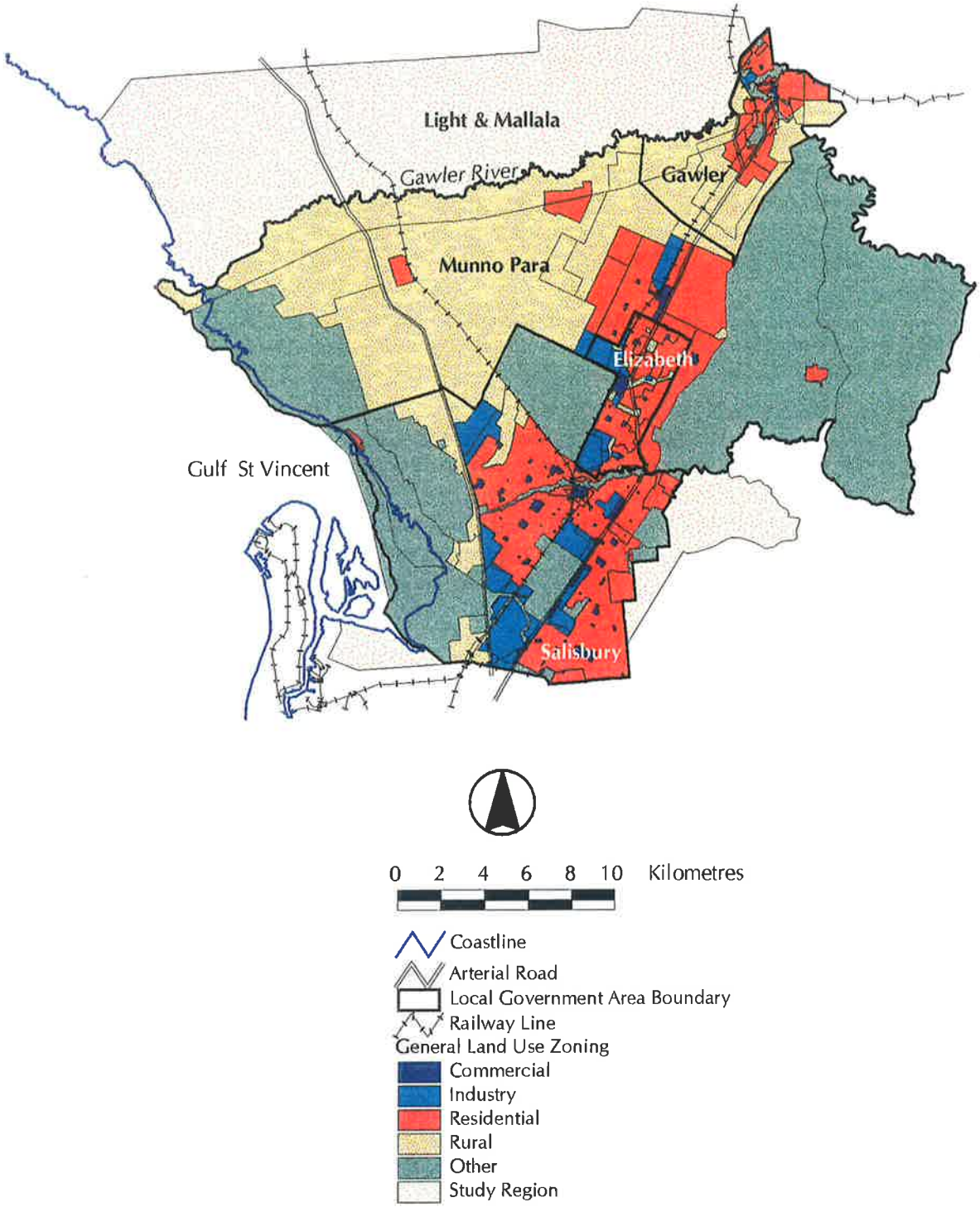


Figure 6.7

Zoning of Land Use on the Northern Adelaide Plains

In that same year, at the direction of Governor John Hindmarsh, settlers were moved to the new city of Adelaide from what is now the seaside centre of Glenelg. In 1836, only four years after Colonel Light presented his city plan, the town fathers had formed a council to run the city's affairs.

The early years of the colony were not smooth but by 1844 the colony was producing wheat in excess of its needs and became self supporting in 1845. It was the discovery of copper at Kapunda in 1842, followed by the Burra find in 1845 that strengthened the growth of Adelaide and pushed its expansion into the outer suburbs (Powell, 1993).

A need to exploit, an integral part of the colonisation process of Adelaide and South Australia, unveiled the virgin countryside and made it familiar territory to the early settlers. While the northern plains were sparsely settled by farmers in even the earliest years of colonisation, settlement in the region was encouraged by the traffic and trade associated with the development of the mining towns to the north. Indeed, the settlement of Gawler became perhaps South Australia's first country town, apart from ports and harbours. The concentrated movements to Kapunda and Burra, and farming and trading caused the establishment of traffic corridors, the majority of which were clearly defined on the northern plains by 1850. Their presence was also to be recorded in the subdivision of the land, which remains essentially the same today.

6.4.1.1. Gawler and Environs

Gawler was officially founded in January 1839 when the potential for a prosperous town was recognised by Colonel William Light and the then Governor George Gawler. In fact, Light also surveyed and planned the township, which was soon settled by Johann Menge, and John Reid and his family. (It was not to become a municipality with a local government and mayor until 1857).

The 'Old Spot' hotel on the main street (Murray St) was one of the first buildings constructed and quickly became the hub of Gawler. The hotel's trade flourished during the 1840s, especially after the discovery of copper at Kapunda in 1842 and Burra in 1845. Yet young Gawler stumbled through its infancy in the 1840s, with little more than a scattering of rough pine timber huts. However, Gawler's economic pulse quickened during the late 40s, largely a result of increasing traffic and the general movement to and from the northern mining settlements. The importance of flour to the developing colony lead to the farming of wheat and encouraged additional settlement on the fertile plains. A more substantial town fabric had developed by 1843, with public schools and churches constructed by the early 1850s (Whitelock, 1989).

The town reached its industrial peak during the 1880s and 1890s, although some signs of change and even decline were apparent in later years. Flour milling declined and a number of new industries such as cement making and starch manufacture were tried and failed, mainly because of the competition from similar enterprises in Adelaide. However, agriculture continued to improve and diversify in Gawler's fertile and well watered hinterland. The significance of the Gawler region

to the wine, grain and wool industries was formally recognised with the establishment of Australia's first agricultural college at Roseworthy in 1883.

The population and size of Gawler continued to grow. An interesting residential development was the spread of settlement to the Gawler Blocks area, now contained within Evanston Gardens, the region between Adelaide Road and the Gawler River. This area grew to house the 'battlers', the less fortunate and working men.

Gawler's industrial base was still strong and diverse during the years until the Great War and before the state-wide and national decline of the Depression period. Gawler suffered a grievous loss of young men in the Great War (1914-1918), having committed nearly 500 (voluntary) soldiers which was a huge number for the small town. However, Gawler's economic diversity stood it in good stead and sheltered it from devastating losses on an economic front during the 1920s and 1930s. Except for the most difficult years of the Depression (1929-1934) commercial activity was satisfactory and local agriculture remained productive.

South Australia experienced some radical changes starting during the 1940s, with significant increases in population largely due to massive immigration. Much of the State's traditional dependence on rural industries and mining shifted to secondary industries – the manufacture of cars and other consumer durables. Nearly all of this industrial growth was confined to the ever expanding metropolitan area which spread inexorably to the south to McLaren Vale and the north to Munno Para. The SA Housing Trust began to build the new city of Elizabeth in 1954.

In the 1960s, Gawler like most towns in Australia became substantially more affluent as the good economic times began to return, and continued through the 1970s. During the same period, residential growth began to cover the once empty plain that had given Gawler its country town isolation from the capital, and the State Government had options for outer metropolitan development that could engulf Gawler. A feeling began to emerge, and then strengthen, that Gawler should not be gobbled up by laissez-faire residential development as so many old communities had been to the north, south and even east of Adelaide – Gawler should keep its own identity. This lead to the appointment of a Town Planner in 1973 to control the scope and direction of building development. Fortunately the current planning strategies and development controls adopted by Gawler and the State Government, as they apply to urban development and open space, will assure the township and character of Gawler will remain.

The history of Gawler is thus almost as long as that of the State, and the town and its inhabitants have played and important role both in the development of the northern plains as well as South Australia. The historic character of the town remains evident today, through the original buildings maintained in the town and by the rural enterprises it supports.

6.4.1.2. Salisbury

Early settlement of the district was spasmodic with farming occurring in ribbons along the road to Gawler, Dry Creek and Little Para River. It was not until the 1860s

that the larger portion of the district was being farmed, and by 1870 settlement neared its end with the transfer of most Crown land to private ownership. Around the same time, the boundaries of Salisbury had been well defined, through the construction of new roads and rail lines, and urban centres were starting to evolve.

The presence of good groundwater supplies in the area lead to the establishment of market gardens and the growing of vegetables (reported to have commenced as early as 1860), an industry which continued to flourish and remains as the last surviving example of the rural heritage of the district.

The character of the region changed very little until the beginning of the Second World War. The need to prepare for it and to rebuild after it had a profound influence on Salisbury. Defence and migration programs, policies on decentralisation and industrialisation, caused rapid growth and established a population of a character at variance with the State in respect of socio-economic rating and ethnic character.

The first industrial enterprise of any scale was opened by Imperial Chemical Industries (ICI) in 1935, when a chain of evaporation pans for harvesting salt became operational. (The salt extraction industry is still operated today by Penrice Soda Products Limited).

Two Federal Government decisions had a profound and lasting affect upon physical and social structure of Salisbury: the decision to establish an explosives filling factory, and the immigration policy of the time (c1940).

The decision to build and Explosives and Filling Factory in South Australia was made in June 1940, immediately after the Ministry of Munitions was established by the Federal Government. The general layout of the facility was completed within a few months, and building commenced in late 1940. Production commenced a year later in November 1941, with production from all plants achieved within the first half of 1942. Maximum production was reached during 1943 when the total employment was 6,400, made up of approximately equal numbers of men and women. The explosives factory ceased operation in 1945, with cleaning of the buildings and grounds ongoing until June 1947 (Rust PPK, 1994).

Although the explosives factory was used for its original purpose for less than 5 years, its location and design proved suitable for a new use which brought huge benefits to Australia for the following 30 years, and helped South Australia become a centre of high technology research and development.

An agreement between the Australian and British governments in December 1946 saw the formation of the Long Range Weapons Establishment (LRWE) at the site in 1947. During the late 1950s, the Royal Australian Air Force (RAAF) acquired land adjacent to LRWE and developed Edinburgh Airfield which was opened by the Duke of Edinburgh on 22 March, 1954.

With the commencement of further, and solely Australian, defence research activities at Salisbury, the LRWE changed its name to Weapons Research Establishment (WRE). Staff numbers peaked at 6,500 in 1964 prior to a significantly

reduced role by the British, a move which was largely a result of changing world politics. Staff numbers at the facility began to decline, and the Department of Defence assumed responsibility for the Salisbury facility from the Department of Supply in 1974. The functions of the research facility were reorganised in 1978, at which time it renamed the Defence Research Centre Salisbury (DRCS). The research functions have largely remained the same to the present time, although with the involvement of more private enterprise, and yet another name change to the Defence Science and Technology Organisation (DSTO). The staff presently engaged at DSTO Salisbury and RAAF Base Edinburgh number approximately 1,600 and 2,200 respectively (Rust PPK, 1994).

In post war years, the Federal Government policy to settle large numbers of immigrants coupled with the State Government's desire to further industrialise South Australia, saw the preparation of plan to form a new urban centre within the then district of Salisbury, known today as Elizabeth.

The combination of urban sprawl from Adelaide, continued urban development around Salisbury (much by the SA Housing Trust) during the 1950s, and then continued rapid urban growth during the period since the 60s has seen Salisbury emerge as a major municipality in metropolitan Adelaide. Approximately one quarter of residential properties in Salisbury have been constructed by the SA Housing Trust.

The location and accessibility of the Salisbury district to the CBD and Port Adelaide has allowed the establishment of some large manufacturing and processing industries, warehouses and service industries.

6.4.1.3. Elizabeth

The City of Elizabeth is a highly structured community, planned as a largely self-contained 'satellite city' during the early 1950s. It is situated some 20 kilometres north of the Adelaide central business district. Its urban form, based on innovative planning principles of the time, establishes defined neighbourhoods served with:

- a local shopping/community focus;
- separation of major traffic thoroughfares from residential enclaves;
- convenient road access via the major northern arterial, bisecting the city, and also rail links;
- strategic open corridors and generous civic and local parks; and
- the Elizabeth town centre, a regional focus of shopping, community and entertainment facilities and employment opportunities.

Housing was largely the product of the South Australian Housing Trust (SAHT) together with limited private development, and produced in large numbers to serve returned service personnel, and also sponsored migrants to the country.

Yet the 'ideal' new city that Elizabeth was supposed to be, where its population lived in organised harmony, did not eventuate. The historical problems of Elizabeth have not resulted because of inadequate implementation of the design, nor in the deficiencies of its residents or some 'invasion' of the disadvantaged, but in the

assumptions of the plan itself and the impact of changing economic imperatives on a working-class, migrant community (Peel, 1992).

Elizabeth was a project based on fitting a set of designs together, in a context of broadly held but loosely defined social objectives, yet only in annual Parliamentary reports was there *any* documentary evidence of attempts to provide basic planning philosophy.

There was confusion, both within government and the general public, about the intent of Elizabeth. At first, some described Elizabeth as a satellite of Adelaide and therefore meant commuting and economic interdependence. Yet later denials from the SAHT emerged: "the Trust's intention from the beginning has been to ensure that Elizabeth shall be a truly self-contained (and self-sufficient) development, not a mere suburban extension of the capital city" (Peel, 1992).

The SAHT's objective in building Elizabeth was to make a home for workers. The area was planned as 6 'neighbourhoods', each of which though contiguous and not necessarily divided in any way from the others, was to be self sufficient as regards to the immediate domestic needs of daily life (although later SAHT reports indicated that each neighbourhood would, in contrast, be "a separate entity").

Planners were faced with the problem of actually designing and achieving a stratified social mix. The chief means was building sales as well as rental houses. Selling houses was also a way of raising funds to built more rental houses. The plan also incorporated a hierarchical structure of housing; significantly higher proportions of rental accommodation were provided closest to the main factory areas in Elizabeth South, and furthest from the middle-class hill slopes.

The Trust certainly did do some things better than previous developments, with the provision of good services and facilities, especially open space, underground electricity, roads and accessible small shops. The roads, however, were unnecessarily wide with wide median strips which looked pleasant but which could not be used. But it was this decent housing, Elizabeth's parks and gardens, and the change of work that drew people to Elizabeth in the first place.

The planning of Elizabeth rested on a vision of a new town life and the proper arrangement of urban space. It was plan with moral as well as economic purposes. Yet all along, the planners forgot that plans can neither dictate nor encompass the lived space of real people. Planners did not consider that a properly planned space could be used in ways which threatened the integrity and social objectives of planning. What they found was that private home owners tried to dominate the renters by monopolising local government; youth occupied and vandalised public space; small backyard businesses were established; people commuted to Adelaide for work; and shoppers by-passed the local shops for the shopping centres in the Town Centre.

6.4.1.4. Munno Para

The City of Munno Para is a rapidly growing urban area on the northern fringe of metropolitan Adelaide, between Elizabeth and Gawler. The city municipality lies

between the Gawler River in the north and the Edinburgh Airfield in the south. The Council area includes the hills face scarp to the east of Gawler and Elizabeth and extends to Gulf St Vincent in the west.

Munno Para contains land developed principally by the South Australian Housing Trust in the early 1960s in a western corridor extending north-wards from the City of Elizabeth. The area experienced a period of rapid growth during the mid 1970s, at which time considerable planning of infrastructure was made. Development of private and former Land Commission and current Urban Land Trust land occurred east of Main North Road mainly during the 1970s, and some during early 1980s. However, the rate of growth which was anticipated and planned for did not eventuate, and it is only in recent years that a renewed upsurge in development has taken place. A strip of land up to the Hills Face Zone and east of Elizabeth has been developed, and extensive new land development is continuing principally on two fronts at Smithfield East and West, whose development is being guided by structure plans.

6.4.1.5. Virginia and Other Towns

Virginia township has evolved from a small settlement which was originally a staging post for coaches travelling north along Port Wakefield Road, into a service centre for the surrounding agricultural community. Prior to the construction of the Virginia By-Pass, the town played a prominent role in terms of servicing the large volume of commercial and passenger vehicles which passed through it. While most of the traffic now avoids the town, a legacy remains in terms of the number of service stations and motor vehicle related businesses on both sides of Old Port Wakefield Road.

Although some new residential development has taken place in the town, most housing is well established, being situated on a wide range of allotment sizes. Indeed, the pattern of land division within the town is most irregular and prevents the effective and coordinated division of allotments for township purposes.

Notwithstanding the decline in population numbers during recent years, Virginia continues to play an important role in providing essential services and facilities to the surrounding region (BTP, 1989).

Virginia, Two Wells, Gawler River and Angle Vale are townships surrounded by rich farmland, orchards and market gardens. Many 'new Australians', especially from southern Europe, came here to live after the Second World War. More recently, immigrants from south-eastern Asia have taken upon farming in this area.

Port Gawler never became the thriving township promised by those offering the land for sale, or by those who dreamed of shipping goods up the silted Gawler River.

6.4.1.6. The Kaurna People

The Kaurna people are known to have been the first aboriginal group which traditionally owned the land of the Adelaide plains. The Wirra group of the Kaurna tribe were more particularly located on the northern plains, and Tindale and Sheard

(1926) record that this group ranged over all the country between Angaston, Lyndoch, Port Adelaide, Yatala and Tea Tree Gully.

A large camp and meeting place was located on the Little Para River where the present Snake Gully Bridge crosses the stream. Here there were permanent springs and water-holes. In 1848, two 80 acre (32 ha) sections of land bordering the Little Para and these springs were set aside as aboriginal reserves. Although this was a traditional ceremonial ground, the limited size of the reservation did not compensate the Kaurna for the deprivation of their hunting grounds. By 1853, the sections had been leased to a European and after 1900 were subdivided and sold (Auhl, 1976).

The Kaurna people came to reside more permanently in a limited range of locations, partly reflecting the alienation of land for pastoral use, and partly in response to the availability of new resources such as food, blankets and shelter (Pope, 1989).

There is considerable evidence to suggest that the Kaurna people suffered a dramatic population decline immediately before and after white settlement. Numerous researchers confirm the occurrence of a smallpox epidemic which was introduced by contaminated materials arriving on a ship at Sydney during the 1820s, and prior to the colonisation of South Australia.

Significant population decline, together with the impact of a foreign culture, introduced extreme strictures on the possibility of cultural sustainability and reproduction. Thus with fewer children being born and surviving to adulthood, the structures of traditional society were even harder to be maintained (PPK, 1992). Their most fundamental and traditional relationship with the land was massively transformed by colonisation and undoubtedly a spiritual and repressive act upon the people.

6.4.2. Existing Urban Infrastructure

A highly inter-connected system of potable water supply mains services the northern Adelaide plains. All major urban centres are serviced, including the rural townships of Virginia, Angle Vale and Two Wells. Water is supplied via the Barossa and Little Para Water Filtration Plants.

The sewerage system services only the urbanised and residential areas of the northern suburbs. The main trunk sewer runs north along Bolivar and then Stebonheath Roads to Gawler, with smaller diameter mains branching to the east to serve the suburbs. A major trunk main also runs due south through Dry Creek, with branch mains serving the urbanised areas of the Wingfield and Unley-Enfield sewer catchments. Secondary treatment of sewage collected from the northern Adelaide Plains occurs at the Bolivar Sewage Treatment Works (STW), situated west of Port Wakefield Road in Salisbury. Further detailed information on water resources, supply, treatment and wastewater facilities is provided in Chapter 7.

The area is generally very flat and because of this it lacks defined water courses which are capable of disposing safely and quickly of excessive amounts of

stormwater runoff. While a number of creeks rise on the Hills Face scarp to the east of Main North Road, their natural channels do not generally extend west of its alignment. Prior to urban development, floodwater from the creeks would spread out over the plains, covering the area with a shallow, relatively slow moving sheet of water. The plains are may therefore be considered to be a vast natural floodplain (BC Tonkin & Associates, 1990).

The major, natural storm drainage paths on the plains are the Gawler and Little Para Rivers, as well as Dry Creek, Cobblers Creek and Smiths Creek. These stream courses along with numerous other minor streams emanating from the Hills Face area of the Mt Lofty Ranges are generally the source of headwaters for the drains crossing the plains.

In the region of Elizabeth, drainage is provided by a number of small creeks which rise on the scarp and are intercepted by a cut-off channel within the City of Elizabeth. This channel directs runoff to Adams Creek which ultimately discharges into a newly constructed detention pond and wetland at the north-eastern corner of the DSTO Salisbury property. This pond discharges into the drain along the northern boundary of the Defence property, and then directed to the sea via a drain along Helps Road.

A single major drainage channel zigzags across the Munno Para district from east to west, with Smiths Creek at its source. The creek merges into an engineered drain in Smithfield Plains; this drain ultimately meets with Thompsons Creek at its confluence with the Bolivar STW outfall channel, from which the runoff is discharged to the Gulf. Very little in the way of stormwater drainage infrastructure is provided in the western portions of Munno Para. To a large extent, the problem of storm runoff is offset by the predominantly agricultural use of the land which enables stormwater to be disposed by means of soakage. Stormwater drainage facilities in the west therefore typically need to prevent flooding from the discharge from the areas of urban development at Smithfield, Munno Para and the hills east of Main North Road.

Within the City of Salisbury the major drainage systems of Little Para River, Dry Creek and Helps Road Drain cut across the area from east to west, discharging into Barkers Inlet within one kilometre of each other. The stormwater system generally comprises a network of small dams, pipes (including culverts), detention basins and open, lined and unlined channels, although in many cases no formal drainage system exists such as in the Burton area (City of Salisbury, 1992). A series of small dams have been constructed along the Para escarpment to provide increased protection for urban areas on the plains. A number of small detention basins and large wetlands have also been constructed to provide the combined benefits of flood retention and water quality improvement. Indeed, the City of Salisbury has been at the forefront of municipal stormwater management using wetlands, and this trend seems likely to continue, with similar initiatives adopted by other councils.

The two arterial roads of the northern Adelaide plains are Port Wakefield Road and Main North Road. A number of other roads provide for major traffic movement to the suburbs. The Salisbury Highway, Bridge Road and Bolivar Road are all aligned parallel to Main North Road and lead into the suburbs of Salisbury. Waterloo

Corner Road and Park Terrace form a primary link between Main North Road and Port Wakefield Road, passing through the heart of the city of Salisbury.

The Two Wells–Gawler Road, as its name suggests, is the main road link north of the Gawler River between the township of Two Wells and Gawler. To the south of and roughly parallel to the Gawler River, Angle Vale Road forms the primary connection between Virginia, Angle Vale and Gawler. Heaslip Road services Angle Vale and the surrounding horticultural districts, leading in a south-westerly direction toward Port Wakefield Road and Adelaide city. A regular grid of predominantly unsealed roads covers the remaining portions of the plains area.

Grand Junction Road, Cavan Road and Port Wakefield Road are the original arterial roads in the southern region of the study area. These routes have recently been supplemented by the Salisbury Highway–South Road Extender.

The rail system in the northern suburbs is far from extensive. The main Adelaide northern metropolitan rail passenger service extends from the suburbs of Dry Creek and Cavan to the north-east, connecting the northern suburbs to the Adelaide CBD. An Australian National rail route also extends between Port Adelaide and Dry Creek. A marshalling yard and engine workshop associated with this route are located at Gillman and Dry Creek respectively (PPK, 1992).

A passenger rail service which operates between Adelaide, Salisbury and Gawler along Adelaide–Peterborough line, the with a regular stop at Dry Creek. This railway line also branches at Salisbury and skirts the southern perimeter of DSTO Salisbury heading in a north-westerly direction to Port Pirie (the Port Pirie–Salisbury railway line). Although most maps of the northern areas still show railway sidings within the DSTO Salisbury complex (i.e. the Penfield railway stations), these lines were abandoned and removed during the mid 1980s.

The young population of the NAP requires good education facilities. For the school age population of approximately 40,000 there are in excess of 44 primary schools and 16 high schools operated by the State Government. Eight (8) of these high schools constitute the Inbarendi College group of the Elizabeth region. In addition there are a number of private schools, adult education centres and special schools, as well as Kaurna Plains School which provides a uniquely aboriginal focus to education. TAFE colleges are located in both Elizabeth and Gawler, with tertiary education offered through the Levels Campus of the University of South Australia.

Two hospitals service the southern suburbs of the NAP and both are located at Elizabeth Vale. The Central Districts Hospital is a private facility, with public hospital care offered through the Lyell McEwin Hospital. A number of workers' medical clinics and surgeries are also situated throughout the region.

6.4.3. Population and Demography

The population of metropolitan Adelaide increased by around 4 percent in the five year period between 1986 and 1991. The suburbs which experienced a major

growth in population over this period were mainly located in the outer northern and southern suburbs.

The northern Adelaide plains accommodates around 20 % of the total population of the metropolitan area (estimated to be 1,057,161) and 14% of the State's population of 1,446,299 (ABS, 1993). The majority of the population in the northern region is located within Salisbury, and this will continue to be the case for some time into the future. In fact, of the 30 local government areas within metropolitan Adelaide, Salisbury is the most populated (ABS, 1993). Refer to Table 6.4.

Table 6.4
Estimated Resident Population and Dwelling Numbers in Local Government Areas during 1991 (ABS, 1993)

Local Government Area	Area, km²	Occupied Area[1], km²	Dwelling Numbers[3]	Population	Persons/ Dwelling[3]
Salisbury	156.20	34.17	35,343	106,008	3.00
Munno Para	277.16	12.32	10,214	31,521	3.09
Elizabeth	20.28	8.72	10,676	28,942	2.71
Gawler	41.05	NA	5,603	15,045	2.68
Enfield[2]	14.20	NA	352	899	2.55
Light & Mallala[2]	252.34	NA	1,437	4,360	3.03
Tea Tree Gully[2]	17.39	NA	3,617	10,886	3.00
Total	778.61	NA	67,242	197,661	2.94
South Australia	984,377	NA		1,446,299	

(1) Source: ABS (1984)
(2) Estimated for that portion of the LGA that lies within the study area.
(3) Total Occupied Private Dwellings from 1991 Census

According to ABS forecasts, significant increases in population would have occurred during the period 1986 to 1996, with an increase of roughly 18,000 persons or more in all areas with the exception of Elizabeth. The population of Elizabeth was actually projected to decline, and indeed the 1991 Census data supports this position; refer Table 6.5. The greatest projected increase in population and dwellings for metropolitan Adelaide and the period 1986-2006 will mainly occur in the north (Tea Tree Gully, Munno Para and Salisbury) with the exception of Noarlunga in the south (ABS, 1989d). The greatest growth in population and dwelling numbers for the coming decade, in both percentage and absolute terms, is projected to occur within the local government areas of Gawler and Munno Para.

High household occupancy rates are generally characteristic of the northern and southern suburbs of Adelaide, where occupancies of 2.7 persons per dwelling or greater are not uncommon (ABS, 1993). Growth in the number of dwelling is predicted for the northern plains, with the greatest increase in Gawler and Munno Para. Yet dwelling numbers are forecast to increase more than proportionally with population, reflecting a dominant trend toward fewer persons per household. The decline in household occupancy is likely to be most prevalent in Elizabeth; refer to Table 6.5.

Table 6.5
Population Projections for Northern Adelaide (ABS, 1986)

	1986, Actual	1996, Forecast	2006, Forecast	% Increase 1986-1996	% Increase 1996-2006
Population					
Elizabeth	31,473	28,310	26,514	-10.0	-6.3
Gawler	12,773	20,174	36,114	57.9	79.0
Munno Para	28,359	47,726	68,001	68.3	42.5
Salisbury	99,044	118,520	121,336	19.7	2.4
Total	171,649	214,730	251,965	25.1	17.3
Dwellings					
Elizabeth	10,796	10,998	11,088	1.9	0.8
Gawler	4,504	7,544	13,830	67.5	83.3
Munno Para	8,807	15,371	23,197	74.5	50.9
Salisbury	31,230	39,313	42,404	25.9	7.9
Total	55,337	73,226	90,519	32.3	23.6
Persons per Dwelling					
Elizabeth	2.92	2.57	2.39	-11.7	-7.0
Gawler	2.84	2.67	2.61	-5.7	-2.2
Munno Para	3.22	3.10	2.93	-3.6	-5.5
Salisbury	3.17	3.01	2.86	-4.9	-5.0
Total	3.10	2.93	2.78	-5.5	-5.1

There are very nearly equal numbers of males and females in each local government area, as demonstrated by the data presented in Table 6.6 (ABS, 1995).

Table 6.6
Estimated Resident Populations, 1995
by Age and Sex in Statistical Local Areas - Preliminary

Local Govt Area	Male	Female	Total	Percent
Elizabeth	13,630	14,611	28,241	14.5
Gawler	8,331	8,737	17,068	8.7
Munno Para	18,855	18,650	37,505	19.2
Salisbury	56,743	55,564	112,307	57.6
Total	97,559	97,562	**195,121**	100.0

The population of the northern suburbs is generally young. While central and southern Elizabeth and central Gawler have pockets of more elderly people (i.e. 50 years of age and older), all other areas of the northern plains have a remarkably young population. The areas of low median age in both the northern and southern suburbs of metropolitan Adelaide simply indicate that these areas have been more recently developed.

Just over 40 percent of the total northern population are younger than 25 years of age, and over 80 percent are younger than 50 years; refer to Figures 6.8 and 6.9.

Figure 6.8 illustrates the age profile of the resident population of northern Adelaide during 1991; the age profiles for each local government area are closely aligned.

The ABS (1989b) predict that over the next ten years there will be a decline in the number of children in the age group 0-14 years, a static state or marginal decline in the population between the ages of 14 and 64 years, but a significant increase in the population over 65 years of age.

Data collected during the 1986 Census indicates that there is tremendous ethnic diversity in the northern suburbs, with representation by people from thirty-eight (38) nations other than Australia; refer to Table 6.7. At the 1991 Census, 256,802 persons in the Adelaide metropolitan area were born overseas. Where the majority of the overseas-born were once from the United Kingdom and Europe, the trend is reversing with an increase in immigrants from south-east Asian nations.

In the northern suburbs, the United Kingdom, the former Soviet Socialist Republic, and Italy still feature as the most common source of immigrants. Vietnam features as the only non-European country in the top 10 countries of origin. Just over 35 percent of the population of the northern suburbs are non-Australian by birth. High percentages of overseas born are evident in Salisbury, Elizabeth and Para Hills. As might be expected, Elizabeth has the highest proportion of non-Australian residents (approximately 40 percent). These statistics simply serve to illustrate that much of the growth in the northern suburbs did indeed occur as the result of mass immigration programs, and that the immigrants chose to (or were encouraged) to live in the city of Elizabeth, a city that was built to house them.

Northern Adelaide also has a significant Aboriginal population. By 1991, the aboriginal and Torres Strait Islanders population living in Salisbury, Elizabeth, Munno Para and Gawler had increased from 1,512 (1986) to 2,015. This comprises nearly 14 percent of the total aboriginal population in South Australia and 20 percent of all aboriginal people living in metropolitan Adelaide (DHUD, 1994).

There are pockets of high population density in the north due to an increase in the number of young families with children as opposed to persons living alone or couple only households. This is particularly true of the western areas of Salisbury and Munno Para.

The middle suburbs have been characterised by population decline and ageing, coupled with continued ethnic and socio-economic diversity. The outer suburbs continue to grow, though at declining rates, and show signs of increasing contrasts between low and high income areas. All these trends underlie significant disparities in living standards and levels of well-being, and are therefore fundamental to many aspects of social health (SAHC, 1990).

6.4.4. Social and Economic Health

Since the early years of European settlement, working class industrial suburbs have developed in the west and north of the metropolitan area. In contrast, middle and upper class residential areas became established to the east and south-east on the

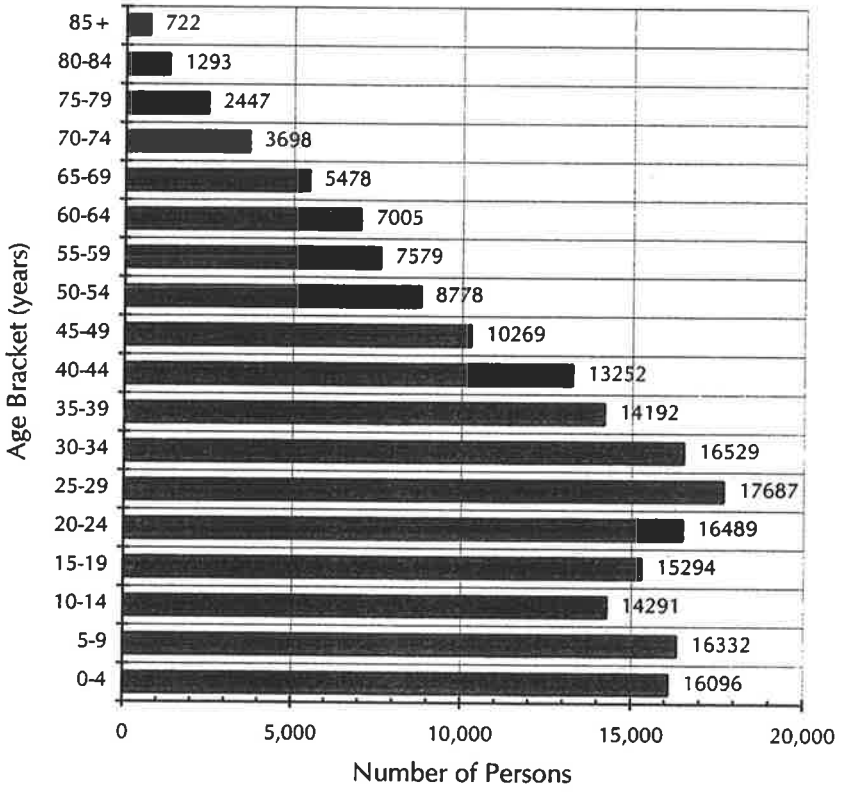


Figure 6.8
Estimated Resident Population of the NAP by Age, 30 June 1991 (ABS, 1991)

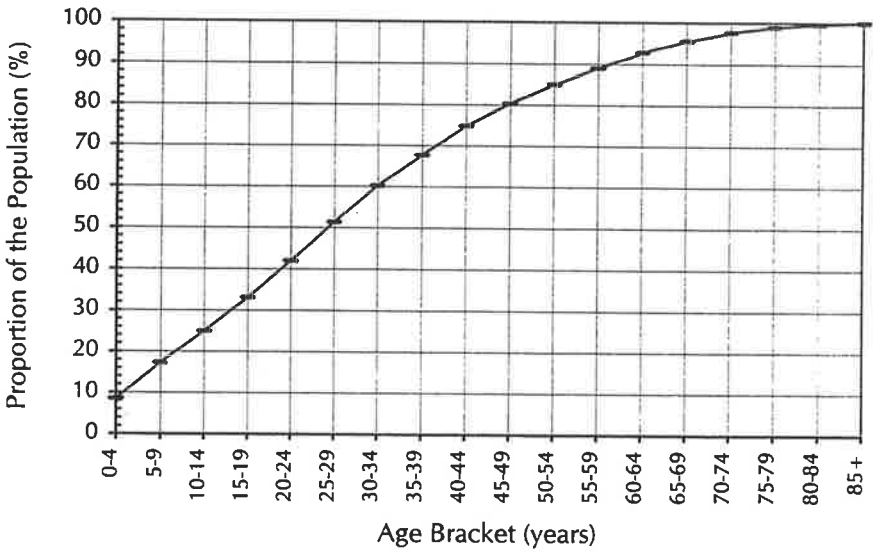


Figure 6.9
Proportion of the Population Within or Younger than an Age Group (after ABS, 1993)

Table 6.7
Country of Origin for NAP Residents, 1986[1]

Birthplace	Elizabeth	Gawler	Munno Para	Salisbury	Total
Australia	19,384	9,724	18,351	64,467	111,926
England	7,199	1,621	5,406	16,104	30,330
U.S.S.R.	960	331	797	4,048	6,136
Scotland	1,036	127	829	1,869	3,861
Italy	204	176	449	2,074	2,903
Germany	356	116	266	1,236	1,974
Aboriginal/TSI	413	54	355	690	1,512
Netherlands	305	69	253	882	1,509
Vietnam	66	15	121	1,235	1,437
Yugoslavia	101	28	105	972	1,206
Greece	39	44	247	703	1,033
Poland	58	50	53	809	970
Oceania	141	84	103	515	843
Northern Ireland	177	35	147	450	809
Ireland	189	35	127	419	770
Wales	205	25	129	394	753
New Zealand	121	60	76	426	683
Malta	43	19	47	342	451
Africa	72	19	56	283	430
Austria	149	15	36	204	404
Hungary	208	10	24	151	393
Other America	63	31	54	240	388
Czechoslovakia	132	8	19	197	356
India	101	10	46	191	348
Cyprus	108	3	15	143	269
Malaysia	43	9	57	146	255
China	143	2	7	95	247
U.S.A.	28	15	36	159	238
Lebanon	16	6	20	147	189
South America	21	4	15	143	183
Philippines	22	4	28	125	179
France	62	8	10	84	164
South Africa	24	2	21	113	160
Egypt	46	2	9	81	138
Chile	72	0	0	61	133
Canada	33	10	15	69	127
Hong Kong	38	0	4	40	82
Singapore	6	2	17	56	81
Indonesia	14	6	10	50	80
Total	32,398	12,779	28,360	100,413	173,950

(1) Source: Australian Bureau of Statistics Census, 1986 (ABS, 1986)

pleasant slopes leading to the Adelaide Hills, and along parts of the metropolitan coastline.

Economic decline, rising unemployment, rising welfare dependency and low population growth rates have been the experiences in Adelaide over the last couple of decades. In recent years, the inner suburbs have generally prospered, to the extent that low income families find it increasingly difficult to afford to live there unless in SAHT housing. The middle suburbs have been characterised by population decline and ageing, coupled with continued ethnic and socioeconomic diversity. The outer suburbs continue to grow, though at declining rates, and show signs of increasing contrasts between low and high income areas.

The northern metropolitan region faces a range of pressures with respect to the development of social and cultural opportunities. These include growth of new urban areas at the metropolitan fringe, the redevelopment of older areas of public housing, and the integration of new housing infill projects with surrounding areas.

In addition, there has been a backlog of service provision in some recently developed areas due to declining levels of funding and previous poor co-ordination of development. Migrants are particularly disadvantaged by the lack of accessible and locally available services (Merenda, 1984).

In general, people living in the northern suburbs are found to be disadvantaged by comparison with the majority of the population of metropolitan Adelaide. All the statistics illustrate that the northern region of Adelaide is economically and socially under-privileged:

- High percentages of single parent families compared to the rest of Adelaide. Of the sole parent families, the vast majority involve a female parent, and many are housed in SA Housing Trust accommodation – not surprisingly, Elizabeth, Smithfield Plains and Gawler West have high concentrations of single parent families.

- Many low income families, particularly in Elizabeth.

- A high proportion of Adelaide's unskilled and semi-skilled workers.

- Low participation of females in the workforce.

- A high percentage of people with limited schooling. The areas with the highest percentage of unqualified persons (those without post-school qualifications) include the outer northern suburbs of Smithfield Plains, Elizabeth Field, Elizabeth North and Elizabeth West.

- Very high rates of unemployment. The highest rates of unemployment are clearly concentrated in the northern and north-western suburbs of Adelaide. In the north, high unemployment is characteristic of the population in Elizabeth and Smithfield Plains.

All these trends underlie significant disparities in living standards and levels of well-being, and are therefore fundamental to many aspects of social health.

The health profile of northern Adelaide is well documented and indicates that for a significant proportion of the population there is a strong association between poor health outcomes and socio-economic disadvantage. The health characteristics of the region are (SAHC, 1990; Geddes *et al*, 1993):

- A significantly higher than average use of General Practitioner services.
- A higher than average hospitalisation rates, especially among adults.
- A comparatively high use of other general medical services in the region.
- A lower than average use of specialist medical services and dentists.
- A higher incidence of morbidity, especially in areas such as respiratory diseases, cancer and circulatory diseases.

Research indicates that significant segments of the northern metropolitan population area are at risk of poor health outcomes, such as people from non-English speaking backgrounds, aboriginal people, sole parent families, unemployed people and other low income earners.

It is clear that the health status of residents of the northern metropolitan area needs to be raised to be equivalent to that of other residents in metropolitan Adelaide, and that social development must form part of any economic development strategy for the region.

There are also varying degrees of locational disadvantage (i.e. ability to access employment, and community services and facilities). In the Adelaide metropolitan area there is a concentration of tertiary-sector employment in the city, and in inner northern and eastern residential LGAs. Manufacturing and immigrants are concentrated in the inner west and some other locations, with blue-collar, low paid workers in outer locations. Yet for much of the northern region, particularly the outer suburbs of Munno Para, there are no substantial and local employment opportunities. There is a need to travel to nearer city locations or into Adelaide for work.

Table 6.8
Average Distance of Travel from Home to Work
(after Robertson *et al*, 1992)

Local Govt Area[1]	All employed		Those not employed in the CBD	
	Males	Females	Males	Females
Adelaide city (1)	3.6	2.9	8.7	8.3
Salisbury (24)	10.4	10.2	9.4	8.3
Elizabeth (27)	11.8	9.5	10.5	7.4
Munno Para (31)	14.0	12.5	12.8	9.9
Gawler (34)	15.6	11.4	13.8	8.6
Kapunda, Light & Mallala (37)	20.7	18.4	19.2	16.1

(1) The number in parentheses indicates the position in a list of 37 LGA groups (with a total of 44 LGAs) ordered from least to greatest average distance of travel.

The data presented in Table 6.8 supports this position. It indicates that there are abundant job opportunities for both men and women in the central business district, but a lack of job opportunities outside the CBD. Robertson *et al* (1992) found that up to approximately 20 km from the city centre, people were prepared to come to the job-rich CBD, but beyond that distance areas in which people will seek for work are less likely to extend close to the city. It was also evident that males travel between 15 to 20 percent further than females for work. While some people living in Elizabeth and Salisbury tended to find work in these areas, displaying something of a local labour market, there were still many people who had to travel a large distance to work.

In the north, the use of public transport was higher than the overall use, with 10 percent of males and 18 percent of females using public transport to travel to work. Although females generally travelled shorter distances to work, the travel times were not significantly shorter, explained by their use of public transport.

Table 6.9
Proportion of Employed Persons Who Travel to Work by Public Transport(1)
(after Robertson *et al*, 1992)

Local Government Area	Males	Females	Total
Adelaide City	15	16	15
Campbelltown	9	18	13
Port Adelaide	9	17	12
Noarlunga	10	12	11
Elizabeth	10	18	13
Gawler	11	12	11
Salisbury	8	17	11
Munno Para	8	15	11
Range, all suburbs	1 - 15	1 - 23	1 - 17
Average, all suburbs	9	15	11

(1) Public transport includes train, bus, tram and taxi

There are also relatively high percentages of dwellings with no motor vehicles in the suburbs of Elizabeth and Gawler. There is correlation between these areas and those with concentrations of people born in non-English speaking countries, unemployed people, low income households and government-owned rental accommodation. This suggests that the presence of a motor vehicle is mainly the result of socio-economic factors rather than the availability of alternative forms of transport (ABS, 1993).

A recent study of socio-economic and health issues of the northern suburbs found that the population were clearly disadvantaged with respect to the majority of Adelaide. The following characteristics were all found to be clustered in the northern suburbs:

- A high percent of the population engaged in blue-collar occupations.
- A low percent of the population have white collar occupations.
- A low percent of the population work part time.
- A high percent are involved in wholesale and retail trade, manufacturing and transport industries.
- A low percent have household income in excess of $32,000 per annum.
- A high percent of the population have no post-school qualifications.
- A low percent have certificate qualifications.
- A low percent have tertiary qualifications.
- A low percent of the population are aged over 54 yrs of age.

So with the exception of Elizabeth in the north, which was developed as a satellite city by the South Australian Housing Trust (SAHT) during the 1950s and 1960s and has many of the demographic characteristics of the middle suburbs, the outer suburbs experienced their main growth during the 1970s and 1980s. They are still areas of population gain, youthful age structure, low residential densities and dependence on the automobile, but have also been significantly affected by recent demographic and economic trends. Growth rates have slowed, populations area ageing and there are signs of economic polarisation. The less affluent SAHT areas in the local government areas of Elizabeth, Salisbury, Munno Para and Noarlunga have experienced marked rises in the incidence of unemployment, single parent families, low income households and households without cars.

6.4.5. Public Open Space and Recreational Facilities

As with the development of most residential suburbs in Australia, a certain proportion is maintained as public open space (typically around 10 percent of the area of any residential development). There are certainly many small to medium reserves throughout the residential suburbs of the northern plains, particularly along the course of the Little Para River. Sports ovals and golf courses are also common. Unfortunately much of the general open space, in sections of Elizabeth in particular, is poorly developed and under-utilised.

There are also a number of sporting and recreational facilities which service not only the local communities but greater the population of greater metropolitan Adelaide. For example:

- Glider air strip at Buchfelde, Gawler;
- SA International Sports Shooting Park near Virginia, Munno Para;
- Speedway Park and Adelaide International Raceway in the suburb of Waterloo Corner, Salisbury;
- The South Australian Equestrian Centre of Winston Park at Waterloo Corner, Salisbury; and
- Globe Derby Park trotting track at Bolivar, Salisbury.

Race tracks for both dogs and horses, and trotting tracks are situated in Gawler, Lewiston, Evanston and Bolivar.

6.4.6. Agricultural Development

During the 1950s, urbanisation spread to the traditional vegetable growing areas of the western suburbs around Marion, Lockleys, Fulham and Underdale. Growers in these areas were forced to seek an alternative vegetable growing district. The growers selected the Northern Adelaide Plains because:

- good quality groundwater was available;
- there were areas of sandy loam soils ideally suited to vegetable production;
- it had a mild climate with a low incidence of winter frost; and
- it was in close proximity to the Adelaide markets (Philp, 1993).

Mild winter and relatively high summer temperatures mean the NAP has a predominantly autumn, winter and spring production season. The maritime influence ensures mild winter temperatures with only 11 frosts per winter (an important factor for the glasshouse industry). These climatic conditions are a key factor why frost sensitive tree crops such as almonds can be successfully produced in the district.

These favourable conditions saw the rapid expansion of the vegetable production from the mid 1950s to the early 1970s, followed by other irrigated horticulture including almond, olive, vine and flower production. But with the horticultural activity came what was essentially mining of the regional groundwater aquifers. This necessitated the introduction of groundwater use quotas, which effectively placed a ceiling on irrigated productivity of the region.

Nevertheless, the Northern Adelaide Plains still produces horticultural products worth an estimated $50 million per annum, with the main product groups being vegetables, fruit, cut flowers and some wine grape production. The mix of good soils, mild climate, good quality ground-water and proximity to the Adelaide market reinformed by a skilled workforce and extensive established infrastructure makes the area arguably Australia's best horticultural region (DHUD, 1994).

Areas north of the Gawler River have also experienced development with the establishment of major intensive livestock industries during the past 15-20 years. This region now contains around 25 percent of the State's pig population, 54 percent of the laying hens and 16 percent of the meat chickens. Much of the feedstock for these intensive animal industries is derived from local grain production.

A more detailed discussion of the agricultural production practices and value follows, which has been adapted from Philp (1993).

6.4.6.1. Vegetables

The $45 million per year NAP vegetable industry can be divided into two major production groups. There are approximately 100-200 field vegetable crop growers (BTP, 1989) and approximately 400 glasshouse growers.

Glasshouse growers generally have small properties of around 2-4 hectares with 20-40 glasshouses. Because these growers normally have a minimal water allotment

geared to glasshouse requirements, they concentrate on the production of high value crops, and can only grow small areas of outdoor vegetables.

Because entry into the glasshouse industry requires less initial finance than for field vegetables, it has traditionally attracted 'first wave' immigrants who have lacked the resources or skills to enter other sectors of the Australian economy. During the 1950s and 60s, the main ethnic groups were Australian, Bulgarian and some Italian. During the 1970s there was a large influx of Greeks, yet since 1983 Vietnamese families have emerged to dominate the glasshouse industry, although the Bulgarian, Italian, Australian and Turkish groups still have a presence in the industry.

By contrast, the field crop industry is dominated by growers of Italian and Australian descent. Field vegetable crops are generally highly mechanised, particularly potatoes and onions.

Field vegetable growers operate larger establishments generally in the size range 4-150 hectares. Approximately 70 percent of the district's area of vegetable production is managed by 25 of the largest growers. Field crops are generally more highly mechanised, particularly with respect to potatoes, onions and carrots where it is not uncommon for growers to have invested $15,000 per hectare in plant and equipment (BTP, 1989).

Potatoes are the most significant crop occupying some 45 percent of the area cropped to vegetable and providing roughly one third of the district gross income. Spring and autumn potato growing seasons supply fresh potatoes to the Adelaide market from June to February almost continuously.

Other significant outdoor vegetable crops are carrot, lettuce, onion and cauliflower. The district is also important for supplying a wide range of minor vegetables, many year round to Adelaide.

The greenhouse vegetable industry is the largest in Australia with approximately 185 ha occupied by protected structures. The majority of this is used for vegetable production, with cucumbers, tomatoes and capsicum being the major crops.

6.4.6.2. Cut Flowers

Cut flowers are emerging as a major NAP industry, with an estimated farm gate value in the order of $10-12 million. Much of this production occurs within greenhouses or shade-houses. A number of glasshouse vegetable growers have diversified into cut flowers because of improved returns. Much of the flower industry is located along Heaslip Road where mains water was available but bore water was too saline. Mains gas is available for glasshouse heating in this area.

The nursery industry concentrating on contained plants and roses is currently valued at an estimated $10 million. This industry uses a combination of glasshouse, shade-house and field production. Both the cut flower and nursery industries are intensive operations concentrated on small areas and employing significant amounts of labour.

6.4.6.3. Tree Crops and Vines

During the 1970s, significant areas of vine and tree crops were planted. Many areas of vines were pulled out during the "Vine Pull Scheme" in the late 1980s. This rationalised plantings in the district back to approximately 200 ha of those on modern production systems and with the most appropriate varieties. The NAP does not have a climate that is ideal for production of high quality grapes, and it is unlikely to develop as a major crop in the district.

Almonds and olives were also planted extensively during the early 1970s. Plantings are relatively static and are unlikely to expand unless yields can be improved to enhance the economics. The district has 28 percent of the State's almond trees covering an area of approximately 480 ha. Value of the production is $1.8 million.

Olive production has been limited to 2 significant growers producing fruit for pickling. To date the economics of producing olives for oil have been relatively poor due to cheap imports from southern Europe. However a significant increase in local and international consumption of olive oil in recent years has sparked fresh interest and potential for oil production. For olive production to expand on the NAP it would require access to cheap irrigated land, improved varieties and production technology and processing techniques.

6.4.6.4. Cereal and Livestock

Approximately 3% of the State's cereal production is located with the study area producing around $12 million of grain per year. The region is also an important field pea and faba bean production district with an annual value of around $4m. Major pea and bean preparation, packaging and export facilities are located at Two Wells.

Broadacre sheep and cattle production are integrally linked with cropping operations and sheep, beef and wool production contribute a further $5 million per year to the region's production.

6.4.6.5. Production Trends

Market and economic forces are the major factors influencing production of individual crops. In the longer term, growers in this district will tend toward higher value crops due to:

- offset increasing land ownership and overhead costs;
- highly capitalised operations run by some growers; and
- limited water supplies.

NAP growers will only be able to retain market competitiveness with superior quality. Development of export markets for flower and vegetable crops is essential for long term development of the area.

Table 6.10
Area, Production and Value of Production on the NAP, 1990-1991[1]

Agricultural Activity	Crop Area (ha), or Number of Items	Production (tonnes)	Proportion of State Product.(%)	Gross Value ($m/year)	Number of Growers
Area of Establishments	56,954,110		0.2		
Pasture, irrigated	308		0.5		
Cereals					
• Barley	27,295	46,340	3.1	6.0	269
• Oats	1,977	2,686	1.8	0.2	80
• Triticale	716	1,405	10.1	0.2	22
• Wheat	21,223	38,008	1.9	5.2	250
Legumes					
• Chick peas	291	357	3.6	0.1	11
• Field beans	2,291	3,065	10.1	0.7	55
• Field peas	10,476	13,824	10.0	3.2	174
• Lupins	444		0.8	0.1	11
Total Crops	64,713			15.7	
Vegetables					
• Broccoli	54	388	15.0	0.5	19
• Cabbage	112	3,467	56.2	1.7	39
• Capsicum	22	306	37.8	0.6	35
• Carrot	136	4,934	37.8	3.7	22
• Cauliflower	185	11,471	76.7	1.1	35
• Celery	37	3,036	68.3	1.7	6
• Cucumber	38	1,435	74.9	1.5	53
• Leeks	3	258	23.6	0.2	3
• Lettuce	226	5,094	54.7	5.5	25
• Mushroom	5	52	3.0	0.2	1
• Onion	224	8,634	15.5	3.5	31
• Parsnip	10	196	93.1	0.3	7
• Potato	989	28,633	16.3	9.2	53
• Pumpkin	7	90	1.1	0.1	3
• Silver beet	7	175	39.5	0.2	8
• Tomato	79	4,702	52.7	4.8	74
Total Vegetables	2,186		22.1	34.7	217
Grapes[2]	241	2442	0.8	0.9	20
Other Horticulture					
• Nursery/flowers	82			2.1	
• Turf	9			0.1	
Total horticulture	837				

Table 6.10 continued
Area, Production and Value of Production on the NAP, 1990-1991[1]

Agricultural Activity	Crop Area (ha), or Number of Items	Production (tonnes)	Proportion of State Product.(%)	Gross Value ($m/year)	Number of Growers
Fruit Trees & Other	Tree No.				
• Apple	70	1			1
• Pear	141	4			3
• Apricot	1,904	27	0.2	0.01	8
• Peach	717	6	0.1	0.01	6
• Plum	225	2	0.1	0.01	4
• Olive	1,300	17	3.3	0.01	4
• Almond	120,367	397	28.1	1.8	34
• Orange	150	3			1
• Lemon	100	2			1
• Strawberry	5	29	2.6	0.2	4
Total Fruit Trees	505			2.0	
Livestock Production	Number				
• Cattle & calves	13,110		1.3	2.0	87
• Sheep & lambs	107,998		0.6	0.3	235
• Pigs	98,865		24.71	19.2	83
• Laying hens	564,100		54.33	9.1	26
• Meat chickens	3,769,461		16.1	7.7	12
• Wool		782	0.8	3.1	228
Total Livestock				41.3	
Total Agricultural Value				96.8	

(1) Statistics for the Local Government Areas of Gawler, Light, Mallala, Munno Para, and Salisbury. No agricultural activity in the LGA of Elizabeth. Source: ABS Agstats, in Philp (1993).

(2) Excludes grape production for LGA of Light as most of this is located in the Barossa Valley.

(3) ABS Statistics for NAP vegetables are inaccurate. Industry estimates and field surveys suggest that actual production is 25% above ABS data for field vegetable and 50% above ABS data for glasshouse vegetable crops. Based on this information, the NAP vegetable industry is valued at approximately $45m. ABS statistics indicate the flower and nursery industry on the NAP is valued at approximately $2 m. Industry data suggests the NAP flower industry is worth $10-12m while the nursery industry is valued at approximately $10m.

6.4.7. Industrial Development

Manufacturing industry is the major employer in the region, providing around one third of all jobs. A higher than average level of manufacturing activity has been attracted to the northern plains because the region is geographically suitable for large scale industry and successive State Governments, through the SAHT, have offered incentives of industrial land, factories and housing to manufacturers located in the region (NADB, 1981).

The main area of industrial development that occurs within the study area is situated in the north-western suburbs of Adelaide of Wingfield, Cavan, Dry Creek and Gepps Cross. Other industry has tended to develop in clusters which can be found in the suburbs of Salisbury South, Elizabeth South and Elizabeth West.

There are a number of particularly notable industrial activities which include car manufacture at General Motors Holden Automotive in Elizabeth, leather tanning

and wool processing at G.H. Michell Co. Pty Ltd in Salisbury, and salt harvesting along the coastline by Penrice.

General Motors Holden Automotive (GMH) have been established at their present site on Philip Highway in Elizabeth for many years, employing many people local to the area of Elizabeth and supporting the local community throughout that time. Not only does the GMH plant employ a large number of people, but component manufacturers (batteries, gaskets, tyre valves and tyres) would also account for many jobs.

Textiles, clothing and footwear also account for a relatively large proportion of the local industrial sector by comparison the rest of metropolitan Adelaide.

A large portion of the Dry Creek area consists of low lying areas used as evaporation basins for salt harvesting by Penrice Soda Products Pty Ltd. The Penrice salt pans were originally established by ICI Australia in 1936, which required clearance of approximately 400 ha of low lying mangrove and samphire swamps. The northern coastline was cleared and converted into salt fields in 1936-37 and the first harvest of salt took place in 1939. Between 1950 and 1976 the area covered by salt pans was increased significantly to accommodate a growing demand for soda ash. The Penrice operations currently cover some 700 ha of Dry Creek (PPK, 1992).

An area of approximately 30-40 ha to the west of Port Wakefield Road has been used as stock paddocks since the early 1900s. They were used as holding yards prior to stock being taken to the adjacent abattoirs. In more recent times, sheep have been held in the paddocks prior to being taken to Port Adelaide for shipping overseas (PPK, 1992).

The Gawler River has been exploited for more than 30 years as a source of high quality garden loam. Loam pits are situated adjacent the Gawler River, either on the lower alluvial terraces in the upper reaches of the river, or on outwash deposits in the Virginia area. The lower alluvial terraces contain the major reserves, both in surface extent and depth and are also the most extensively worked. The main deposits within the alluvial terraces are on the inside of the narrow meanders where accumulations of fine grained material have been deposited as the river has scoured the opposite bank. The location of these loam pits (including those which have been abandoned) are shown in Figure 6.10 (after BTP, 1989). While demand for Gawler River loam has progressively increased as supplies from other areas have been worked out or closed, planning restrictions imposed on the establishment of new loam pits has virtually contained excavations to those pits which existed prior to 1982. No new pits have been approved since 1982 by the South Australian Government, although continued operation of many of the existing pits is of concern because:

- management practices do not appear to make provision for effective rehabilitation of worked areas;
- the activity of loam extraction is incompatible with the role of the water course as a major drainage line; and
- the activity is at odds with the proposal for Gawler River to comprise part of an open space link in terms of the Metropolitan Open Space System (BTP, 1989).

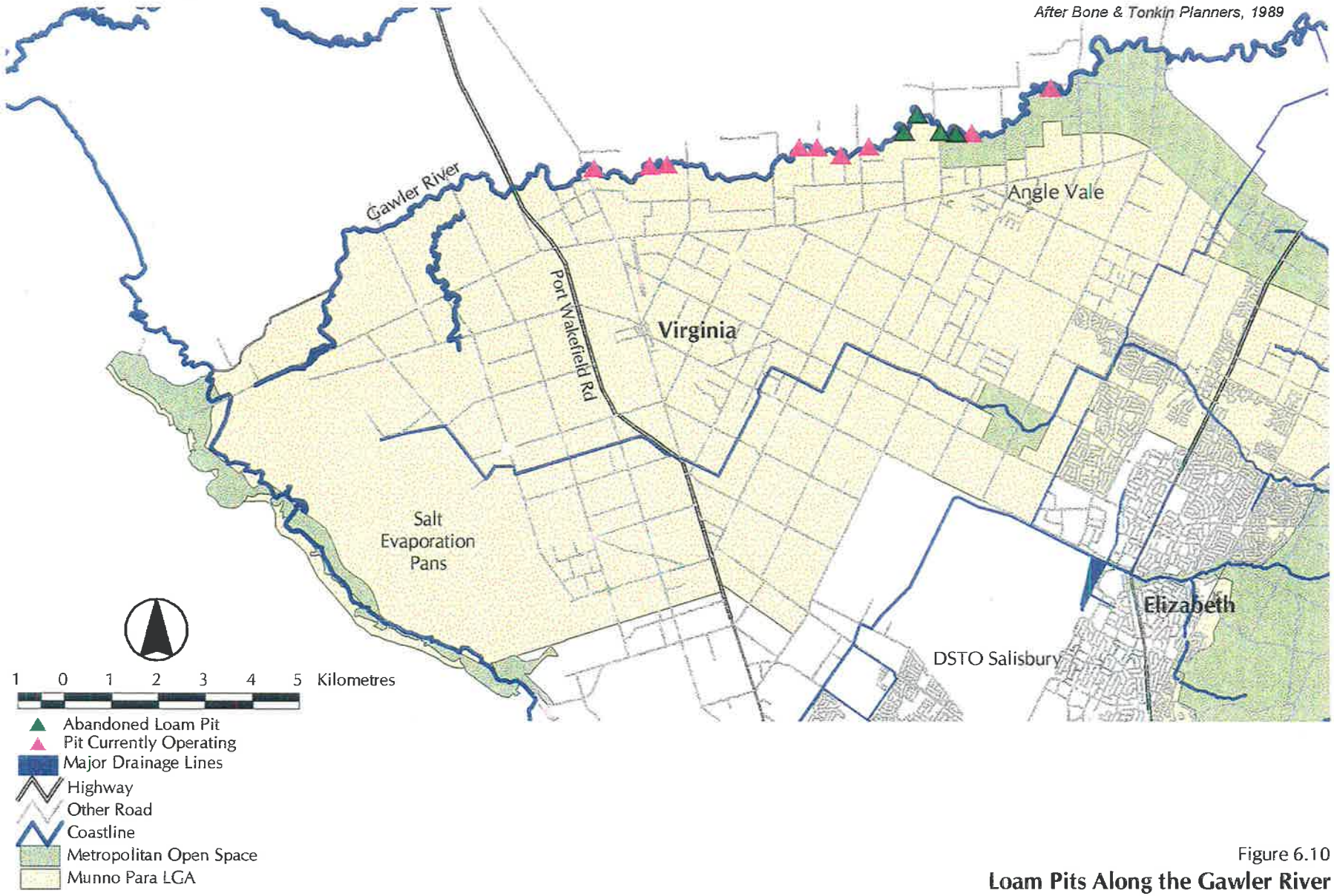


Figure 6.10

Loam Pits Along the Gawler River

Other large industrial and manufacturing operations occur at the Adelaide Malting Company at Cavan, tyre manufacture and testing at Bridgestone Australia in Salisbury South, and poultry processing by Steggles and Ingham Enterprises at Elizabeth West and Burton respectively.

6.4.8. Special Activities

Perhaps one of the most significant developing features within the northern-western region of Adelaide, and which affects the study area, is the new multi-faceted urban environment under development by MFP Australia.

The MFP initiative is all about building a better future, overcoming all the environmental, lifestyle and technological challenges that have emerged as a result of the poor development practices of the past. The MFP aims to provide a balance of economic and social development, in an environmentally and technologically sustainable urban form. A 'smart city' is to be developed over the next 20-30 years at a specially selected site in Adelaide's north western suburbs (see Figure 6.11).

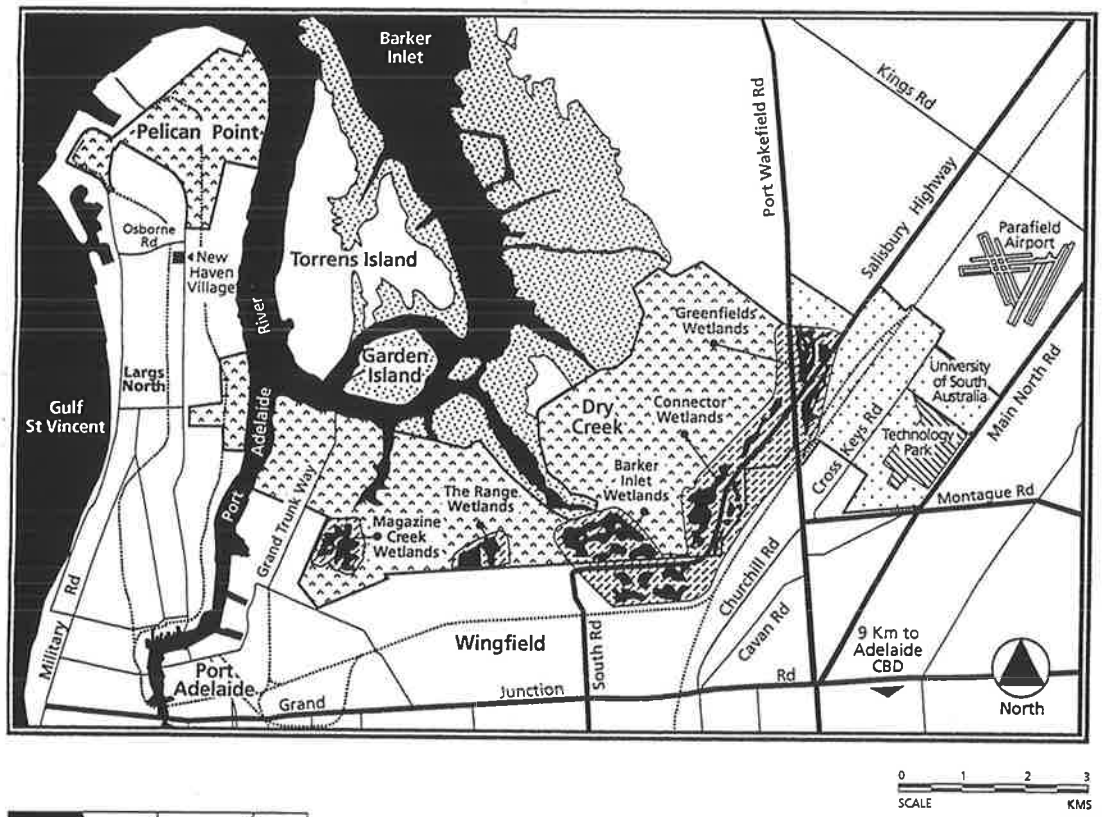
The MFP core site consists of low lying and filled land, situated behind levee banks. Disposal of solid and liquid wastes and other fill materials has occurred and will continue in the northern portion of Wingfield, both within and immediately adjacent to the site. In general, most of the core site is in public ownership. Several parcels of land are leased to private interests (rifle range, motor sports, industry), although the most significant area that is not in public ownership or is subject to lease arrangements is the Penrice salt production facilities at Dry Creek (PPK, 1992).

To the south of the MFP core site is the Wingfield industrial area. This area contains many established manufacturing and service industries as well as a substantial amount of vacant or under-developed land. Most of this area is zoned General Industry, with smaller pockets of Heavy and Special Industry. There are some small residential areas at Dry Creek and Ottoway.

On the basis of a Commonwealth State agreement reached in 1994, the original core site for the MFP was extended by 480 ha to include Technology Park and adjacent land (MFPA, 1994; 1996a). This extension would allow development of the smart city to progress while environmental remediation and engineering issues associated with the original core site were addressed.

Technology Park consists of a 85 ha site approximately 1 km east of the MFP core site. The Park has been developed for the establishment of technology intensive organisations and has been successful in attracting many companies. Indeed more information technology and telecommunications companies, such as Motorola and Galaxy Pay TV, continue to establish operations at the site. More than 1,300 people are now employed at Technology Park, an increase of nearly 400 since the beginning of 1995 (MFPA, 1996a).

In June 1994, consortia were invited to register proposals to develop the MFP city, a combination of industrial, research and education activities in the socially and culturally diverse urban environment. A strong national and international response





MFP Stage One Development

Technology Park

Future MFP Development

Wetlands

Mangroves

Figure 6.11
The Multi Function Polis (MFP) Core Site

was received, and in 1995 a consortium of Delfin Property Group Ltd and Lend Lease Corporation Ltd was engaged to prepare a concept design and business plan for Stage One of the MFP urban development. As part of the planning process, an international design workshop was held in Adelaide in April 1995. The workshop formulated a base structure plan for the project providing for some 5,000 dwellings and approximately 10,000 people.

The 620 ha site for Stage One involves an extension to the original MFP core site, taking in sites at the Greater Levels previously owned by Technopolis Pty Ltd and Woolworths Ltd. It also includes Technology Park and the immediately adjacent Levels Campus of the University of South Australia.

The Delfin Lend Lease Consortium predict that the first stage of development will attract total construction investment of $950 million over a 10-12 year period, with substantial economic benefits accruing to the State. Some 1,200 to 1,500 construction jobs will also be created (MFPA, 1995).

MFP Australia believe that Stage One will bring substantial economic, social and environmental benefits to the region. It will:

- create 1,500 construction jobs, including 500 in the housing industry, during its 10 year construction period;
- create 4,500 permanent new jobs in high technology industry on site (which the multiplier effect is estimated to raise to 10,000 jobs);
- bring in more than $850 million of work to the engineering and construction industry;
- attract international and interstate investment of more than $200 million;
- quadruple to 160,000 m^2 the commercial space on site;
- increase significantly exports in environmental management technologies, high-technology products, housing related products and education;
- place an emphasis on quality in a region which is expected to accommodate up to 50 percent of Adelaide's new housing over the next 20 years;
- become a benchmark urban and social project of world significance and interest;
- help to resolve regional stormwater, traffic and environmental challenges;
- provide a focus for Adelaide's growing initiatives in technology; and
- boost tourism and local wealth generated by visits and conferences.

MFP Australia are also engaged in a number of other ventures that impact upon the northern Adelaide plains. Management and restoration of the urban and natural environments are the themes of several programs, particularly as it relates to wastewater, stormwater and catchment management. MFP Australia have lead the development of the Barker Inlet Wetlands (a 172 ha wetland system), The Range and also Magazine Creek wetlands. Together with the City of Salisbury's Greenfields and Connector Wetlands they will form what is believed to be the world's largest constructed urban wetlands system (MFPA, 1995). It will make a significant contribution towards minimising the pollution of the fragile marine environment by capturing, purifying and controlling the release to the sea of a major portion of Adelaide's runoff. Other projects include the Virginia Pipeline Scheme for the reuse of treated effluent from the Bolivar STW; the restoration and

management of the Wingfield Landfill; and restoration and management of the landfills on Garden Island with rehabilitation of the natural environment.

The University of South Australia campus at The Levels is located immediately to the north of Technology Park. The Levels campus occupies approximately 70 ha of land and currently focuses upon the engineering and applied sciences disciplines.

Vast areas of broadacre land are located adjacent to The Levels campus and Technology Park. The broadacres include a large amount of privately owned land, some of which is vacant and some which has been subdivided for industrial use during recent years. Also located in this area is land in State Government or semi-government ownership such as the South Australian Meat Corporation (SAMCOR) land and former stock paddocks east of Main North Road.

6.5. The Direction of Future Development

During the 1950s and 60s, the economic and political circumstances of the time lead to an emphasis upon physical, rather than strategic planning, for an expanding population and economic base, consistent with post-war trends. An indeed little was provided in terms of a long term direction for urban development until the preparation of the *Report on the Metropolitan Area of Adelaide* by the Town Planning Committee in 1992.

The 1962 Town Planning Committee predicted, with some considerable accuracy, the amount of land required for the next 30 years. That land was indeed taken up, but by 300,000 fewer people than forecast. The rapid increase of households compared to population over the plan period was not foreseen. Unfortunately, several other of the crucial working assumptions were wildly astray – demographics, car ownership, prediction of workforce structure (Badcock, 1987) – which has meant that some metropolitan development has been misguided.

Since that time Adelaide has essentially continued to grow incrementally along a north-south axis, with some loose strategic planning guidance provided during the 1970s, but arguably in spite of various development alternatives canvassed in several reviews of metropolitan development (Badcock, 1987).

During the late 1970s and early 80s, the notion of 'progress' and 'development', which had underpinned Western economies since the industrial revolution, were being seriously questioned at all levels, with an emerging emphasis on the environment and quality of life. Following the creation of the Urban Development Coordinating Committee by State Cabinet in 1983, a discussion paper was prepared to publicly canvass a number of metropolitan growth options, which was released in February 1986. The options were evaluated in detail during 1987 and the adopted strategy reported in 1987 (UDCC, 1988).

The strategy essentially reaffirmed the growth patterns and staging sequence for the development of new residential land that was originally established in 1978 (with minor amendments). The staging sequence is illustrated in Figure 6.12; in the northern suburbs there would be:

- continued concentration of development at Salisbury;
- phased development at Golden Grove;
- commencement of development at Smithfield in parallel with Golden Grove as required following the substantial completion of development at Salisbury;
- development of Munno Para West; and
- deferral of development of Evanston until the substantial completion of development in Smithfield (UDCC, 1988).

A further two areas were identified for future fringe housing, including the Sandy Creek–Roseworthy region in the north. These areas were not considered to be required until around 2000-2001, but could possibly be deferred depending upon the success of the recently adopted urban consolidation policy.

Despite these planning efforts, Adelaide's development became the cause of protracted and heated debate. Many projects, urban growth, housing costs and homelessness, traffic congestion, pollution and vandalism all provoked strong reactions. Much of the debate focussed on individual development proposals, often because of the absence of an overall vision for Adelaide's future development (Planning Review, 1991). This recognition of the need for preparation of a long term development plant and a change in the direction of urban development initiated the only comprehensive review of metropolitan development since that conducted in 1962, which was reported as the *Planning Strategy for Metropolitan Adelaide* (Planning Review, 1992a).

The review found that the outward growth of Adelaide had resulted from relative affluence, a rapid expansion in numbers of households and the dominant desire for detached dwellings. It was considered that after the turn of the century, Adelaide's urban growth will be concentrated to the north though slower growth could continue in the south. This growth would require the development of centres for economic and social activities in the growth areas. Furthermore, to achieve the shift towards growth in the north, the quality of urban living environments on the northern Adelaide plains needs to be improved.

Major strategies were therefore developed and directed towards greening the northern plains and reassessing northern development in the context of broader social, environmental and economic concerns. The principles upon which the longer term view is based are: creating employment centres closer to where people live, providing a satisfactory residential environment, protection of areas of ecological importance, conserving natural resources, redressing inequities in urban areas, preserving the essential character of Adelaide and reducing energy use and transport demand. The details of the strategies which will guide development in the northern suburbs are summarised below (after Planning Review, 1992a).

6.5.1. Population Characteristics

The northern Adelaide plains will experience continued growth in the decades to come, almost certainly accommodating the major share of the expanding metropolitan population.

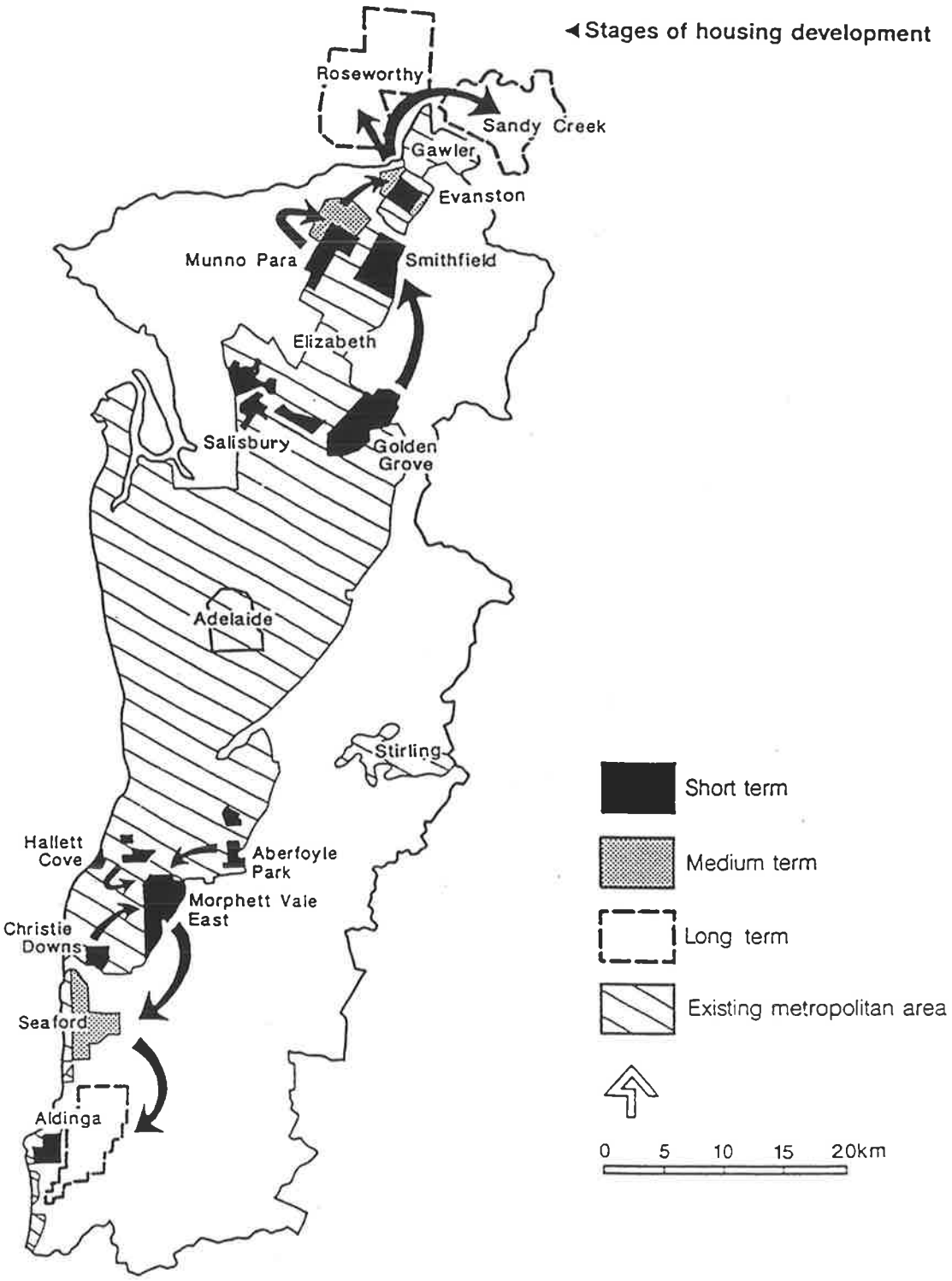


Figure 6.12
Metropolitan Adelaide Development Staging Sequence
(after UDCC, 1988)

The region will see growing numbers of families with young children resulting in continuing demand for family housing and services. The demand for children's services associated with the employment of women is also likely to increase due to increasing numbers of women entering the workforce.

An increasing number of elderly people will live in the outer northern suburbs. Indeed, over the period 1986 to 2016, the number of people 65 years and older is expected to triple and will be equivalent to one quarter of Adelaide's elderly population. As a result, there will be increasing demand for a range of aged services, facilities and housing.

Particular parts of the northern region have a large number of people disadvantaged in terms of socio-economic status, transport need and health. Specific strategies will aim to improve the living conditions and quality of life of people in those areas.

6.5.2. Housing Demand and Choices

People value highly the ability to get the housing they prefer; their preferences should not be unnecessarily constrained.

Urban consolidation, achieved through development of vacant sites and redevelopment of degraded areas, will provide a significant number of new and more diverse houses at higher densities. Yet even with vigorous consolidation strategies, the character of existing urban areas will change only slowly and the number of houses provided will not be sufficient to divert all demand from outer areas.

Fringe development is not a problem in itself, but there are problems in creating and maintaining high quality living environments in some fringe areas.

Over the 1980s, the rate of growth of household formation was more than twice that of population growth. These trends are forecast to continue and are likely to result in shifts in demand for housing away from the common detached house towards more compact dwellings. The strong and continued preference of the majority of people in Adelaide is for owner-occupied detached houses, but other forms of houses are desired by an increasing proportion of people, such as the young, single and elderly (Stevens *et al*, 1991).

The fastest population growth will occur in the northern sector. The occupancy rate for the region will continue to be higher than for the central sector, reflecting the continued settlement of young families in the area. Occupancy rates will, however, decline reflecting the increasing numbers of smaller households which are emerging.

As the population grows, so too will the number of dwellings required to house them. However, the composition of households will continue to change, and the trend toward fewer persons per household will mean that disproportionately more dwellings will be required.

Greater diversity in the range and style of dwellings will also be needed. Housing needs will become more diversified as the number of small single person and youth and elderly couple households increase. This is not to say that families with children will not remain one of the most significant groups in the community, rather they will no longer dominate the housing market.

The Planning Strategy (Planning Review, 1992a) had predicted that the fastest population increase in Adelaide would occur in the northern sector. This prediction is being fulfilled as illustrated by data on the number of single dwellings approved in a twelve month period. At March 1992, the number of approvals for northern Adelaide[1] was 2,300 but this had increased to 3,200 by December 1992 as compared with only 1,750 approvals in the southern sector (DHUD, 1994).

By the year 2011 it is forecast that the population of the northern metropolitan region will have increased from 181,500 in 1991 to 263,600. It is expected that the distribution of this growth will be as shown in Table 6.11. These figures are not a prediction but a projection of past trends.

Table 6.11
Distribution of new housing in northern Adelaide, 1994-2001

Local Government Area	Allotments per Year (1994/95)
Gawler	200
Elizabeth	50 through redevelopment
Munno Para	700, increasing to 900 by 2001
Salisbury	1100, decreasing to 850 by 2001

Based on these assumptions, there is likely to be a shortfall in the supply of land available to meet demand by 2011. However, over the coming years to 1999, there is likely to be an over supply of available housing land in northern Adelaide.

The redevelopment of the Defence property of DSTO Salisbury with consolidation of the research and development activities into a smaller parcel of land will open up around 500 ha for new urban development beyond that considered in the projections outlined above. This will provide an opportunity for the establishment of a higher quality of housing and urban form, checking the spread of residential suburbs towards Gawler, and making better use of the existing infrastructure in Salisbury and Elizabeth.

6.5.3. The Environment of the Northern Plains

South Australia has experienced the highest rate of mammal extinction in the world; over 85 percent of native vegetation has been cleared in South Australia's agricultural area; and there is doubt about the quality of future water supplies. A

[1] *Northern Adelaide in this context means the Local Government Areas of Gawler, Munno Para, Elizabeth, Salisbury and Tea Tree Gully.*

positive new direction to future planning is offered in the principles of Ecologically Sustainable Development (ESD).

The sacrifice of the natural environment to urban sprawl will not be perpetuated under future development plans. The maintenance and improvement of public open space and recreational facilities, with rehabilitation and restoration of the natural environment, will be a high priority objective.

The environmental significance of Adelaide's projected population increase lies in how the physical development is planned and managed to reduce pressure on native plants and animals, protect water catchments, avoid major conflicts between urban and rural land use and reduce energy consumption.

Early proposals for the establishment of the Metropolitan Open Space System (MOSS) sought to create a clearly defined and connected system of land which has an open or natural character. The system was intended to provide a visual contrast to the built urban environment, and contain a range of active and passive leisure uses (BTP, 1989).

The need for such open space linkages has been identified and confirmed by the Planning Strategy for Metropolitan Adelaide. The strategy also has a number of references to planning for regional open space using the MOSS for recreation purposes. The strategy stresses the need for linkages between regional open space areas and the development of a network of walking and cycling trails along these linkages (DHUD, 1993).

A metropolitan wide project is proposed for the management of native wildlife corridors, the Metropolitan Open Space System (MOSS) and a coastal linear park, in which places of cultural and environmental significance such as the mangroves of Dry Creek and St Kilda, the Hills Face Zone and Mt Lofty Ranges are incorporated. The Salisbury, Elizabeth and Munno Para councils have a stated policy supporting preservation of the hills escarpment face as rural land on the basis that it is the single most significant topographical feature of the Northern Adelaide Plains (Cameron, 1979).

The shift towards growth in the north will require the quality of the urban environment to be significantly improved. The first stage will involve progressively replanting the plains with native species. Areas for revegetation include the MOSS land as well as public road reserves and land in Commonwealth, State and local government ownership.

Opportunities for development of coastal recreation and leisure other than at St Kilda will be limited, so that the sensitive ecology of the mangroves, wetlands and fauna habitats are conserved and available as resources for education and eco-tourism.

As part of the Elizabeth regional centre redevelopment, the Elizabeth Aquadome, Central Districts football club oval and facilities and a future indoor sports stadium are likely to be integrated into a regional recreation and sports complex called the 'Recreation and Sports Hub'. This type of integrated facility would enable

significant economies of management and operation and it would become a regional focus for the northern region (DHUD, 1993).

The open land separating Gawler from Munno Para will be retained, as will the productive market gardens of Virginia. There is a possibility that the Gawler race-course could be relocated to a site in Munno Para within the MOSS (DHUD, 1993).

There are few significant water courses crossing the northern Adelaide plain, and the few that do exist have since been converted into concrete drains. Gawler River and its tree lined banks are an important natural asset to the rather featureless plains and one which ought to be protected against further degradation and abuse by the uncontrolled mining of loam deposits.

All levels of government will cooperate and support stormwater management initiatives for the northern plains, including recharge of local aquifers, ponding facilities to improve local amenity and provide native bird sanctuaries, harvesting of stormwater for irrigation of local parks, and the reduction of discharges of the sea to reduce impacts on the marine environment.

Stormwater management systems will be geared toward maximum retention and reuse including recharging the underground aquifers depleted through intensive horticultural bore irrigation.

6.5.4. Land Supply

Demand for new housing will be met by increasing the amount and rate of redevelopment and through continued, although slower, fringe growth to the north and to a lesser degree to the south.

The task will be to maintain sufficient land to match market demand and the community's preferences, and to improve the image and services especially in areas of recognised disadvantage and in the region as a whole.

Housing in areas of Salisbury will be fully developed in the near future. Golden Grove will continue to develop until it is complete in 1997. The Commonwealth land at DSTO near Elizabeth is likely to become available for development by the year 2000. This comprises around 500 ha and will be important for continuing land supply in the north.

Although growth has been slow in the northern parts of Munno Para, the southern parts have developed in a concentrated manner but this has been poorly located in terms of accessibility to the Elizabeth Regional Centre and lacks the advantage of an accessible focal point of facilities capable of providing for the full needs of that population. Hence, development should be focused on the Munno Para Centre prior to major urban expansion commencing south of Gawler. Opportunities for infill urban development in and around Gawler should continue to be realised in the interim period.

Redevelopment of the older areas of Munno Para comprising extensive tracts of public housing development is warranted. A comprehensive examination of that area should be undertaken to identify inefficient and degraded areas, and also new housing opportunities for a range of accommodation needs and which promotes also greater diversity of housing form and tenure, and lifestyle. Redevelopment of these areas by comprehensive renewal and also sensitive infill is warranted.

Residential development will need to proceed east and west of Main North Road at Munno Para if supply is to keep pace with demand and housing affordability maintained. In particular, a significant level of residential development can be expected to occur in the Smithfield East and Smithfield West areas over the next 10 years.

The SAULT land to the west and north of Elizabeth and Smithfield Plains provides the best opportunity for integration and should be the next location for residential development in the areas west of Main North Road.

A buffer of non-urban land between Munno Para and Gawler will create distinct, contained communities with an individual focus. This will ensure more people live closer to the central areas of Adelaide, reinforce the role of major existing centres and employment areas and assist in the preservation of Gawler's unique identity and character.

The expansion of Gawler from its current urban fringe will ensure more efficient use of existing infrastructure (physical and social), facilitate better integration between existing and new urban areas and avoid the creation of isolated communities. Areas for urban expansion exist to the north, west, south-west and east of the existing built-up area. Together they form a compact area separated from the surrounding farm lands.

The communities of Angle Vale, One Tree Hill and Virginia have expressed a desire to retain the individual identities of their townships. Tight controls are therefore required on the rural outskirts to maintain and where necessary reinforce a sharp contrast between township and rural areas.

The establishment of an urban-rural boundary with the horticultural area to the north west effectively creates a northern growth corridor of approximately 8 km width between the horticultural area and the Hills Face Zone. The northward extension of this corridor is limited by a range of environmental and heritage constraints north of the town of Gawler, including the proximity of the Barossa Valley (Perkins, 1994).

6.5.5. Elizabeth Regional Centre

Elizabeth regional centre is designated for major expansion of employment and services. Land is available for development within the current centre so long as consideration is given to long term parking needs. The centre can attract further substantial retail development in the short term. They should be designed to enhance the centre as an attractor of investment as well as its amenity.

As the Elizabeth Centre redevelops, it will provide easier access to the rail station, so that the railway line can better perform its function of linking Elizabeth to the central business district of Adelaide.

Increasing the visual and environmental amenity of the region and the regional centre is a priority. A linear park, as part of the MOSS system, should be designed to connect through the DSTO land to the immediate west of the centre and link floor control and open space areas to the west.

6.5.6. Technology and Industry

The MFP is an economic development concept with an important urban dimension, focussed on the core site at Gillman, Dry Creek and The Levels. Significant investment has already taken place in the areas of Port Adelaide and Technology Park. This needs to be continued and augmented to deal with environmental health concerns, restoration of degraded and contaminated land and effective effluent and stormwater management.

From technology park through to Port Adelaide, new industries are expected to take advantage of industry clusters and new infrastructure, as well as direct access by road, air, sea and rail to export markets arising in part from MFP related businesses.

Some older industrial areas will be gradually turned over to residential, community and recreational purposes. Development should capitalise on service and transport infrastructure already built or programmed in Port Adelaide, Dry Creek, Technology Park and The Levels to support this projected economic activity. In this way, development and spending will serve the strategic needs of both the metropolitan area and the MFP.

MFP business and related recreational and residential development will take place on the eastern side of the Le Fevre Peninsula, in Port Adelaide centre and the area to the east, in Dry Creek and The Levels industrial area, in Salisbury and Elizabeth.

The road network will continue to develop, and the capacity of the network increased to support both the increased population growth and long distance road freight transport to and from the north and north western suburbs.

6.5.7. Traffic and Transport

Adelaide's growth should be progressively focussed on the northern Adelaide plains (Planning Review, 1992a, p.12). Urban renewal should also be concentrated at higher densities around centres of activity and along major transport routes.

A key objective for Adelaide's future is to reduce the demand for travel. Services are more accessible if located in neighbourhood, district or regional centres and well served by public transport.

Adelaide's road system provides relatively little congestion, flexibility in choice of routes, speed and comfort, factors which will continue the dominance of the care as

the main form of personal mobility. It is anticipated that major investment in the road network will be focussed in the north and north-western parts of the metropolitan area to support likely growth in industry, particularly manufacturing.

Nevertheless, the recommended structure for the future public transport system has two main elements. The first is a system of local transport focussed on centres of shopping, commercial and social activity which serves the needs of each local community. The second is a mass transit system joining the main centre of the metropolitan area together.

6.5.8. Horticulture

The recognition of the importance of the Northern Adelaide Plains horticultural region to Adelaide and the State will ensure its survival and protection against the encroach of suburban development. With greater certainty about the permanence of the horticultural area and the families it supports, growers and industries will seek to consolidate their position in the local market place and expand their export markets. Economic security and prosperity will be a more likely outcome.

An estimated 50 percent expansion of cultivated land could be achieved if new markets were developed and a suitably priced sustainable water supply was available. Indeed, it is estimated that an additional 9,200 ha is available for horticultural plantings over the 3,500 ha already cropped if additional water sources are developed for irrigation (Roger Stokes & Associates, 1995a). The future of the areas is threatened by deterioration of the groundwater resource. In the Virginia area a 40 metre deep cone of depression has developed in the aquifer since the 1950s and salinity has increased. Irrigation is a pre-requisite to the success of the horticultural industry. Even with current water restrictions in place longer term sustainability of the industry cannot be guaranteed without a new water source.

Accordingly an alternative water source to augment groundwater supplies must be found or restrictions will need to increase. Options considered for providing an alternative water source include the use of tertiary treated effluent water from Bolivar, diversion of stormwater from the hills and local runoff being used to recharge the aquifer, and construction of dams on the Gawler River. The most realistic option is considered to be the reuse of treated effluent water.

6.6. Summary

In terms of production relative to other market garden regions in South Australia, the Northern Adelaide Plains is responsible for the majority of the State's fresh vegetables. More than 75 percent of all celery, egg fruit, endives, witloof, parsnips, spinach, beetroot and glass house tomatoes are grown on the NAP. In sheer economic terms, the region is of considerable importance to northern Adelaide and the State.

Accordingly, future development in the area should be founded on a basis of protecting and promoting what is clearly a viable and valuable agricultural resource.

The retention of much of the area for market gardening purposes will, in itself, retain its open character. However, the opportunity existing to build on the area's natural features, limited as they are, so that a permanent and identifiable open space network is established. The major elements of the open space system are therefore proposed to be:

- 100 metres either side of the Gawler River for its entire length;
- the Port Gawler Conservation Park and adjoining coastal margins;
- Thompsons Creek, north of the salt evaporation ponds;
- the Angle Vale Recreation Reserve;
- Penfield Recreation Reserve located to the north of the intersection of Womma and Andrews Roads; and
- Rural B land between the industrial land of Gawler and the residential land of Munno Para.

Development to the north west is appropriately curtailed by the horticultural triangle. An urban-rural boundary has been defined following a land suitability assessment (draft Northern Adelaide Plan, 1993). These strategic planning results have begun to act as a catalyst for economic initiatives in the area. The major initiative is a government lead commitment to construct a $40-50 million pipeline to deliver treated effluent to horticultural properties in parallel with the reduction of groundwater use. Other initiatives include Landcare projects, aquifer recharge pilot studies, education of horticulturalists in reduced chemical use, experiments with efficient irrigation methods, exploration of additional export markets for fresh quality produce, and feasibility studies on the potential to expand local value-adding enterprises (Perkins, 1994).

Beyond the turn of the century, diversity can be expected to be a dominant characteristic of Adelaide's population. That diversity will need to be reflected in local living environments. Needs at different stages of life will need to be met by choice of the form, size and layout of houses. Neighbourhoods should provide support, safety and services within easy reach.

Slower fringe growth, major environmental improvements and the emergence of a multi-centred city will be the cornerstones of Adelaide's development as it moves into the next century (Planning Review, 1992a).

High mobility is likely to be desired by the Adelaide community. Although technology may remove much of the need for travel and many activities will be located closed to where people live, travel for work or pleasure is likely to be a feature of the Adelaide lifestyle. Private cars are expected to be the preference of the vast majority of the community.

However, public personal transport will be of many forms. A rapid public transport system would concentrated on linking major urban centres supported by park-and-ride interchanges, local and community bus services, cycle routes and walkways for the most efficient and complementary use of each transport form. Within relaxed and safe neighbourhoods, walking and cycling could be the principal ways of getting around.

Excellence in science, engineering, education, law, medicine and the arts should provide resources for local industry and export. 'Information processing', recreation, tourism (and notably eco-tourism) and hospitality may be particularly important.

The central business district is likely to maintain its dominant commercial and cultural influence. More distribution of employment and other activities throughout the metropolitan area is, however, likely. Well designed multi-use buildings should allow greater mixture of activity in suburban centres.

Good environmental practice will prevail throughout the city. Urban development will create less demand for energy through more efficient layout of land, efficient design and use of materials, use of solar power, and reuse of water and sewage. The water catchments would be guarded to protect water quality, and the marine environment secured. Stormwater will be a resources and the creek system a major aesthetic and environmental asset to Adelaide's suburbs.

Perhaps one of the greatest opportunities for urban development which provides economic, social and environmental benefits to the region lies in the proposed MFP Stage One development. In close proximity to industrial infrastructure and sources of labour, with links to the ports and the city of Adelaide, the proposed site is well located. The involvement in the newer, clean and high technology growth industries of environmental management, information technology and telecommunications, and education provides abundant opportunity for economic growth and prosperity. On top of all that, the development will occur in what is essentially a greenfields and wasteland, where environmentally appropriate technologies for land rehabilitation and development can be employed. There is tremendous potential, it now only needs to be recognised in the coming decades.

7

Water Resources for the Northern Adelaide Plains

The Northern Adelaide Plains is a prime horticultural region on the outskirts of metropolitan Adelaide. The availability of good groundwater has been the reason that the horticultural enterprises have successfully developed in the Virginia/Angle Vale area into such an important industry for South Australia. Over-use of the groundwater resources has resulted in a gradual decline in groundwater levels and water quality. Indeed, if pumping continues at the present rate, horticultural activities will be severely restricted and may ultimately decline.

Alternative water resources and management strategies therefore need to be developed to sustain the horticultural industry on the Northern Adelaide Plains, as well as to mitigate against other water-related environmental problems. A more complete understanding of the nature, availability and potential for use of fresh and waste water resources on the NAP is therefore required. The following text describes the range of available water resources and their use and development potential.

7.1. The Climate

The South Australian climate is characterised by hot, dry summers with relatively mild nights, and cool but not severe winters with most rainfall occurring during the months of May to August.

South Australia is by far the driest of the Australian States and Territories with over 80% of the state receiving an average of less than 250 millimetres of rain annually. Adelaide is the driest capital city of any of the Australia states, with only 500 mm of rainfall each year. Over the southern half of South Australia the main source of rain is from showers associated with unstable moist westerly airstreams occurring regularly during the winter months of June to August (Baker, 1991).

The rainfall is generally light and unreliable in the summer months because of the influence of air masses from the interior of the continent. Summer rainfall is due to occasional thunderstorms or an unusually northerly low pressure system.

The wettest part of the state is in the Mount Lofty Ranges, immediately east of the capital, Adelaide. The Ranges rise to around 730 m above sea level, presenting a steep western escarpment to the Adelaide Plains on which the city stands, and therefore have an orographic affect upon rain bearing cloud masses. The Mount Lofty Ranges encompasses almost all of the catchment area available for metropolitan water supply.

The hottest months are January and February, when monthly-mean maximum are about 29°C and 25°C in higher parts of the Mt Lofty Ranges. Prolonged periods with temperatures over about 38°C occur in January in association with northerly airstreams with long trajectories over the interior of the continent.

Periods with temperatures below 16°C are confined to the May to September period. They are usually associated with intense depressions moving across the Great Australian Bight, allowing the influx of cold southerly to south-westerly airstreams from far south of the continent. Mt Lofty receives snow on average 1 day per year, while hail is most frequent during winter and spring, usually in association with cold fronts (Linacre & Hobbs, 1977).

7.2. Rainfall

An examination of available historical data was undertaken to establish general rainfall characteristics for the Northern Adelaide Plains region. Rainfall data was provided by the Water Resources Group of DENR from their HYDSYS (hydrological time series) database. Some data was also provided by the Bureau of Meteorology using their Drizzle program (using archived monthly rainfall data) and also through DENR in the HYDSYS format.

Data was available for 22 rainfall gauging stations, of which 18 were daily-read rainfall stations. A brief summary of station information is presented in Table 7.1. The region is well instrumented to record total daily rainfall, with 14 daily rainfall gauging stations currently in operation, however the installation of additional pluviometers throughout the region is necessary for more detailed hydrological studies (such as urban flooding).

The station name shown is that associated with the station number stored in the HYDSYS station database. The period of record is the duration from the commencement of monitoring to the end of the most recently digitised HYDSYS data file that was available at the time of writing. Those stations for which the period of record is shown as 1992 are typically still in operation. More detailed information is provided in Appendix A.

The period of record of daily-read rainfall ranges from 132 years at station 023078, down to 17 years at station 023092. However, the record is not necessarily complete over the period shown at all stations; station 023092 has records between the months of July and December only. Pluviometer (continuous) records are available for a maximum period of 6 years.

The analysis of rainfall for the region has shown that the Northern Adelaide Plains lies within a region of low mean annual rainfall, when compared with the majority of urban centres in Australia. Aggregating the records for all rainfall gauging stations, the mean annual rainfall for the region as a whole is found to be 445 mm. The wettest year on record (based upon the average rainfall over the region) is 1889 with a total rainfall of 780 mm, while the driest is 1967 with 234 mm. 1992 was another very wet year with a total rainfall of 709 mm.

Table 7.1
Northern Adelaide Plains Rainfall Stations

Station Number	Station Name	Data Type[1]	Mean Annual Rainfall, mm	Period of Record
023003	Gawler Railway	D	457	1924 - 1969
023013	Parafield Aero Amo	D	459	1929 - 1992
023015	Penfield Weapons Research	D	466	1948 - 1979
023016	Port Dock Railway Station	D	415	1925 - 1986
023018	Torrens Island Quarantine Station	D	439	1928 - 1996
023023	Salisbury Post Office	D	468	1871 - 1996
023025	Smithfield Post Office	D	471	1898 - 1996
023026	Pooraka Post Office	D	492	1876 - 1996
023028	Two Wells Post Office	D	401	1881 - 1993
023030	Virginia Post Office	D	436	1881 - 1996
023037	Parafield Plant Introduction Centre	D	492	1907 - 1996
023057	Northfield Research Centre	D	511	1966 - 1996
023078	Gawler Post Office	D	476	1861 - 1996
023079	Dry Creek (Saltworks)	D	434	1960 - 1996
023080	Elizabeth Park (Buick)	D	519	1972 - 1996
023081	Bolivar Treatment Plant	D	454	1972 - 1996
023083	Edinburgh Meteorological Office	D	447	1972 - 1996
023092	Virginia 2	D	IAR[2]	1970 - 1987
AW504553	Little Para Reservoir Met. & Pluvio.	C	517	1987 - 1992
AW505504	North Para River at Turretfield	C	428	1986 - 1992
AW504566	Leichardt Avenue Pluviometer	C	N/A	1992 - 1993
AW504567	Joslin Avenue Pluviometer	C	N/A	1992 - 1993

(1) C: continuous pluviometer data, D: daily-read rain gauge
(2) Incomplete Annual Record over period of record preventing calculation of mean annual rainfall

Annual rainfall ranges between 397 mm and 522 mm at gauging stations across the region, with total annual rainfall tending to decrease moving towards the north-west of the region, as shown in Figure 7.1.

The distribution of monthly rainfall is typical of the temperate climate of the region. Figure 7.2 illustrates the average monthly rainfall for the region, as well as the minimum and maximum of mean monthly rainfall for all gauging station within the region. On average, over 60 percent of total annual rainfall occurs during the 6 month period of May through to October. The highest monthly rainfall and lowest

variability occurs during June and July (rainfall is on average 57 mm), as compared with February which records the lowest monthly rainfall (16 mm) and highest variability.

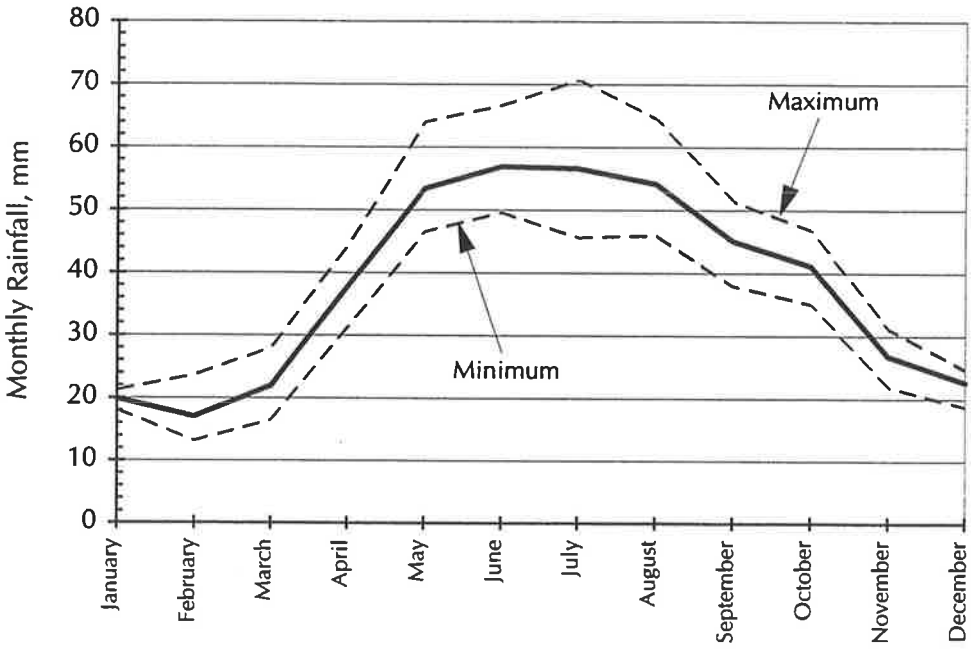


Figure 7.2
NAP Monthly Rainfall Characteristics

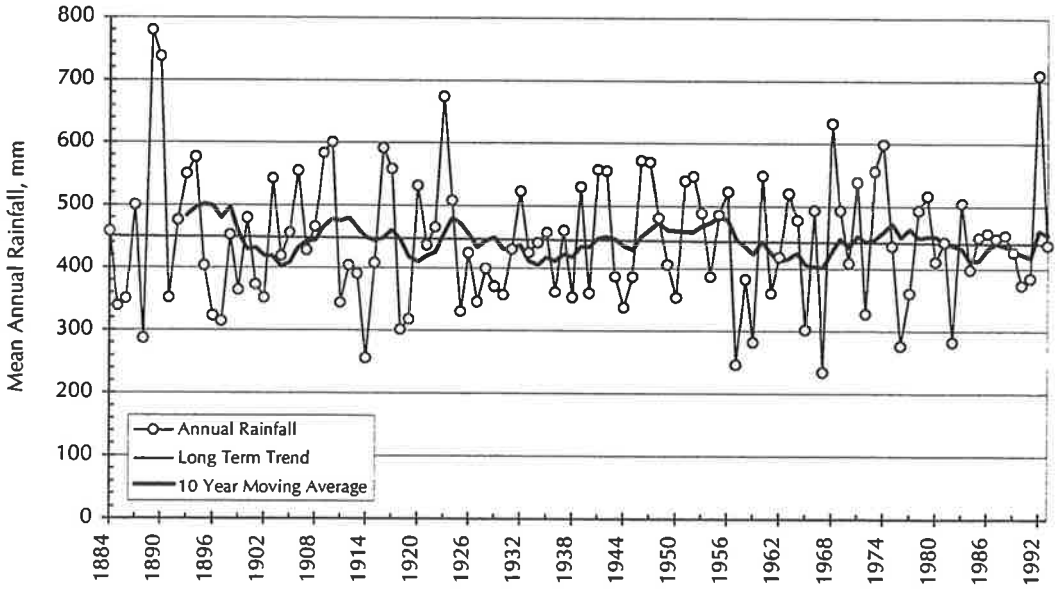
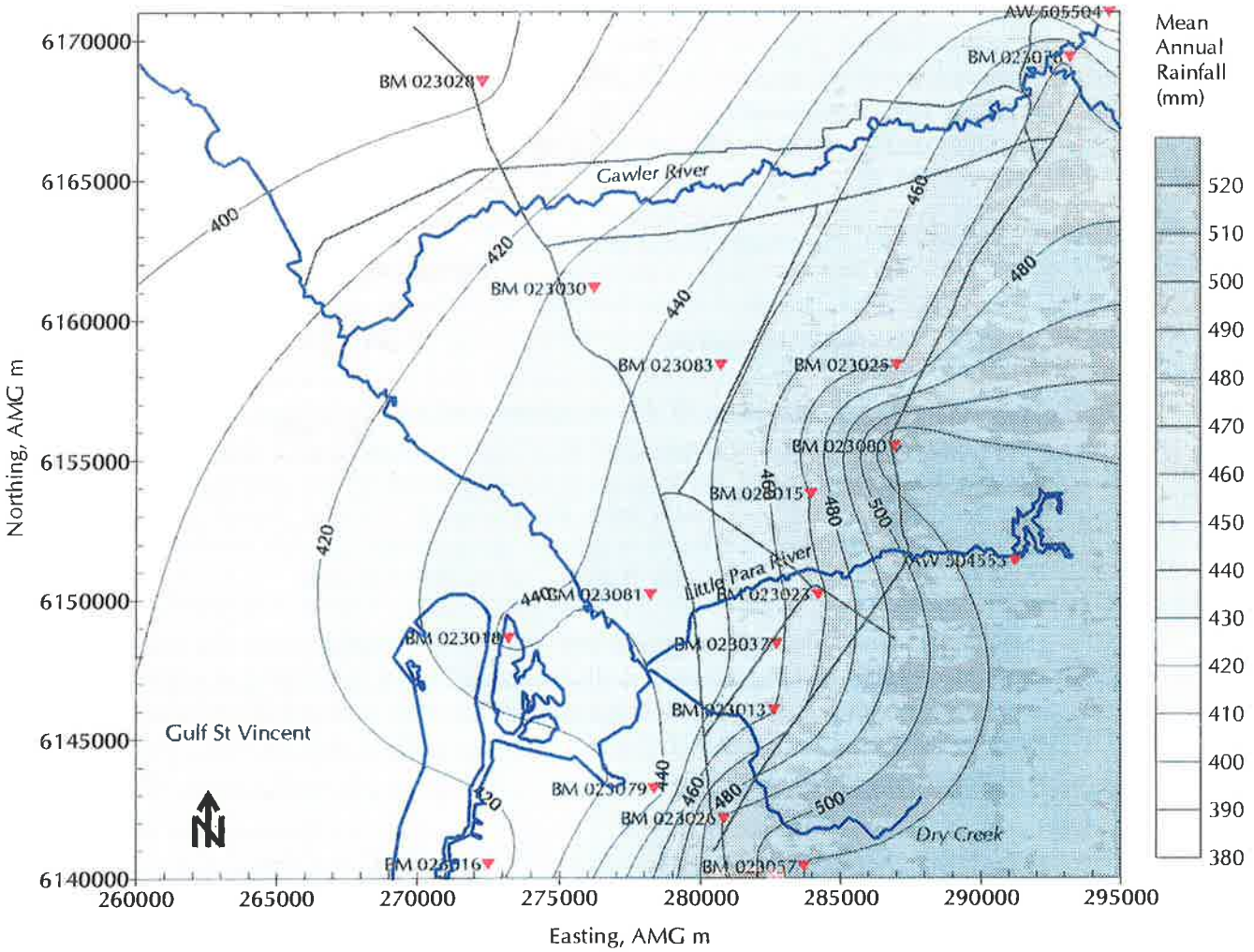


Figure 7.3
Historical Rainfall Distribution for the NAP Region

As can be seen in Figure 7.3, the trend of regional annual rainfall is negative in slope, indicating a marginally decreasing mean annual rainfall. This phenomena



LEGEND

- Rainfall Gauging Station
- Major Road Corridor
- Coastline or River
- 450 Rainfall Contour (Isohyet)

Figure 7.1

Mean Annual Rainfall Distribution for the Northern Adelaide Plains

may be associated with the downward trend of a long-term climatic cycle, however this is not supported by the plot of cumulative deviation of annual rainfall from the mean (Appendix A). Nor is the introduction of additional rainfall data from more recently installed gauging stations likely to cause this trend; most of the newer stations have been installed in higher rainfall areas and the mean annual rainfall for these stations is generally found to be higher than the regional mean. Furthermore, a trend toward higher mean annual rainfall is usually observed with increasing urbanisation, as reported by Landsberg (1970). It is also interesting to note that there appears to be less variability over time with the 10 year moving average of the mean annual rainfall. The cause of these trends remains unknown.

7.3. Surface Water Resources

The surface water resources of the Northern Adelaide Plains are restricted to two ephemeral rivers, and stormwater runoff. These sources do not provide a reliable supply, nor are there any existing facilities for storage of the intermittent flows to improve the availability of water from these sources. Hence, development of the region has hinged upon a reliable supply of groundwater, as well as water supplied from the reservoirs in the Mt Lofty Ranges and the River Murray.

Only a few streamflow gauging stations have been established in the region; the location of these gauging stations is illustrated in Figure 7.4. Most of these have a short or discontinuous record, and thus the information derived from these records must be used with caution. A complete listing of gauging stations and other details is provided in Appendix B.

7.3.1. Gawler River

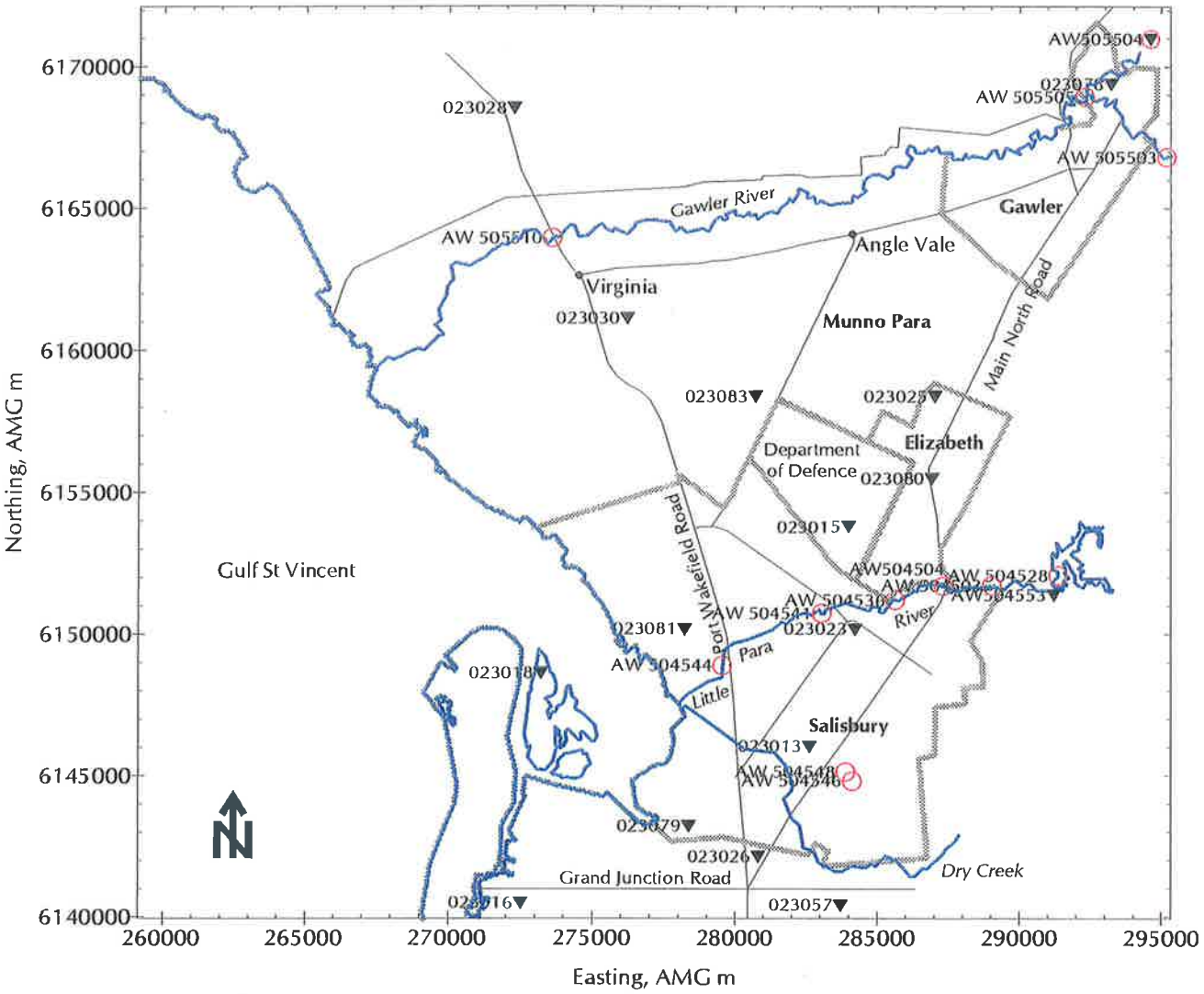
The Gawler River is an extension of the two major tributaries of North Para River and the South Para River, their confluence occurring at the township of Gawler.

There are relatively few streamflow gauging stations established on the Gawler River. A useful period of digital record was available for only two gauging stations, with additional supplemental record obtained from the nearest upstream gauging stations on the North Para and South Para Rivers; refer to Table 7.2.

Table 7.2
Gawler River and Upstream Gauging Stations

Station	Name	Period of Record[1]
AW505503	South Para River 2.6 km south-east of Gawler	May 1968 - Oct 1993
AW505504	North Para River at Turretfield	Nov 1971 - Nov 1993
AW505505	Gawler River at Gawler Junction	Jun 1969 - Jan 1993
AW505510	Gawler River at Virginia Park	May 1972 - Jul 1989

(1) Indicates latest available digital data. Gauging stations with 1990s end of record are typically still in operation but with the latest record not transferred to a digital format.



LEGEND

- Streamflow Gauging Station
- Rainfall Gauging Station
- Council Area Boundary
- Major Road Corridor
- Coastline or River

Figure 7.4

Location of Rainfall and Streamflow Gauging Stations on the Northern Adelaide Plains

Flow in the Gawler River is largely regulated, an effect of the high degree of regulation of the South Para and North Para rivers. The South Para Dam and downstream diversion weir (to service the Barossa Reservoir) control the flow in the South Para River. The flow in the North Para River has been significantly modified from the natural flow regime, largely a result of the development of many farm dams within the Barossa and Flaxman Valleys and surrounding region, as reported by Cresswell (1991).

A series of flow duration curves were prepared for the Gawler River based upon the historical flow records for each gauging station. These curves relate the magnitude of stream flow to a frequency or percentage of time that a particular flow is equalled or exceeded. Traditionally, flow duration values of 90, 95 and 99 percent have been used as measures of a stream's low flow potential. The 90 percent value is used as a measure of the groundwater contribution to streamflow (McMahon & Mein, 1986).

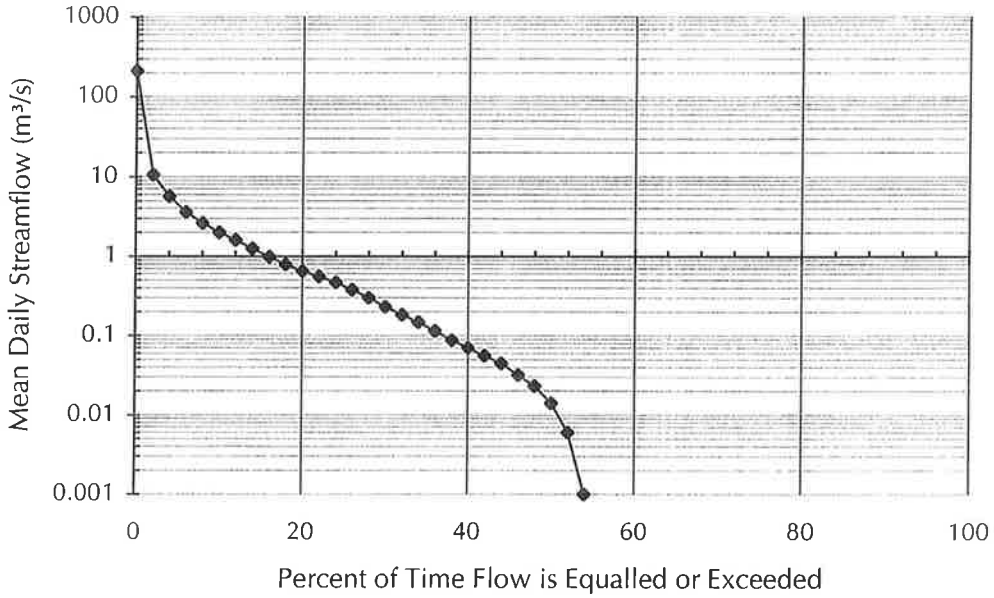


Figure 7.5
Flow Duration Curve for Gawler River at Gawler Junction, AW505505

The flow duration curve for the Gawler River at Gawler Junction is illustrated in Figure 7.5. This and other flow duration curves for the Gawler River indicate that a cease-to-flow condition is common not only during the summer months but during a great proportion of the year. Flow typically only occurs during the months of July to October, and in many cases is relatively small in magnitude.

Furthermore, this data indicates that flow is recorded at Gawler Junction only 54 percent of the time, and even less frequently (36 percent of the time) downstream at Virginia Park. This also suggests that there are considerable instream losses between the two streamflow gauging stations. A plot of the flow duration curves for both stations illustrates that the infrequent and high flow conditions are very similar,

confirming that the magnitude of the flood peaks is maintained along the Gawler River.

An examination of flood flow events in the Gawler River indicates that flood peaks are typically attenuated between Gawler Junction and Virginia Park, with a lag between peaks of around 15 hours. There is a marginal increase in total flow recorded between the two stations, typically in the order of 0-5 percent.

Based upon a comparison of historical annual discharges of the two main tributaries of the Gawler River, the North Para River typically contributes 75 percent of the total flow, and the South Para River the remaining 25 percent. Of that discharge recorded at Gawler Junction, only 85 percent is generally measured to pass the gauging station at Virginia Park (again based upon total annual flows for a common period of record). The historical annual discharges measured at each of these gauging locations (over the full periods of record) is illustrated in Figure 7.6.

Table 7.3
Historical Median Annual Flows in Gawler River System, ML

Month	South Para River, AW505503	North Para River at Turretfield, AW505504	Gawler River at Gawler Junction, AW505505	Gawler River at Virginia Park, AW505510
January	10.4	48.1	0.0	0.0
February	0.5	2.7	0.0	0.0
March	0.0	0.0	0.0	0.0
April	0.0	0.2	0.0	0.0
May	0.1	90.8	0.0	0.0
June	17.8	166.1	35.4	10.5
July	62.5	333.8	375.3	3145.0
August	694.9	1,771.1	3,089.2	4,946.0
September	1,111.0	4,808.8	7,162.2	6,037.0
October	976.6	4,125.2	5,502.2	1,561.0
November	256.5	804.8	1,066.1	72.0
December	46.1	167.3	83.0	0.0

Analysis of weekly flow passing Gawler Junction for the full period of record has supported the flow duration data, with a distribution of weekly discharge strongly skewed to the right. Around 43 percent of the time the total weekly discharge is recorded to be approximately zero, with a discharge of up to 200 ML for another 29 percent of the time. During the remaining 18 percent of the time the discharge is highly variable, typically between 400 and 5000 ML.

Unlike flow duration curves, low flow frequency curves are based on data sequences that are independent and homogeneous; therefore, they can be used to determine the probability of occurrence of a flow event of specified magnitude. An important use of low flow frequency curves is in reservoir capacity-yield analysis, despite the disadvantage that flows into the storage tend to be over-estimated because of the cross-nesting of the mass curves of each record.

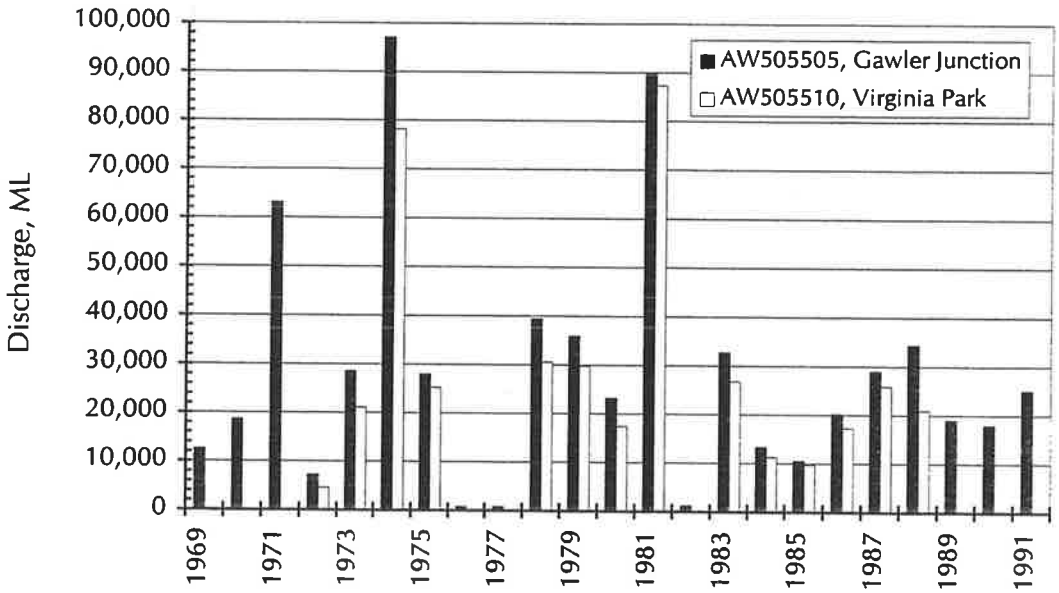


Figure 7.6
Historical Annual Discharge of the Gawler River

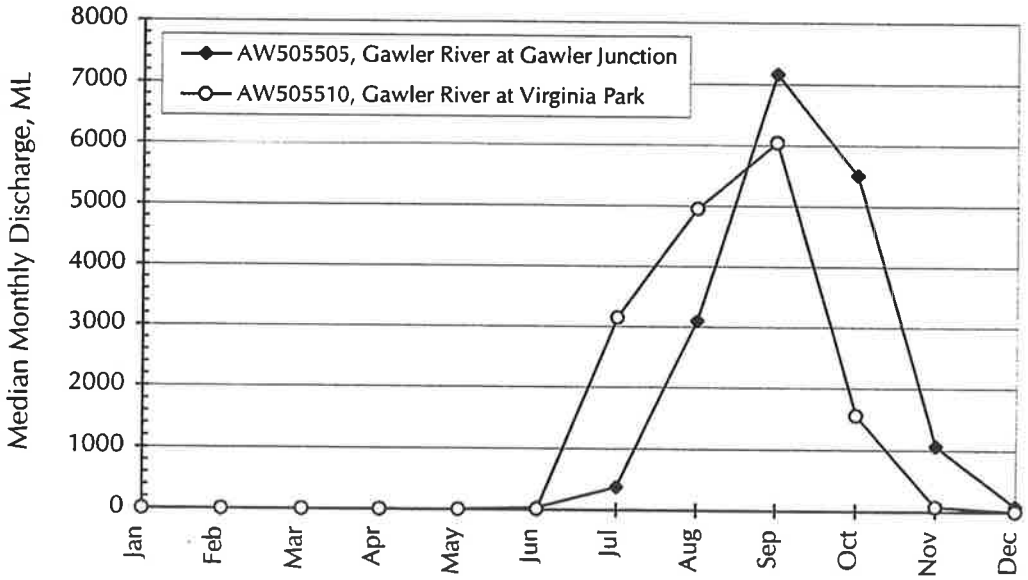


Figure 7.7
Median Monthly Discharge for the Gawler River

The low flow frequency characteristics of the Gawler River are partially summarised in Table 7.4; the low flow frequency plots for durations up to a year are contained in Appendix B. This data indicates that the yield from the Gawler River is generally low and unreliable, and that the Gawler River does not constitute a viable surface water resource for other than localised uses (e.g. stock watering). This position has been confirmed by past experience. Historically, farmers with properties along the

Gawler River have pumped water from the river during period of flood into dams for later irrigation. This water is expensive because of evaporation losses and the high cost of constructing large dams in flat country. Irregular flow of the Gawler River also makes it difficult to rely on this water source for irrigation (Philp, 1993).

Table 7.4
Gawler River Yield Reliability from Low Flow Frequency Analysis, ML

Station	50% Probability of Equal or Larger Flows		20% Probability of Equal or Larger Flows	
	1 Month	6 Months	1 Month	6 Months
AW505503	<0.001	220	<0.001	35
AW505504	10	700	10	450
AW505505	0.1	550	0.1	90
AW505510	1	900	1	1

Numerous plots and tabulated data are presented in Appendix B providing further supporting and clarifying information to that presented above.

7.3.2. Little Para River

The Little Para River passes through the central portion of the study area to the coast, and its flow has been monitored by numerous gauging stations during the past. Many of these gauging stations were established for a short period of time by the SA Department of Mines and Energy; the periods of record were short, intermittent and of little value to this study.

Only six gauging stations possessed a digitised record that might provide some useful information on the flow regime of the Little Para River; refer to Table 7.5.

Table 7.5
Streamflow Gauging Stations on the Little Para River

Station	Name	Period of Record(1)
AW504503	Little Para River upstream of Para Fault	May 1968 - Jan 1993
AW504504	Little Para River at Carisbrooke Park	May 1968 - Jul 1984
AW504528	Little Para Reservoir Spillway (flow over spillway)	Aug 1981 - Feb 1989
AW504536	Little Para River at Moss Road	Aug 1981 - Oct 1983
AW504541	Little Para River at Halbury Road	Feb 1980 - Jun 1983
AW504544	Little Para River downstream of Port Wakefield Rd	Feb 1980 - Jun 1983

(1) Indicates latest available digital data. Gauging stations with 1990s end of record are typically still in operation but with the latest record not transferred to a digital format.

As can be seen from Table 7.5, the period of record for the majority of gauging stations on the Little Para River is relatively short, and are therefore of limited value in characterising the flow regimes of the river. Attention has therefore focussed

upon the record provided by the gauging station upstream of the Para Fault, AW504503. Refer also to Figure 7.4 for the location of the gauging stations.

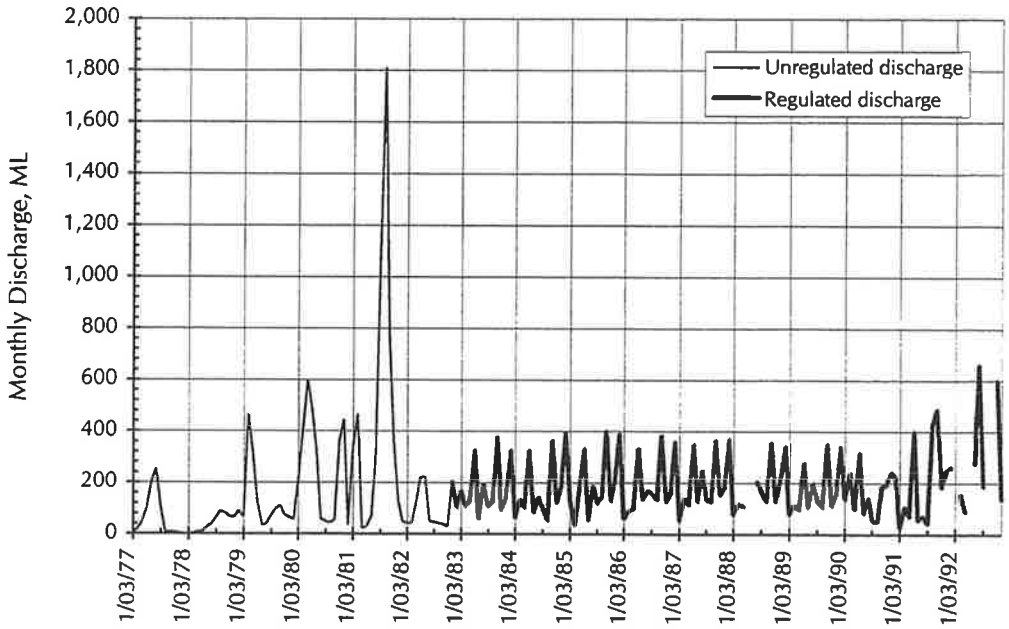


Figure 7.8
Historical Monthly Discharge for the Little Para River

The mean and median monthly discharges for the Little Para River are summarised in Table 7.6 below. Flow distributions for Australian streams are typically right skewed; the fact that the mean and median monthly flows for the Little Para River are so relatively close is an indicator that the river is highly regulated.

The historical record for flows downstream of the dam (Figure 7.8) indicates that since the commencement of operation of the Little Para Reservoir and filtration plant, the releases from the reservoir have been regulated. The operating policy for the reservoir incorporates three main releases of stored water of 300-400 ML each year during the months of February, June and November. Between 1,500 ML and 2,000 ML is released annually for the purpose of groundwater recharge (via the Para Fault), which is somewhat less than the 3,300 ML recommended by Dillon (1977).

The low flow frequency analysis for gauged flow along the Little Para River also indicates a similar position to the Gawler River, that is, that the river does not constitute a viable surface water resource for other than localised uses (e.g. wetlands, habitat development, park irrigation). It would appear likely that a large proportion of the water released from the Little Para Reservoir does contribute to recharge of groundwater along the Para Fault as intended, and therefore largely fails to contribute to flow downstream of the Fault or Carisbrooke Park on Main North Road.

Table 7.6
Historical Discharges from the Little Para Reservoir(1), ML

Month	Average	Median
January	186.9	186.9
February	309.5	337.6
March	88.2	77.3
April	122.6	113.8
May	107.8	101.8
June	330.2	326.8
July	109.2	84.3
August	220.7	190.5
September	119.9	125.8
October	143.7	126.2
November	361.9	362.3
December	184.1	129.3
Annual	2,153	2,195

(1) Based on regulated flow conditions, post January 1983

Table 7.7
Little Para Yield Reliability from Low Flow Frequency Analysis, ML

Station	50% Probability of Equal or Larger Flows		20% Probability of Equal or Larger Flows	
	1 Month	6 Months	1 Month	6 Months
AW504503	38	850	30	440
AW504504	0.13	550	0.01	150
AW504536	7	IR(1)	<1	IR
AW504541	10	500	<10	36
AW504544	<1	550	<1	5.5

(1) Insufficient Record to enable calculation of yield for this time period.

The flow duration curves for the Little Para River also illustrate that flow in the Little Para River decreases significantly with distance from the Para Fault. Indeed, low flow is recorded less than 40 percent of the time in the lower reaches of the river below Moss Road. Flow is typically only recorded at all gaugings during flood events.

7.3.3. Dry Creek

Investigations indicated that there were no gauging stations situated on Dry Creek for which streamflow data was available. Given that the portion of the Dry Creek catchment within the Northern Adelaide Plains Proclaimed Region (and therefore the study area) is relatively small, this portion of the Dry Creek catchment has been ignored during further study.

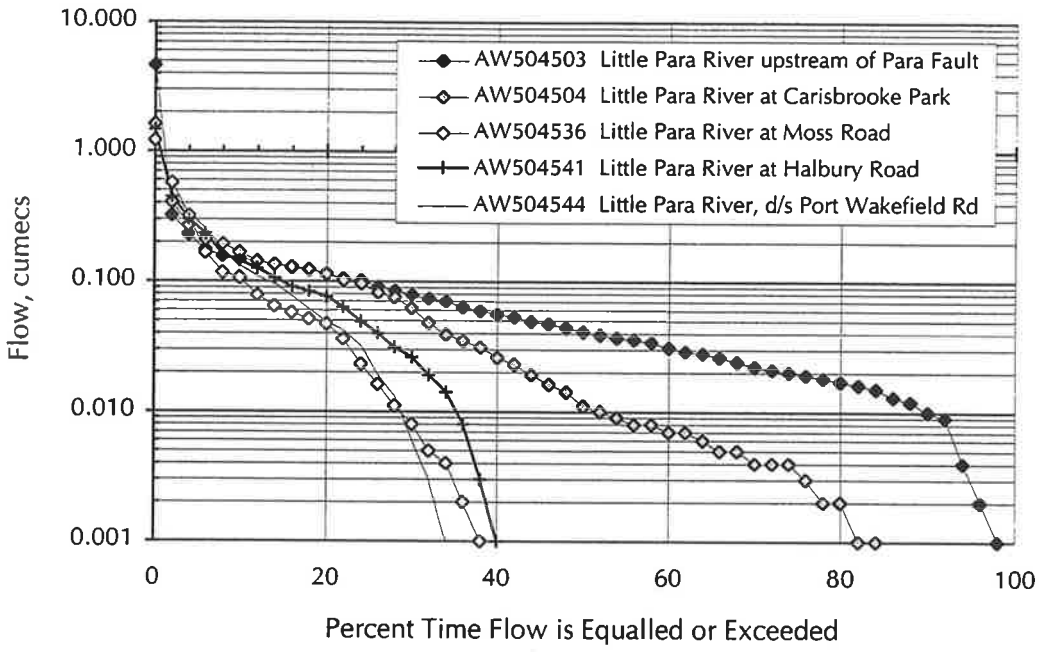


Figure 7.9
Flow Duration Curves for Little Para River

7.3.4. The River Murray

Unfortunately the Mount Lofty Ranges catchments are small, and although the rainfall can be high in some catchments, the overall yield is in most years insufficient to meet the demand from metropolitan Adelaide. Therefore it is necessary to supplement supplies derived from local catchment runoff by pumping from the River Murray.

The direction of flow and use of the Murray both change abruptly at North West Bend near Morgan; refer Figure 7.10. Irrigation, especially for horticultural production, is the major water use upstream of Morgan. In the Lower Murray, irrigation is also evident on the river flats between Mannum and Wellington that support a large part of South Australia's dairy industry. A relatively recent development is the establishment of private pumping to irrigate horticultural, vegetable and pasture crops such as lucerne.

However, water piped from the Lower Murray provides one and a quarter million people living outside of the Murray Valley in South Australia with at least some of their supply. Below Morgan the water needs of urban and industrial South Australia dominate. The Murray provides at least half of the State's water consumption, and much more in dry years. Adelaide receives an average of 55 percent of its water from the Murray and this rises to over 90 percent during drought years (e.g. 1982-83 drought). The typical percentage of water supplied to Adelaide from the River Murray is also expected to rise in future years (Doering & Liepe, 1992).

The Iron Triangle towns of Whyalla, Port Augusta and Port Pirie have almost all their water (typically 90 percent) piped from the River. The furthest water is piped is from

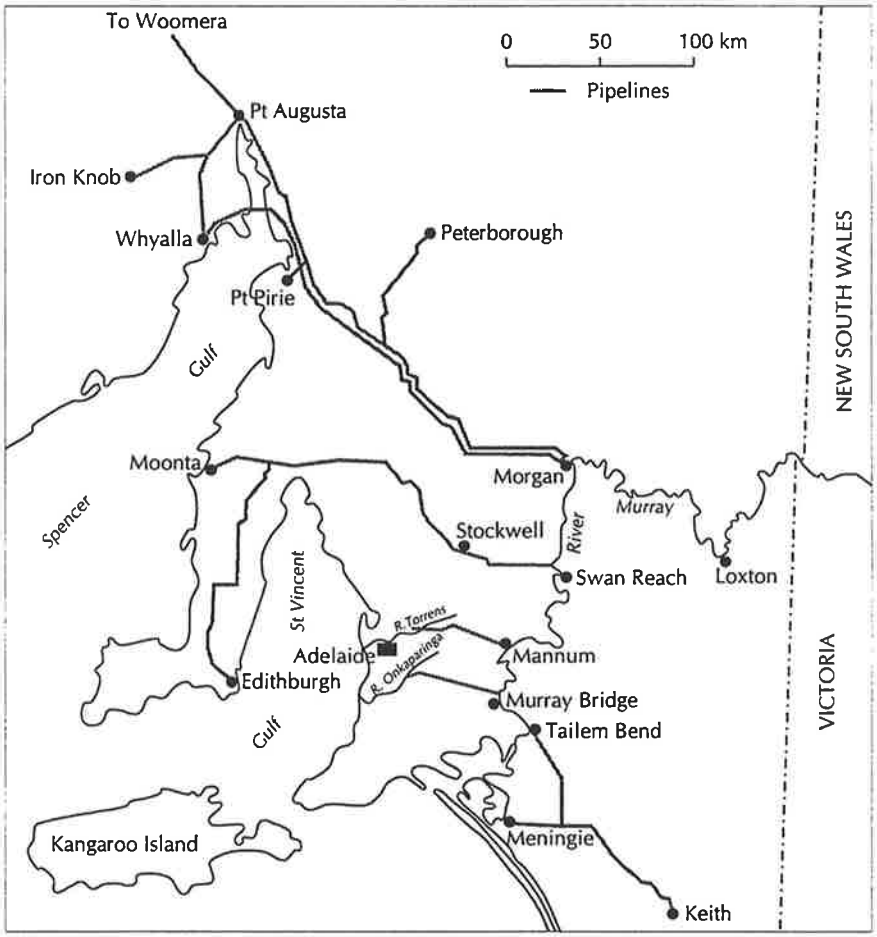


Figure 7.10
Areas of South Australia Supplied with Water from the River Murray for Domestic and Industrial Purposes

Morgan to Woomera, a distance of 450 kilometres. The existence of these centres in their present form is only possible because of a number of pipelines originating between Morgan and Tailem bend that pump Murray water to large areas of the State. The pipelines are constant reminders of the dependence of the South Australia on the Murray and give meaning to the statement that "the Murray is the lifeline of the State".

The mean annual flow of the Murray to South Australia is 6570 GL, significantly above the State's entitlement of 1850 GL under the Murray-Darling Basin Agreement. Total water diversions from the Murray in South Australia average about 520 GL/year (about 28 percent of the State's entitlement). Irrigation accounts for some 385 GL, most of this in the Riverland region. Small quantities are diverted for rural supplies and towns in the valley, but most of the balance is accounted for by Adelaide and the Iron Triangle towns.

Water quality is probably the most critical resource management issue in the Lower Murray. Salinity issues, though dominant, are by no means the only water quality

problems. Others include turbidity, nutrients and bacteriological contamination. Sources of these pollutants include agricultural and recreational activities, especially the drainage water from irrigated dairy pastures and effluent from holiday shacks.

To varying degrees, salinity affects all water users. It is often above the 800 EC units recommended by the World Health Organisation as the highest desirable level for drinking water (the WHO maximum permissible level is 2500 EC). The estimated cost of salinity to South Australia is more than $42 million/yr, more than 80 percent of which is borne by domestic users of Murray water (through costs of replacing household appliances and fittings and consumption of soaps and detergents).

The Mannum–Adelaide Pipeline was completed in 1954, and this supplements the Torrens system (and thereby the Little Para Reservoir). The Murray Bridge–Onkaparinga Pipeline, commissioned in 1983, supplies additional water to the Onkaparinga System and Mt Bold Reservoir. Both pipelines also serve country areas along their routes.

The volume of water to be pumped from the River Murray is continuously reviewed and updated by the SA Water Corporation, using the Headworks Optimisation Model – Adelaide (HOMA) linear programming model (Crawley, 1993). Natural inflows to reservoirs in the water supply catchments are predicted for a 12 month period on the basis of historical streamflow data or synthetic data that is statistically equivalent. For each month of operation, a target end-of-month storage is then determined on the basis of predicted demand and storage inflows. (Predicted demand is based upon the previous 5 years demand.) The linear programming model operates upon these predicted values and a set of constraints (such as pumping and storage capacity) to determine the pumping strategy with minimal pumping cost. At the end of each month when actual demand and natural inflow are known, the model is re-run to establish the new pumping schedule.

Over the period of operation of the Little Para Reservoir, water has been imported to the study area via the Mannum–Adelaide Pipeline, contributing an average of 3,600 ML per year (approximately 17 percent of the reservoir's storage capacity), with a maximum diversion of 7,690 ML supplied in 1990.

The South Para system has been supplied with an average of 1820 ML per year over the period 1972-1991, via the Swan Reach to Stockwell pipeline through the Warren Trunk Main. A maximum of 9320 ML was supplied in 1978.

7.3.5. Stormwater

The majority of information relating to stormwater flows in the NAP region has been generated via hydrological studies for design of stormwater drainage systems, and therefore relates to flood flows rather than potential stormwater yield.

Indeed, an early study into the resource potential of urban stormwater (Fisher & Clark, 1989) acknowledged that within the Adelaide area the availability of urban streamflow data was limited to the River Torrens and Aldgate Creek, although the urban component is not accurately identified at either of these locations. Since that

time little has changed, with only a small number of catchments with urban components being gauged, typically for research purposes and at this stage with a short period of record that is often plagued by unreliability or important data gaps.

Perhaps the most important information relating to stormwater runoff that has emerged in recent years is associated with "The Paddocks" wetlands in Salisbury. Two gauging stations have been established for monitoring of this artificial wetland at a recreational reserve situated at Para Hills; refer to Table 7.8. The streamflow gauging station situated at the inlet to this wetland therefore provides some information on the magnitude of runoff generated from the upstream urban catchment (of approximately 60 hectares) for a given rainfall event.

Table 7.8
Streamflow Gauging Stations at "The Paddocks" Wetland

Station	Name	Period of Record(1)
AW504546	Para Hills Drain at Paddocks Inlet	1990 - 1993
AW504548	Para Hills Drain at Paddocks Outlet	1990 - 1993

(1) Indicates latest available digital data. Gauging stations with 1990s end of record are typically still in operation but with the latest record not transferred to a digital format.

Given that there is no historical data relating to stormwater runoff for the region, empirical relationships developed as part of this research have been utilised to estimate stormwater yield. The data available for The Paddocks has been incorporated in a larger study into rainfall-runoff relationships to enable predictions of storm runoff from rainfall. This derivation of volumetric runoff coefficients for urban and rural or open space land uses is reported in Chapter 10 and Appendix L.

A study of management options for metropolitan Adelaide stormwater estimated that the total stormwater flow into the Gulf St Vincent from the Adelaide metropolitan area is around 210,000 ML per annum. This includes around 25,000 ML of spill from Mt Lofty Ranges water supply reservoirs. Stormwater enters the Gulf from 21 major catchments (with a total area of around 1600 km^2) and numerous minor direct outfalls. A summary of the catchment areas and respective stormwater yield estimates appear in Table 7.9.

There were originally 6 drainage authorities in metropolitan Adelaide, each of which administered a scheme within its respective catchments. On the NAP, they were the Little Para River Drainage Authority and the Dry Creek Drainage Authority. In the 1990s, the Authorities have largely been replaced due to the formation of Catchment Water Management Boards. In 1998, the Northern Adelaide and Barossa Catchment Water Management Board was formed, and have the responsibility for the planning and management of water resources in the study region. Prior to the formation of this Board, the Drainage Authorities together with the MFP Development Corporation oversaw the development of an *integrated* water management plan for their area of jurisdiction (a subset of the study area). This plan is innovative by comparison to previous catchment plans in that it attempts to integrate the management of all water resources, including treated sewage effluent

(PPK, 1997). It is uncertain how many of the recommendations made in this plan will be adopted by the new Catchment Board.

Table 7.9
Drainage System Catchment Areas and Yields (ECA, 1991)

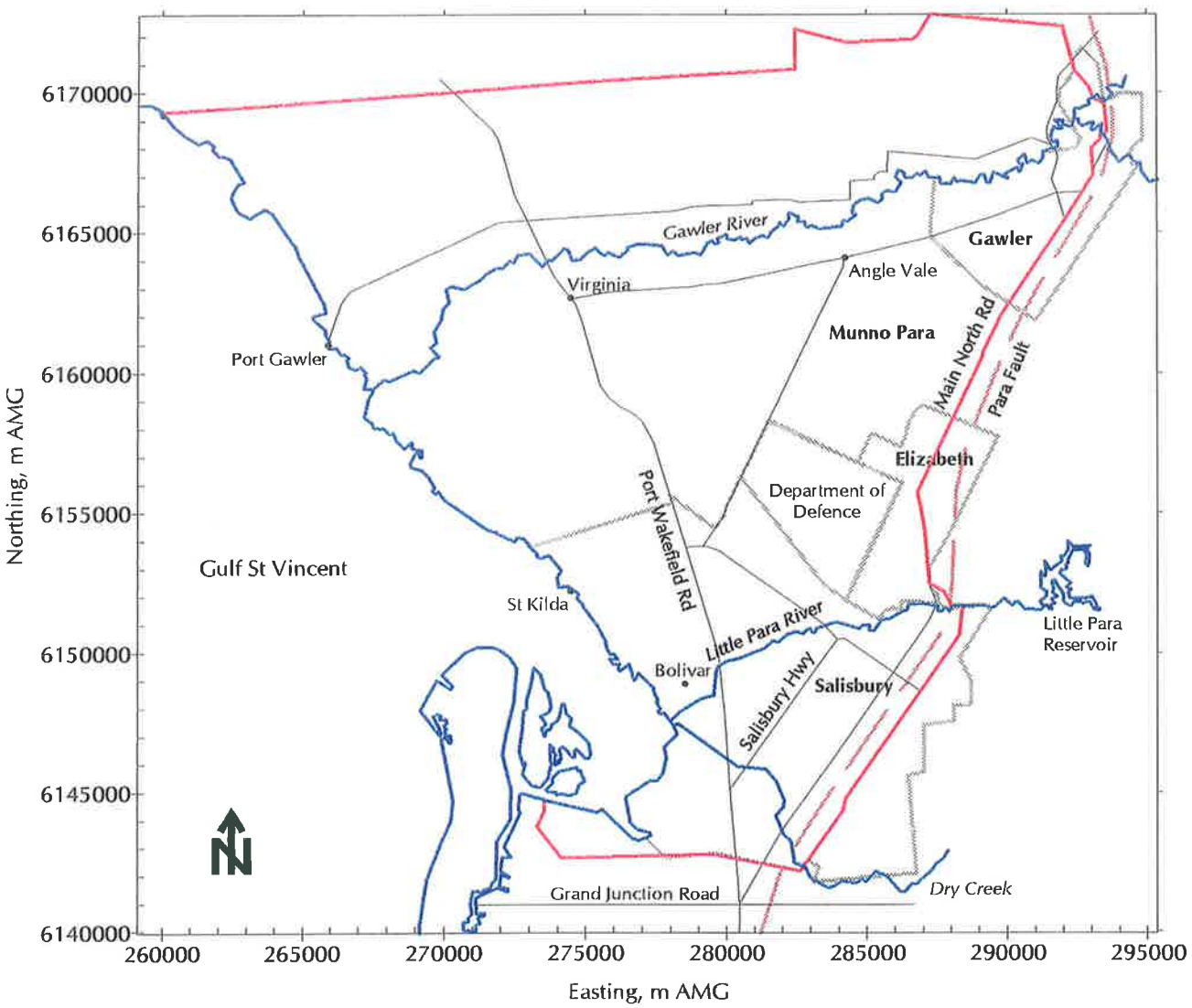
Catchment Name	Rural		Residential		Ind./Comm.		Total	
	km²	ML	km²	ML	km²	ML	km²	ML
Gawler River	115.4	9,790	6.0	215	-	-	121.4	10,004
Munno Para	112.9	7,472	26.6	2,843	3.0	1,211	142.5	11,526
Helps Road	42.2	1,925	42.8	3,717	6.5	5,936	91.5	11,578
Little Para River	9.5	1,165	33.5	3,693	1.0	417	44.0	5,275
Dry Creek	18.6	1,527	83.8	6,285	7.0	3,253	109.4	11,065
North Arm East	5.4	497	16.1	604	4.4	1,881	25.9	2,982
HEP Scheme	-	-	6.4	245	6.5	2,867	12.9	3,112
Days/Dunstan Rd	-	-	4.5	162	5.0	2,070	9.5	2,232
TOTAL	304.0	22,376	219.7	17,764	33.4	17,635	557.1	57,774

For the purpose of estimating the volume of stormwater potentially available for harvesting and reuse, the volumetric runoff coefficients have been used in conjunction with mean monthly rainfall data and estimated urban and open space areas. While the entire study area occupies approximately 630 km², 336 km² was considered to constitute a useful water resource catchment area, of which around 114 km² had been urbanised. The useful catchment area is considered to include the urban areas and upstream hills face zones, the runoff from which would be available for use at downstream parks, open space and agricultural lands.

7.4. Groundwater Resources

Groundwater is an important local water resource, with use in metropolitan Adelaide of approximately 27,500 ML per year, as shown in Table 7.10. Major zones of irrigation use are in the Northern Adelaide Plains, around West Lakes and through the Adelaide Plains, and in the Willunga Basin. Industrial use occurs in the Dry Creek-Port Adelaide zone, in Thebarton and other sites across the metropolitan area. The NAP and the Willunga Basin are proclaimed areas under the Water Resources Act due to actual or possible future over use of their groundwater resources (ECA, 1991).

Groundwater can be considered to be the primary water resource of the NAP, providing water for irrigation and thereby supporting a major horticultural industry. The basin is part of the St Vincent Sedimentary Basin which underlies the coastal Adelaide plains and extends northward to the Crystal Brook area. The boundaries of the NAP Proclaimed Region are defined on the basis of salinity of the groundwater in the Tertiary aquifers. The isohaline of 3,000 mg/l is taken as the boundary of the basin, as groundwater of greater salinity is not normally used for irrigation. The eastern boundary of the basin is geologically defined as the Para Fault, as shown in Figure 7.11 which includes the Proclaimed Region boundary.



LEGEND

- Council Area Boundary
- Major Road Corridor
- Coastline or River
- Para Fault
- Northern Adelaide Plains Proclaimed Region Boundary

Figure 7.11

Northern Adelaide Plains Proclaimed Region

Table 7.10
Groundwater Usage in Metropolitan Adelaide, ML[1]

Groundwater Basin	Irrigation	Industrial	Rural	Domestic	Total
Northern Adelaide Plains	16,600	1,500	200	-	18,300
Adelaide Plains	3,100	2,700	-	100	5,900
Noarlunga Basin	200	-	-	-	200
Willunga Basin	3,100	-	-	-	3,100
Total	23,000	4,200	200	100	27,500

(1) From EWS (1987), Rescignano (1983), EWS (1990), Gerges (1985), and Edwards et al (1987)

Rapid expansion of the irrigated area during the period 1950-1968 resulted in annual withdrawal from the aquifers exceeding the natural recharge (Desmier, 1987). The aquifers are thus under stress due to over-use. Groundwater extraction for irrigation and industrial applications exceeds the natural recharge to the aquifer system by around three times, causing continued deterioration of the aquifers.

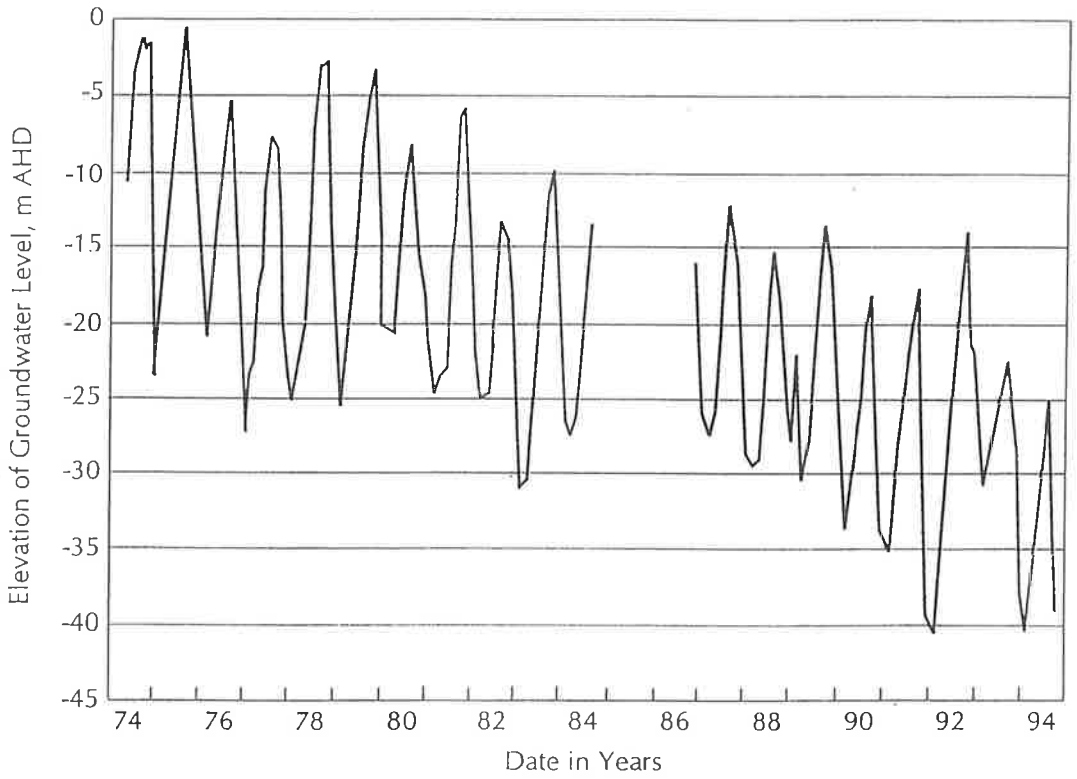


Figure 7.12
Declining Groundwater Level in Well MPA064, Munno Para (after Gerges, 1994)

As a consequence, potentiometric levels in the confined aquifer have fallen (Figure 7.12), particularly in the areas of the most intense activity. A large cone of

depression has developed around Virginia which is continuing the expand. If this continues, the large imbalance between groundwater withdrawals and replenishment will result in a continuing decline in water levels, progressive reduction in yields available from the aquifers, and associated increases in pumping costs. Furthermore, prior to irrigation development the natural groundwater flow was to the coast but the formation of a cone of depression has reversed flow from the coast towards the centre of the depression.

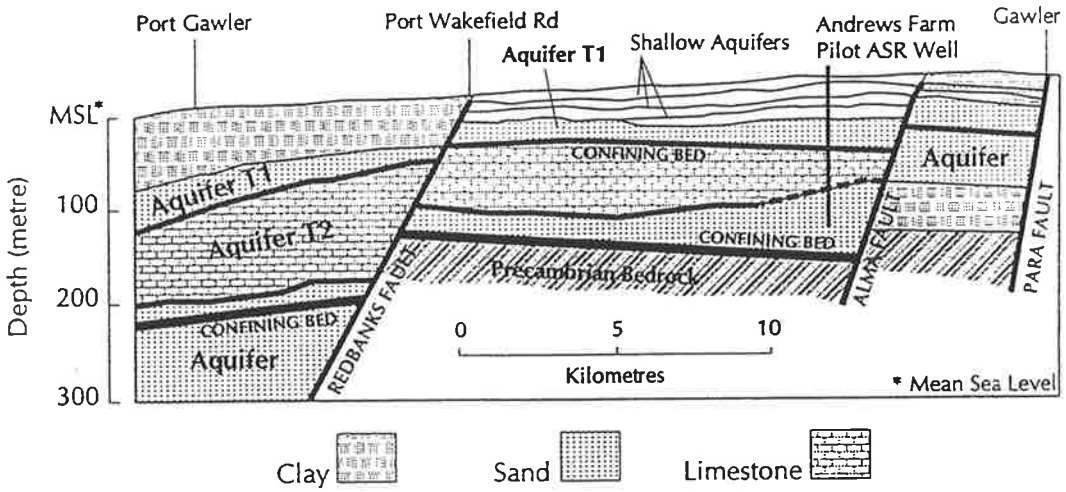


Figure 7.13
Typical Geological Cross Section (after Gerges, 1994)

In time, the ability of the licensees to withdraw their water allocations will be restricted. The water pumped from the main aquifers will be partly replaced by downward leakage from the overlying saline aquifers through abandoned wells. There will be localised increases in salinity which will adversely affect crop yields and irrigation viability.

7.4.1. Existing Conditions

There are four thin Quaternary aquifers which are silty-clayey sand or gravel. All Quaternary aquifers except for the uppermost, are semi-confined, having a maximum thickness of 8 to 10 metres. Refer to Figure 7.13 and Table 7.11.

The Tertiary sediments of predominantly limestone, sandstones and sand, contain three semi-confined aquifers, designated T1, T2 and T3 in order of increasing depth. The depth to these aquifers ranges between 50 metres below ground level in the Golden Grove area to around 600 metres west of the Para Fault. The aquifers are well defined west of the Para Fault, and are approximately 100 metres in thickness. Aquifer T2 flows in a north north-westerly direction due to the heavy extraction from the market gardening areas around Virginia.

Gerges (1993) indicates that aquifers T1 and T2 are in fact the same unit north of the Gawler River and west of Port Wakefield Road, only severed by the Munno Para

Clay (with a maximum thickness of 12 metres) in the remaining areas between Waterloo Corner and the Gawler River.

Table 7.11
Stratigraphic Column of Tertiary-Quaternary Succession in Northern Adelaide Plains Sub-Basin (Coffey Partners International, 1993)

Age	Unit Lithology	Maximum Thickness (m)	Aquifer
Holocene	**St. Kilda Formation:** shell beds, sands and clays. Found in coastal areas.	5	
Early Pleistocene	**Pooraka Slay:** clays, silts and sands, generally red-brown	3	
Middle Pleistocene	**Glanville Formation:** sands and shell beds, adjacent to coast	5	
Early Pleistocene	**Hindmarsh Clay:** clays, silts, sands and gravels in outwash areas. Occurs over almost whole of basin.	120	Aquifers Q1, Q2 and Q3
Pliocene - Pleistocene	**Carisbrooke Sand:** fine sands and silts with some clays and thin gravel beds in outwash areas. Occurs over whole area except within 4-5 km of the coast.	54	Aquifer Q4
Late Pliocene	**Hallett Cove Sandstone, Dry Creek Sands:** limestones, calcareous sandstones and sands. Usually abundantly fossiliferous. Occurrence generally restricted to an area south of Two Wells.	75	Aquifer T1
Mid-Early Miocene	**Port Willunga Beds (upper part):** fossiliferous sandy limestones, fine grained, occurring south of Two Wells.	45	Aquifer T1
Early Miocene	**Munno Para Clay:** blue-grey sandy, shelly clays, missing in some coastal areas and north of Two Wells.	12	Confining Bed
Early Miocene - Late Eocene	**Port Willunga Beds (lower part):** fossiliferous limestones with sands and sandstones, grading to a dense siliceous unit towards the base.	170	Aquifer T2
Late Eocene	**Blanche Point Marls:** marls, siltstones, limestones, fossiliferous and glauconitic.	40	Confining Bed
	South Maslin Sands: sands, glauconitic and poorly fossiliferous.	40	Tertiary T3
Late - Middle Eocene	**Muloowurtie Clay:** green to blue clays, carbonaceous and silty.	30	
Middle-Early Eocene	**North Maslin Sands:** pebbly quartz sands, slightly clayey, carbonaceous; fluviatile and estuarine deposition.		
Proterozoic	**Adelaidean System:** slates, quartzites, dolomites, tillites, shales and limestones.		

The early work of Shepherd (1975) and others suggested that recharge to the aquifer system was 7,410 ML per year, 5,010 ML in downward leakage from the Gawler River, 2,350 ML from the Little Para River, and the rest originating from small creeks and rivers. Direct rainfall over the plains was not considered to contribute directly

to the groundwater recharge. Natural groundwater outflow from the Quaternary aquifers is estimated to be 500 ML per year.

Shepherd (1975) considered that natural recharge to the Tertiary aquifers is equivalent to the natural through-flow of 1,050 ML per year which occurred by downward leakage from the Quaternary aquifers; Quaternary aquifer recharge is therefore approximately 6,360 ML per year. However, while there may be some leakage from the Quaternary aquifers to the Tertiary aquifers, this is not the primary recharge mechanism as previously indicated by Miles (1952) and Shepherd (1975). Gerges (1987, 1993) suggests that the most likely source of recharge to the Tertiary sediments is underflow from the fractured basement rock aquifers of the Adelaide hills and not as previously thought via the Quaternary sediments.

Camp Scott Furphy Pty Ltd (CSF, 1992) state that a study of the Tertiary aquifer hydrographs has shown that there is only a marginal decline in water levels over the last few years and thus no apparent decline in storage. Based on this they estimate vertical leakage from the Quaternary to Tertiary aquifers under the influence of pumping (head difference) as 14,950 ML/year compared with a total Tertiary withdrawal of 16,000 ML/year.

Consequently they consider the current water level behaviour is expected to be maintained until the Quaternary aquifers are significantly depleted of groundwater at which time the ensuing lack of vertical leakage will result in a substantially expanding cone of depression.

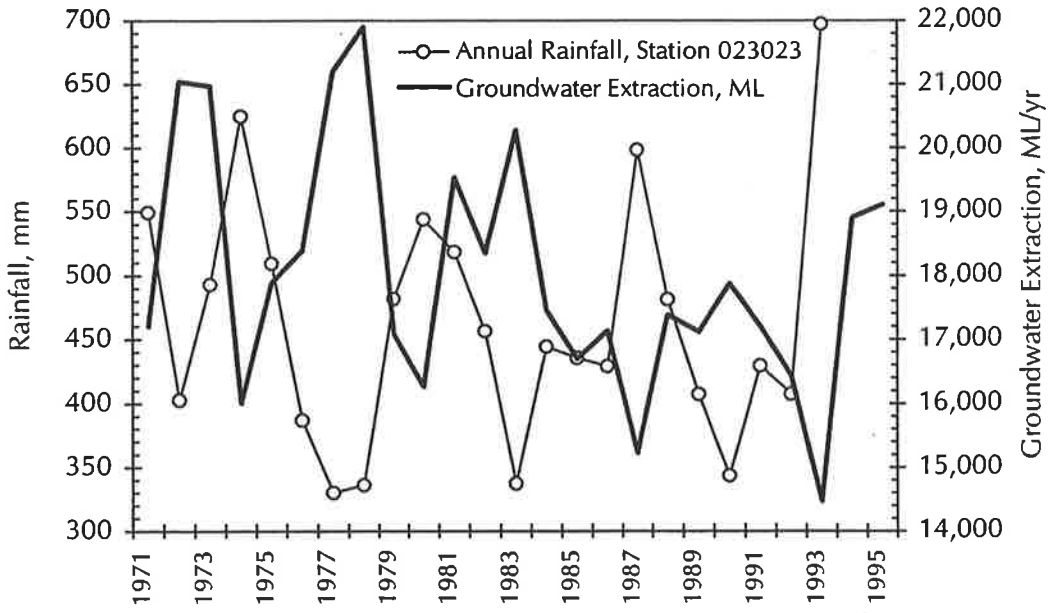


Figure 7.14
Groundwater Extraction History for NAP Aquifers

Water levels in the lower Quaternary aquifers in the areas of heaviest pumping of the Tertiary aquifers show a decline over the past 10 years reflecting this vertical leakage of the lower Quaternary aquifers into the Tertiary system.

Groundwater extractions have averaged 18,043 ML/yr over the last 21 years (compared with natural recharge of approximately 7,410 ML/yr), as illustrated in Figure 7.14. This figure was derived using the bore extraction records provided by the SA Water (formerly the Engineering and Water Supply Department), maintained since the commencement of bore metering in 1970. The sustainable yield of the system of Tertiary aquifers has been estimated at 6,000 ML/a; this was based on a concept where replenishment of the aquifers occurred via vertical flow. The replacement of this concept with one of lateral flow replenishment has suggested that the sustainable yield may be in the order of 5,000 to 10,000 ML/a, however this is yet to be determined (KME, 1996).

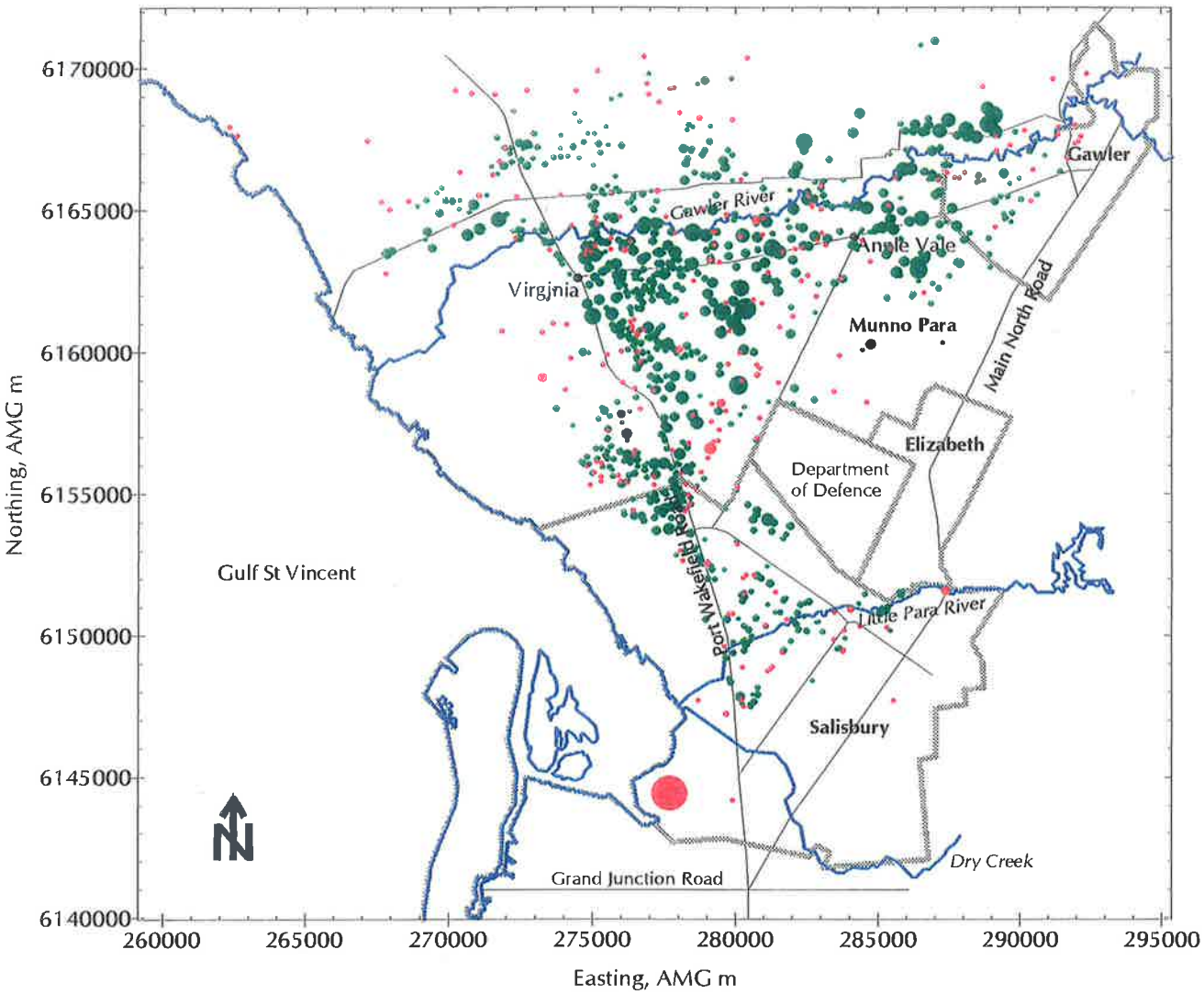
Industrial use by Penrice Soda Products Ltd forms a significant proportion of the total consumption, using approximately 1,000 ML per year to pump salt in a slurry to the process works at Osborne. Other major consumers adjacent to Penrice (but outside the Proclaimed Region) include the abbatoirs of the South Australian Meat Corporation (SAMCOR) and the Torrens Island Quarantine Station. Their combined annual extraction of around 2,700 ML has resulted in a cone of depression centred at Dry Creek, and a localised increase in salinity of 800 mg/L over the past 20 years; refer Figures 7.15 and 7.16.

The bulk of the extracted groundwater comes from the Tertiary sediments, with aquifers T1 and T2 contributing to approximately 90% of all irrigation and industrial requirements. Indeed, extraction occurs mostly from the second Tertiary aquifer T2 in areas where the groundwater has a salinity of less than 1,000 mg/L.

There were 1060 bores and wells in the basin, greater than the prescribed depth of 8 metres, metered by the Engineering and Water Supply Department during the 1991/1992 water year. In 1975, 304 bores were unmetered and produced approximately 130 ML per year (equivalent to 0.7% of the total annual withdrawal at that time). Some bores remain unmetered, although the exact number is unknown. The location of metered bores for irrigation and predominantly industrial purposes, and the relative magnitude of annual groundwater use, is depicted in Figure 7.15.

The number of metered groundwater extraction bores has also steadily increased over the past 20 years, although it can be seen from Figure 7.17 that there has been a general downward trend in consumption per bore over the same period.

As previously mentioned, groundwater extraction and the imbalance between extraction and recharge through over exploitation has resulted in regional cones of depression. The cones of depression are the result of the inability of the aquifer to transmit water to its centre where a high concentration of pumping wells exist. These cones exist primarily in the Tertiary aquifers T1 and T2, essentially centred about the Virginia irrigation district and Penrice extraction bore.



LEGEND

- Groundwater Extraction for Industrial, Commercial or Residential Purposes
- Groundwater Extraction for Irrigation
- Council Area Boundary
- Major Road Corridor
- Coastline or River

Figure 7.15

Location and Use of Groundwater Wells on the Northern Adelaide Plains

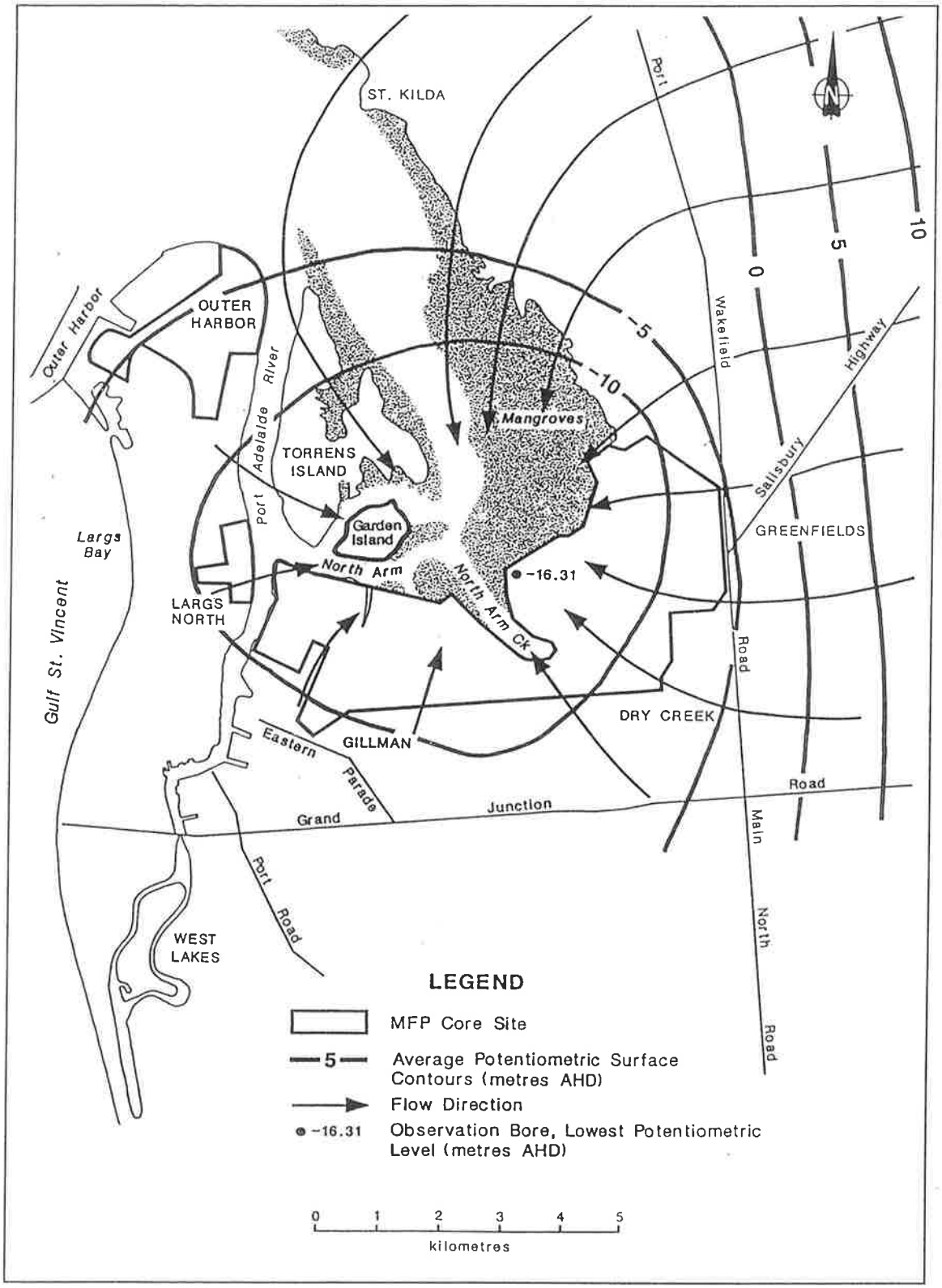


Figure 7.16
Potentiometric Cone of Drawdown in the Dry Creek Area

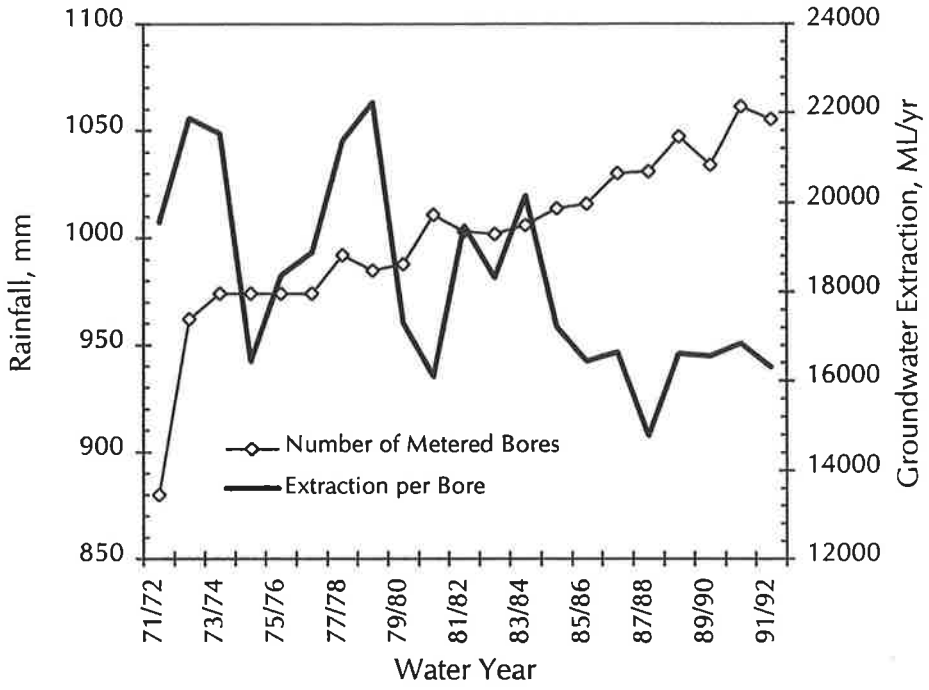


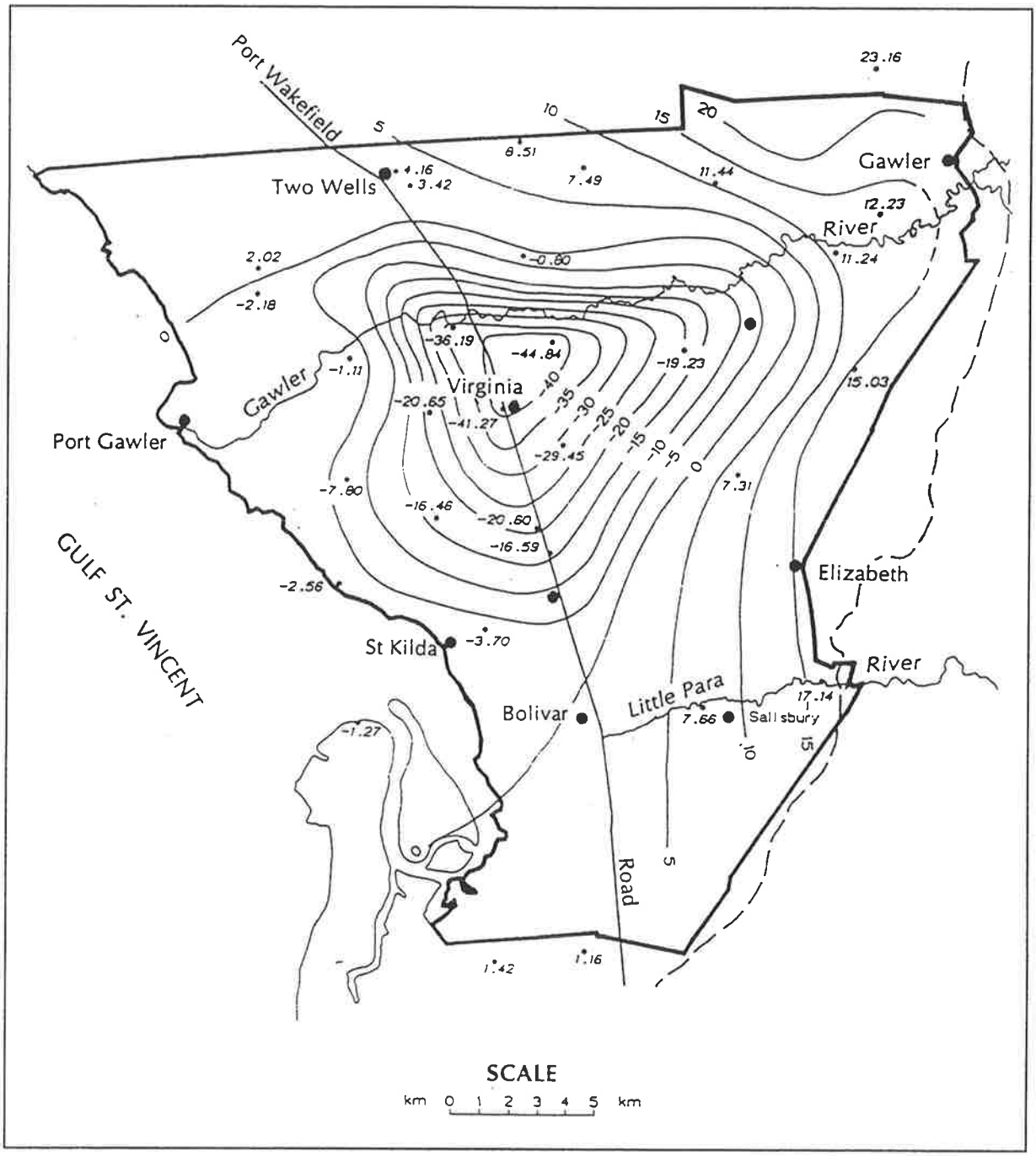
Figure 7.17
Historical Groundwater Bore Numbers and Per Bore Extraction

The cones of depression in the Tertiary aquifers increase to a maximum extent in February or March when the water level has declined by up to 65 metres. This depression decreases to a minimum in August or September of each year, as illustrated in Figures 7.18 and 7.19. The water levels do rise after irrigation declines and peaks around August-September. The lack of complete recovery is reflected in a water level of -25m AHD in aquifer T2 in the Virginia area, and a cone of depression still below sea level over an area of 120 km².

7.4.2. Seasonal Consumption Patterns

Due to the low transmissivity of the aquifers on the NAP, the yield from the extraction wells during the summer months (November to February) can be low. The water level in the wells is low, and consequently not only can a limited quantity be extracted but it is also costly to do so.

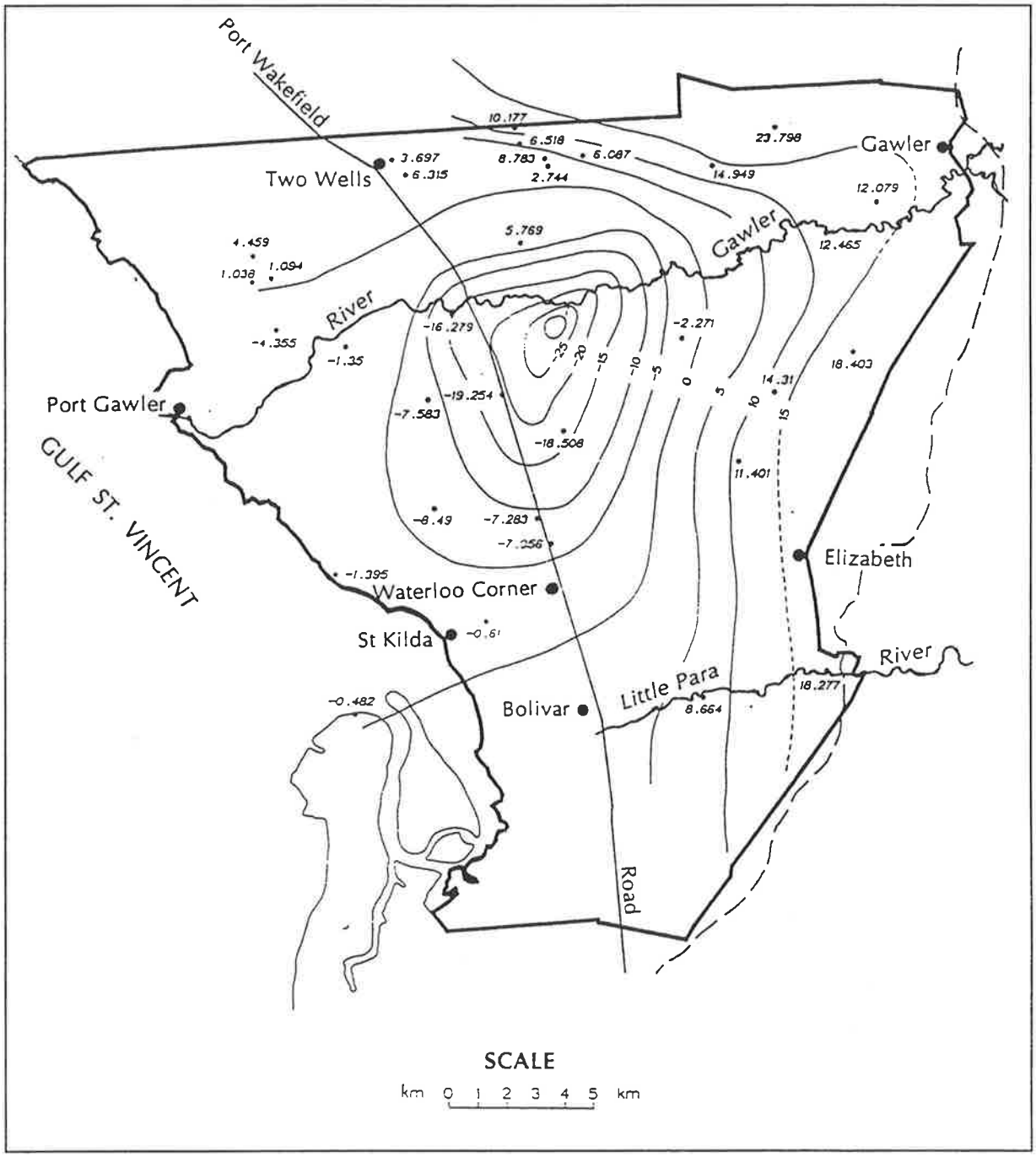
In general, high value crops are grown on the NAP throughout the year. The vast majority of crops are planted in late Winter so that they mature for harvesting by December. Market constraints also play a role in the patterns of cropping. While the Riverland and Mallee regions can easily compete in the production of crops such as potatoes and tomatoes, the Northern Adelaide Plains is unique in that it can produce a broader range of crops of a commercial higher value, and at different times of the year to other regions.



LEGEND

Northern Adelaide Plains Proclaimed Region	
Limit of St Vincent Basin	
Potentiometric Surface Contours (mAHD)	10
Observation Bore	
Potentiometric Level (mAHD)	-7.283

Figure 7.18
Potentiometric Surface Contours of T2 Aquifer, March 1988



LEGEND

Northern Adelaide Plains Proclaimed Region	———
Limit of St Vincent Basin	— —
Potentiometric Surface Contours (mAHD)	10
Observation Bore	•
Potentiometric Level (mAHD)	-7.283

Figure 7.19
Potentiometric Surface Contours of T2 Aquifer, September1988

The peak demand for irrigation water would therfore occur, under current circumstances, during the months of November and early December, and late February and March. This would conflict with the water consumption pattern that might otherwise be assumed (i.e. inversely proportional to rainfall). However, were alternative supplies of water at suitable quality and price available during the months of December and January these may well become the peak consumption periods (Schrale, 1993). The pattern of consumption of groundwater on the Northern Adelaide Plains is approximated in Figure 7.20 (after Roger Stokes & Associates, 1995).

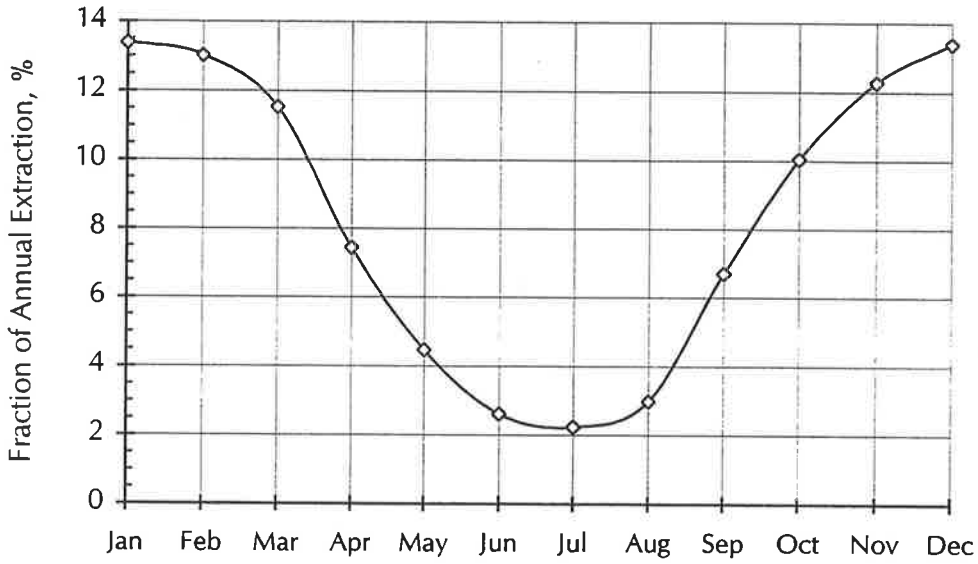


Figure 7.20
Seasonal Pattern of Groundwater Consumption on the NAP

7.4.3. Groundwater Salinity

Adelaide plains aquifers show variable salinity caused by the interplay of upward and downward leakage, lateral flow, faults and various mechanisms of natural recharge (Gerges, 1987).

Upper Quaternary aquifer water quality is dominated by surface drainage. Salinity generally decreases with depth, however it is common to observe a low salinity aquifer between two saline aquifers.

Quaternary aquifers generally contain water of higher salinity than the Tertiary aquifers (refer Table 7.12). Data collected in 1987 and used to prepare the salinity distribution of aquifer T2 shown in Figure 7.21, indicates that much of the aquifer from which groundwater is extracted has a salinity less than the 1,200 mg/L.

Aquifer T3 is too saline for use, with salinity typically ranging between 6,500 mg/L and 64,000 mg/L. This groundwater is usually discounted from water resource inventories. In the upper Tertiary aquifers, localised increases in the salinity of 200-400 mg/L occurred over the 13 years prior to Shepherd's (1975) report, which is equivalent to a salinity increase of 15-30 mg/L per year.

Table 7.12
Aquifer Salinity Ranges (after Shepherd, 1975)

Aquifer	Maximum Salinity (mg/L)	Minimum Salinity (mg/L)
Quaternary I	2,830	1,320
Quaternary II	15,000	2,085
Quaternary III	21,600	1,825
Quaternary IV	1,900	745
Tertiary T2	830	745

The salinity of the Tertiary aquifers has increased as a result of induced leakage from the overlying Quaternary aquifers, by leakage via corroded well casings, uncemented and poorly cemented wells, and to a lesser extent from lateral flow from the surrounding highly saline area. Leakage from defective wells (which can tend to be localised) has had the greatest impact on groundwater salinity; this has possibly been misinterpreted during the past as a regional decline in groundwater quality. In spite of the presence of the cone of depression for several decades, the lateral movement of saline groundwater from the fringes of the area toward the cone has been relatively very slow (Gerges, in Roger Stokes & Associates, 1995).

No change in the salinity of the bores in the coastal area has been observed, even though the potentiometric surface is generally below sea level.

7.4.4. Future Resource Potential

The 3,000 hectares of irrigated lands of the Northern Adelaide Plains constitutes a unique and important horticultural region, which is based upon a reliable, good quality supply of groundwater. The Northern Adelaide Plains Water Resources Committee (1991) suggests that if this tradition is to continue, groundwater withdrawals will need to be significantly reduced when compared with historical levels, and alternative water supplies will need to be developed. Such action should ensure the preservation of the yield and quality of the groundwater derived from the aquifer systems.

Shepherd (1975) suggested that the average salinity over the entire region would increase at a slower rate of 4 mg/L per year, assuming that there was no change in the volume extracted from the Tertiary aquifers. Within the cone of depression salinity was likely to increase at a rate of 10 mg/L per year. However, at present extraction rates, it is likely that in the long-term the volume in storage in the Tertiary aquifers will decrease, resulting in greater increases in salinity.

A further submission was made that on the basis of transmissivity values presented in Table 7.13, aquifers T1 and T2 were incapable of supplying the quantities being pumped in relation to the drawdown recorded, without leakage from overlying aquifers and confining beds. In addition, the shallow aquifers were expected to be completely depleted by the year 2000, after which Tertiary aquifers would behave as unconfined systems. Shepherd (1975) concluded that salinity would become a

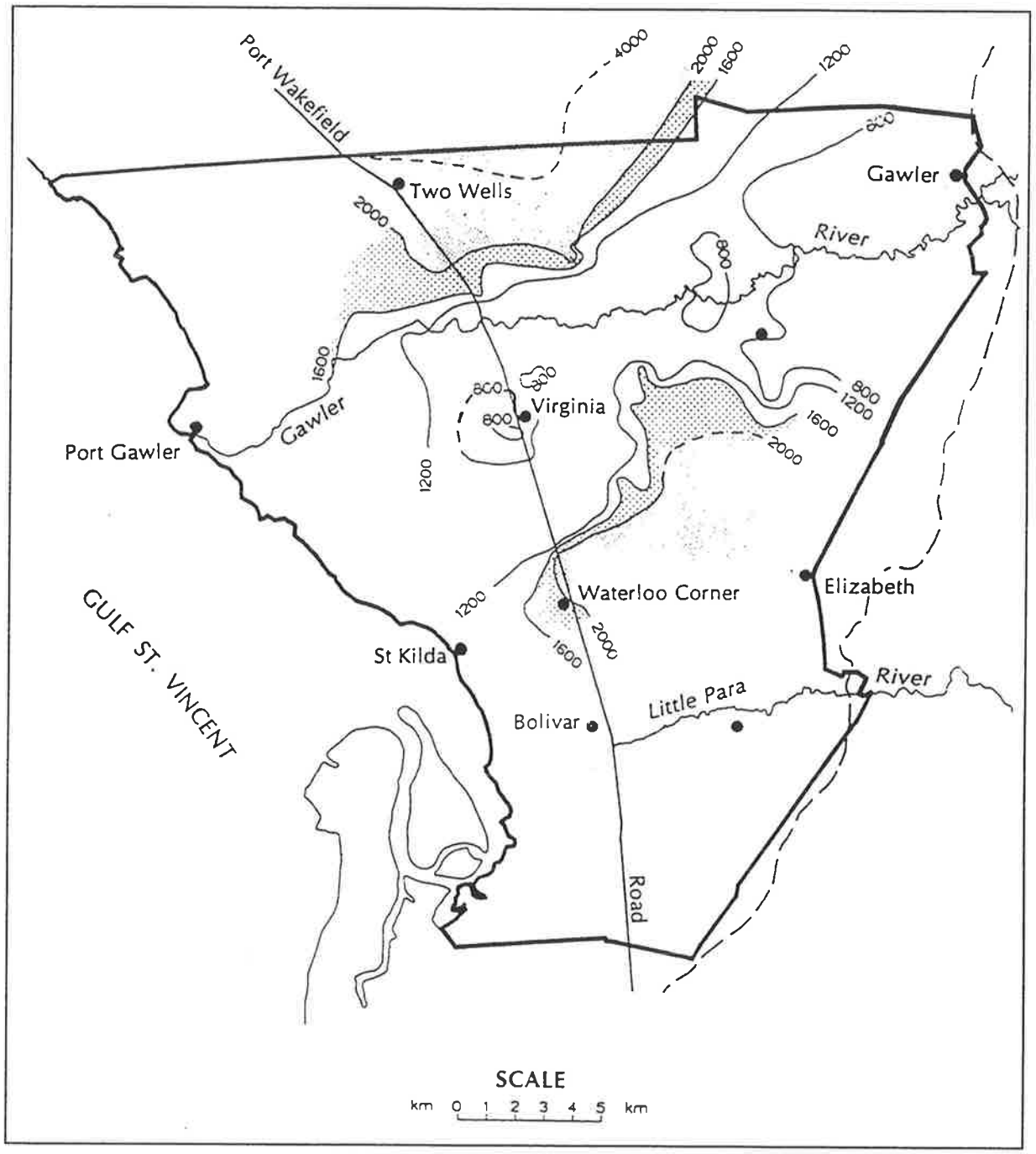


Figure 7.21
Salinity of the T2 Aquifer

major problem long before depletion, possibly within 10-15 years (circa 1985-1990), leaving few areas where good quality water would be obtainable.

Table 7.13
Parameters of Aquifers

Aquifer	Transmissivity (T) (m^2/day)	Permeability (K) (m/day)	Storage Coefficient (S)
II	272	34	5.2×10^{-3}
III	255	25	-
T1	69.8	1.6	7.9×10^{-4}
T2	56.3	0.45	4.6×10^{-4}

While Shepherd's work is considered to have been the best interpretation of the data available at the time, the predictions of highly saline and unusable Tertiary aquifers prior to the 1990s has not eventuated. Furthermore, the new theories regarding recharge mechanisms place doubt upon the time frames outlined for the productive lives of the aquifers.

Gerges (1993) considers that continued extraction at current rates from Tertiary aquifers T1 and T2 poses no short to medium term problem, since the water resource is so vast that present extraction rates could be accommodated and continue unabated for decades before total depletion. Refer to Appendix C.

7.4.5. Aquifer Recharge

While no remedial action might therefore be considered necessary, some reversal or reduction in the depletion of the aquifers may be beneficial, such as that which may be offered by reduction in the volume extracted or artificial recharge. This may lead to raising of the water table or potentiometric surface which could offer benefits of:

a) reduction in groundwater pumping costs, especially in cones of depression;
b) reduction in downward seepage of saline water from Quaternary aquifers through old bores and highly permeable deposits;
c) restoration of natural flow patterns, and possible retardation of the inland movement of the salt water-fresh water interface;
d) use of traditional waste waters, such as storm runoff and treated sewage effluent, reducing pollution and degradation of the normal receiving surface water bodies, environment and ecosystems; and
e) improvement in the quality of the groundwater (i.e. salinity).

Aquifers T1 and T2 are the most appropriate for recharge, since they are the aquifers being most severely depleted. Gerges (1993) regards the aquifer system to be operating in a state of equilibrium, where inflow less outflow must equal the change in storage. Therefore, if groundwater extraction exceeds the natural recharge resulting in a loss of storage, the there is the potential to store water in the aquifer equivalent to the reduction in natural storage by extraction (i.e. 18,000 ML/year).

Preliminary investigations into the viability of a recharge scheme for the Tertiary aquifers were undertaken by Shepherd (1975). A proposed scheme involved 40 (to 60) recharge injection bores covering 250 km² at a minimum spacing of 2 km, recharging for a period of 100 days at 2.5 litres per second. It was concluded that the artificial recharge as indicated would have limited benefits, possibly increasing storage by 3,000-3,500 ML per year, but at the time of the study, it would have been economically impractical.

Renewed interest in the use of stormwater has initiated a number of investigations into the viability of aquifer recharge, on the Northern Adelaide Plains in particular. The South Australian Department of Mines and Energy, Department of Environment and Natural Resources, CSIRO Division of Water Resources (Centre for Groundwater Studies), and the Hickinbotham Group are all playing a role in current investigations into aquifer recharge and use of stormwater. A flood mitigation and water treatment complex of wetlands has been constructed at Andrew's Farm where the stored stormwater may be used for artificial recharge. A trial project is underway to assess the potential of the confined aquifer system to support artificial recharge and re-use. The aquifer system was found to be capable of accepting, storing and releasing recharged stormwater. Some clogging of the well and near aquifer material was observed but it is believed that appropriate filtering prior to injection will overcome this problem. The use of dual purpose injection/discharge wells also helps to control the clogging problem by re-developing the well at the beginning of each pump-out season. Significantly, on the basis of preliminary cost estimates, it was concluded that artificial recharge and reuse of stormwater could prove economically viable (Gerges, 1994).

Coffey Partners International (1993) also undertook research into the recharge potential of the Northern Adelaide Plains as a contribution to a regional stormwater management study. It was concluded that recharge could be initiated to Tertiary aquifer T2 using 15 to 20 injection bores with the potential to recharge 5,000 ML per year, subject to quality and surface storage restrictions. Information from Gerges (1993) suggests that this figure may be a reasonable estimate.

While these rates of injection may theoretically be achieved, the actual rate of recharge can only be determined by field tests. As there is spatial variation in land use, water and wastewater availability, geological and hydrogeological properties, so too there is variation in recharge potential.

The quality of water available for recharge can impose severe restrictions upon the rate and even feasibility of recharge. Consideration must be given to the interaction and water quality variations that might result from aquifer recharge in conjunction with the applications of extracted groundwater. In addition, a desirable suspended solids load of less than 1 mg/L is proposed by Coffey Partners International (1993), although Gerges (1993) suggests a more generous 20 mg/L. However, these loads are still very low when compared with that contained in typical urban runoff (e.g. 200 mg/L or more), and therefore water quality requirements for recharge by injection are such that, except in special circumstances, a very highly treated wastewater is required (AWRC, 1982). Williams & Daniell (1996) have found that the suspended solids load from a large urban catchment can be effectively and significantly reduced by the presence of grassed drainage swales; suspended solids

loads during storm events ranged from 10-40 mg/L compared to 50-750 mg/L for adjacent urban catchments with more conventional drainage systems.

Numerous other factors can affect aquifer recharge operations. For example, recharge may further be restricted by:

a) The reduction in extent of the cone of depression thereby reducing the number of effective recharge bores.
b) A reduction in the depth to the potentiometric surface would reduce the available recharge head (under gravity feed) and thus reducing the recharge rate. This is not a problem where pressure injection bores are used.
c) The need to prevent the potentiometric surface rising above ground level. Should the potentiometric surface or water table rise above ground level, water-logging and free-flowing bores could result, which may cause serious structural damage to buildings constructed over old bores.

Therefore, while it is considered that sufficient groundwater resources exist within the Northern Adelaide Plains aquifers to accommodate current demand for many decades, the productive life of the aquifers for industrial and irrigation purposes depends upon the cost of pumping and availability of alternative water resources. Environmental, economic and social benefits may accrue from aquifer recharge, but this will be dependent upon water quality and storage requirements, and thus ultimately the availability of financial resources and the political 'will' of government.

There are certainly differing opinions on the recharge mechanism of the Tertiary aquifers on the Northern Adelaide Plains. Regardless, it is clear that there are declining water levels and degradation of the water quality of the aquifers. It would also appear that there is potential for contamination of the aquifer system used primarily for supply of groundwater through downward leakage of pollutants (e.g. petroleum hydrocarbons, solvents, etc) known to exist in the Quaternary and water table aquifer systems.

The present rate of extraction of groundwater from the aquifers is thought by many to be unsustainable in the long term. Further investigations should be initiated, leading to the establishment of a groundwater resource management strategy for sustainability. Work is currently being undertaken by Primary Industries and Resources SA (formerly the Department of Mines & Energy) to provide guidance by way of maps on areas suitable for artificial recharge of the aquifers. However, the maps are yet to be released due to difficulties in deciding upon the appropriate rule base from which the guidelines can be derived (pers comm. Gerges, 1997).

7.5. Water Supply and Wastewater Treatment

7.5.1. Reservoirs and Water Treatment Plants

The Northern Adelaide Plains are served primarily by two reservoir systems – the Warren/South Para/Barossa system and the Little Para Reservoir. The Anstey Hill

Water Filtration Plant also provides treated water to a small, southern portion of the study area, as shown in Figure 7.22.

The South Para River is the main source of supply for three reservoirs – the Warren, Barossa and South Para. The catchment area for these three reservoirs is approximately 230 square kilometres.

The Warren Reservoir was built to serve the Barossa Valley and the lower northern country areas, and this is still its principal function. However, it has inter-connections with the South Para Reservoir and so contributes to the metropolitan Adelaide system; this will become increasingly important in the future. Water from the Warren's natural catchment is supplemented by River Murray water from a branch main off the Mannum–Adelaide pipeline.

Table 7.14
Reservoir Construction and Capacity (after EWS, 1992)

Reservoir/System	Type of Dam	Year Completed	Capacity, ML
South Para System			55,810
Barossa Reservoir	Concrete arch	1902	4,510
South Para Reservoir	Earth and rock fill	1958	(44,900)
South Para Res. raised		1960	51,300
Warren Reservoir	Earth and rock fill	1916	5,080
Little Para Reservoir	Rock fill	1977	20,800

The Barossa Reservoir is an offstream storage, fed by an aqueduct from a weir on the South Para River. With a capacity of 4510 ML it was the largest concrete arch dam in Australia at the time of its construction. A water filtration plant is also situated at the Barossa Reservoir, the plant having been commissioned in October 1982.

The South Para Reservoir is the largest in South Australia, with a capacity of 51,300 ML. It does not directly serve consumers; its water is discharged through an outlet tower and tunnel into the South Para River and so via the diversion weir into the Barossa Reservoir. From here, the Barossa Trunk Main extends to Elizabeth where it merges with the main metropolitan distribution system. Although the area served by these three reservoirs varies from time to time, generally they supply the Gawler, Salisbury and Elizabeth areas.

The South Para Reservoir can be supplemented either from the Warren Reservoir or from the Swan Reach-Stockwell Pipeline via the Warren Trunk Main. In the 37 years since construction was completed (1958), the South Para has relied primarily on natural inflow in all but 6 particularly dry years (1976-79 and 1985-86), with minor diversions in another 2 years (1973 and 1983). Furthermore, there have been no contributions to storage in the South Para Reservoir since 1987.

The majority of natural inflow to the South Para Reservoir system occurs during the winter months, although the historical record for the period 1972-1992 indicates that there is typically some inflow from natural runoff during all months of the year. The mean and median natural inflows are 18,380 ML/year and 19,500 ML/year

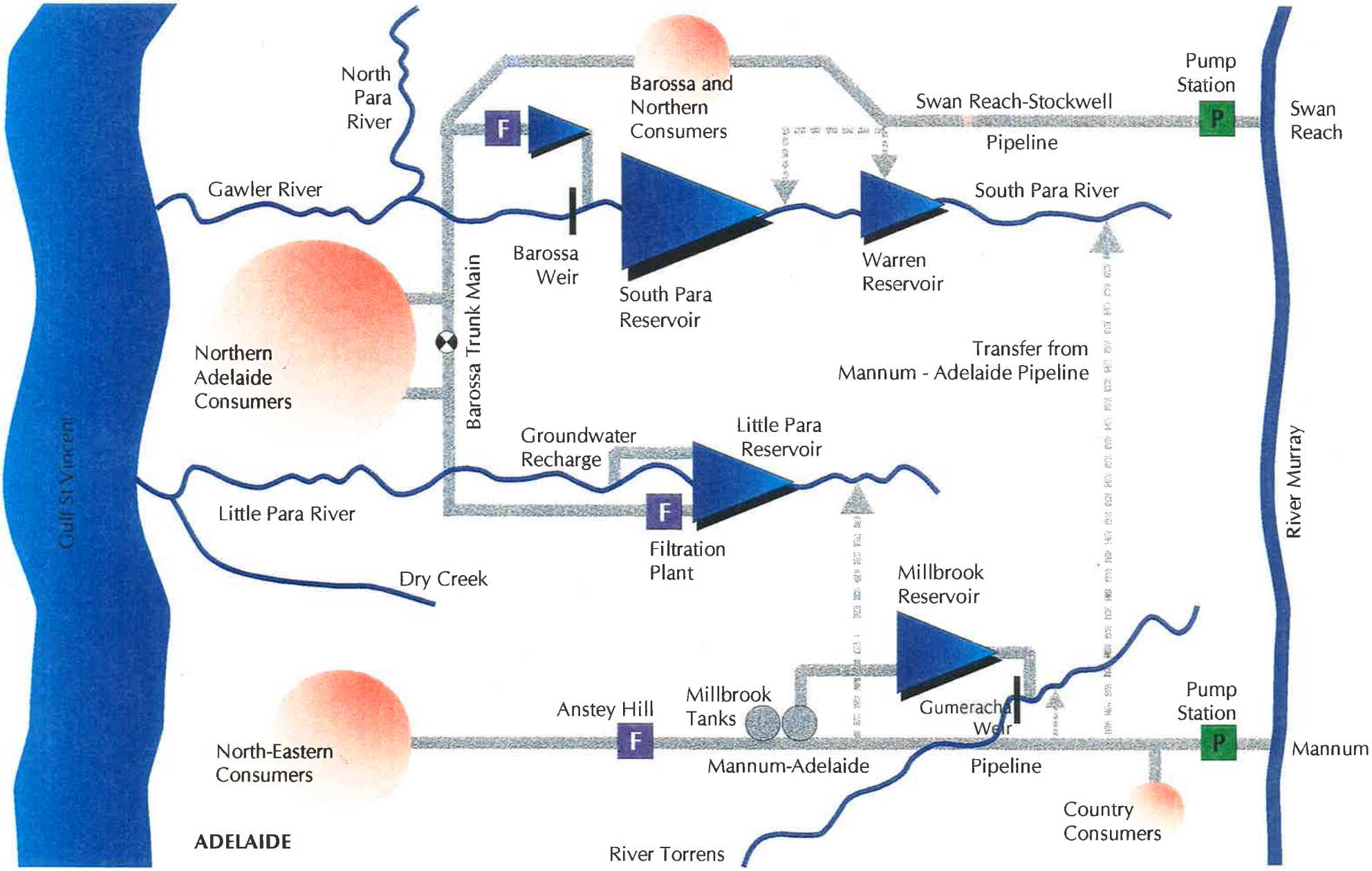


Figure 7.22

Northern Adelaide Water Supply System

respectively, with more than 90 percent of this total flow accumulating between June and October. The mean diversion to the South Para Reservoir from the Warren Trunk Main over the same period of record is 1,820 ML/year (a total diversion of 38,160 ML during only 8 of the 21 years of available record). The volume of water diverted from the main is also, on average, higher during the winter months.

Evaporation losses are typically equivalent to 7.5% of the total storage capacity (of South Para and Barossa Reservoirs combined), and 20% of the average inflow from natural runoff and diversions. The mean combined storage capacity of the South Para and Barossa reservoirs varies between 25,600 ML and 38,000 ML in a year.

Mean annual consumption from the South Para system is 16,700 ML which is approximately 80 percent of the average inflow and 30% of the reservoirs' capacity. During the period of available record, total inflow typically exceeded annual consumption by 4600 ML, however there was in 7 of the 21 years a shortfall of between 1380 and 15,510 ML, as illustrated in Figure 7.23. These shortfalls were either met by available reservoir storage (e.g. 1982) or by increased pumping from the River Murray (e.g. 1976).

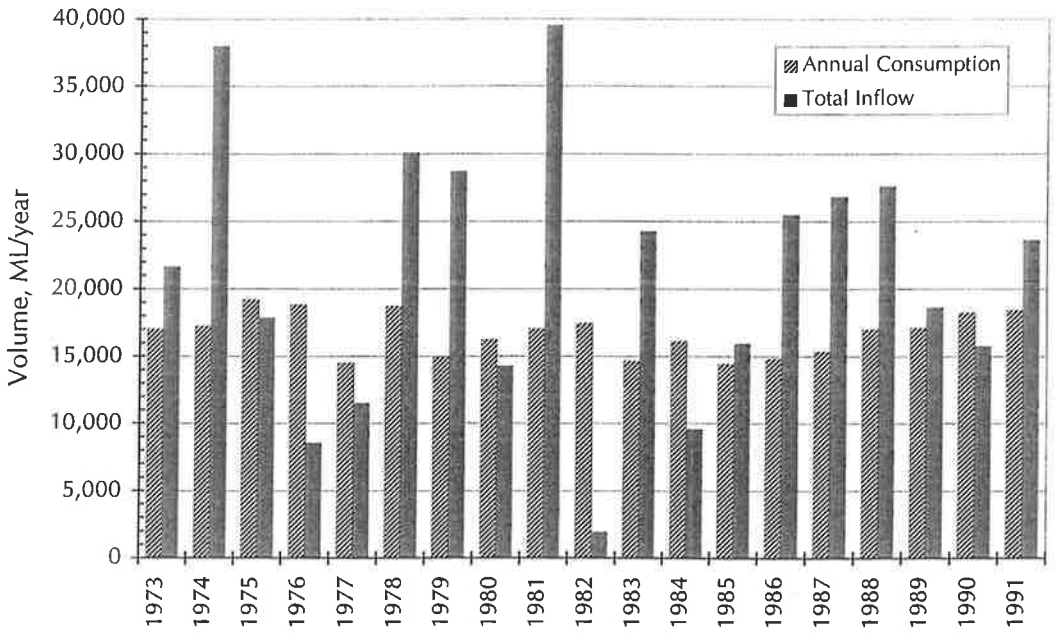


Figure 7.23
Historical Annual Inflow and Consumption from the South Para System

The Little Para River was selected for a reservoir as it had an excellent dam site close to the Mannum-Adelaide Pipeline and was centrally located to the distribution areas to be served. The Little Para Reservoir is an onstream storage formed by a rock fill dam, and has a capacity of 20,800 ML.

The Little Para Reservoir was commissioned on 9 January 1979, and is considered, in operational terms, to be part of the Torrens System, because it draws almost all of its water from the Mannum-Adelaide pipeline. It functions largely as a balancing

storage for River Murray water. In the nearby quarry, established to provide rock for the dam wall, is a water filtration plant which was opened on 23 November 1984.

The area served by the reservoir varies but is capable of supplying the Para Hills, Parafield and Salisbury areas during summer, although at present is only used to supply the Parafield and Salisbury areas (EWS, 1991). During summer months it supplies filtered water to approximately 80,000 people in the Elizabeth, Salisbury and Para Hills area. The capacity of the reservoir and filtration plant is being stretched during peak demand periods, due to rapid development in this area. However, it is increasingly being supplemented by water supplied from the Anstey Hill or the Barossa Reservoir.

The Little Para Reservoir is typically taken out of service during winter to be refilled as low system demands during winter make it uneconomical for the Little Para Water Filtration Plant to be continually on line. Furthermore, other demands on the Mannum-Adelaide pipeline are low making utilisation of this excess capacity for filling the reservoir an efficient activity. At this time, other systems which can serve the Northern Adelaide Plains are also easily capable of meeting the demand.

The majority of natural inflow to the Little Para Reservoir system also occurs during the winter months, although it is less than 50% that of the South Para, reflecting the considerably smaller catchment area. The historical record for the period 1978-1992 indicates that there were only 5 months during which no natural inflow occurred, although more than 85 percent of the annual flow typically occurs between the months of June and October.

The mean and median natural inflows to the Little Para are 8,190 ML/year and 7,360 ML/year respectively. The mean diversion to the Little Para Reservoir from the Mannum-Adelaide Pipeline over the same period of record is 5,400 ML/year, with 63 percent of this occurring during June through October. This diversion is equivalent to 25 percent of the reservoir capacity and 70 percent of the mean annual natural inflow.

Evaporation losses are typically equivalent to 8% of the total storage capacity.

Mean annual consumption from the Little Para system is 9,900 ML which is approximately 51 percent of the average inflow and 47 percent of the reservoir's capacity. Furthermore, an annual release of around 1,500 ML is made for aquifer recharge purposes. During the period of available record, total inflow typically exceeded annual consumption (including aquifer recharge releases) by only 42 ML, however there was, significantly, in 7 of the 14 years a shortfall of between 1,515 and 12,280 ML, as illustrated in Figure 7.24.

The reservoir also has a flood mitigation role. For most of the year it is less than full in its main role as a balancing storage for River Murray water, the storage capacity varying between 7,200 and 16,000 ML. The reservoir therefore has the capacity to contain flood peaks and release flood waters at a controlled rate via the dam release valves, if at all. In addition, controlled releases of water are made back into the water course when necessary to maintain the level in a local groundwater system.

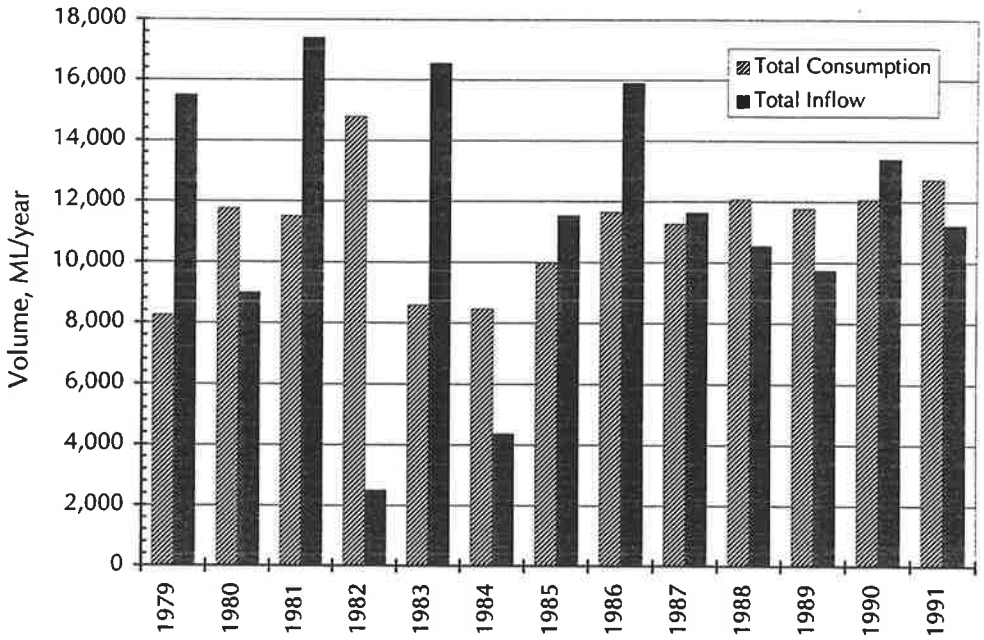


Figure 7.24
Historical Annual Inflow and Consumption from the Little Para System

7.5.2. The Reticulation System

Due to the considerable complexity and inter-connectivity of the water infrastructure servicing metropolitan Adelaide, there is a high degreee of operational flexibility in the system and water can generally be supplied to the demand zones from a number of different sources.

The areas served by a given source at any one time depend upon many factors such as the relative holdings of different reservoirs, demand and the quality of water from the reservoirs and pipelines, and other operational requirements such as the maintenance of burst pipes.

As previously discussed, the Barossa and Little Para Water Filtration Plants can supply similar areas, the Little Para system typically operating during the summer months to service the increased demand.

7.5.3. The Sewerage System

Sewage from the Northern Adelaide Plains, and indeed a greater proportion of Adelaide, is treated at the Bolivar Sewage Treatment Works situated near the coast to the south-east of the study area. This is the only treatment plant situated to the north of metropolitan Adelaide.

The Bolivar Sewage Treatment Works (STW) was commissioned in three stages between 1964 and 1969, replacing the heavily overloaded Islington Sewage Farm

(EWS, 1991). Treatment processes at the works include screening, pre-aeration sedimentation, bio-filtration, lagoon stabilisation and sludge digestion.

The Bolivar STW is the largest plant serving the needs of Adelaide, and its establishment made possible extension of the metropolitan sewerage system to serve Salisbury, Elizabeth, Modbury, Tea Tree Gully and other areas which could not have been drained to the Islington Sewage Farm on account of its location and limited capacity. In 1970 the Elizabeth trunk sewer was extended to Gawler.

The Bolivar STW has a connected population of approximately 550,000 and receives large volumes of industrial wastewaters. It is designed for a maximum population of 600,000 plus industrial wastes equivalent to 700,000 people; that is, it will handle the equivalent pollutional load of 1.3 million people. If the need arises, it can also be extended to provide capacity beyond this figure.

The largest sewer main in Adelaide is the trunk sewer extending from Islington to Bolivar with a diameter up to 2.6 metres. Other sewers are from 150 mm diameter upwards, usually laid between 2 and 5 metres below ground level on a grade following the natural fall of the ground within these limits.

The sewer systems are designed to run 60 percent full under average daily peak conditions to allow for increased flows from stormwater and groundwater intrusion during very wet periods, and to provide ventilation (EWS, 1991).

The reclaimed water from sewage treatment works can be used for irrigation and industrial purposes, subject to certain limitations imposed by public health considerations and the presence of dissolved salts and other minerals. At Bolivar, effluent is used extensively for watering lawns and gardens around the works, and for flushing and cleaning purposes. The effluent is also available for reuse on the Northern Adelaide Plains for certain industrial, recreational, agricultural and irrigation purposes.

Digested sludge produced by the anaerobic digestion process is the relatively stable material derived from the dissolved and suspended solids in the sewage. It has good soil conditioning characteristics because of the high organic content but a moderately low fertilising value. At Bolivar, the sludge is pumped to drying lagoons, and later sold to a fertiliser company which uses it as a filler after sterilisation via heat treatment.

Data was provided by SA Water relating to the volume of treated sewage effluent produced by the Bolivar STW. The mean daily volume of treated effluent ranges between 127 ML/day in April to 150 ML/day in September. Over the period of available record, January 1989 to December 1993, the mean flow always exceeded 120 ML/day, with a median value for the entire period of 135 ML/day. There is little variability in the monthly distribution, although there are certainly daily cycles with peaks typically around 8 am and 7 pm (CMPSF, 1996).

The volume of treated effluent increases and typically peaks during the later winter and autumn months of August through to November. This can in part be attributed to increased inflow to the plant associated with stormwater flows and into the

autumn months due to increased groundwater inflow. Figure 7.25 also illustrates this effect, depicting the average daily flow history for the Bolivar STW and the notable spike during the latter months of 1992, in response to the extremely wet winter.

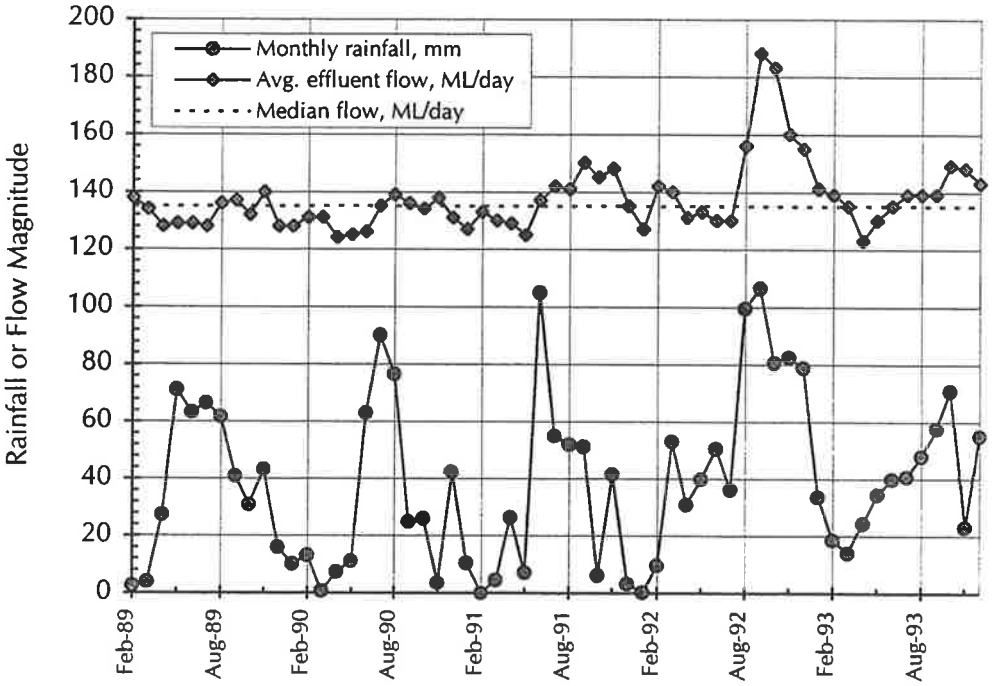


Figure 7.25
Historical Daily Flow of Treated Effluent at Bolivar STW

7.6. Mains Water Consumption

Domestic water usage accounts for 69 percent of Adelaide's total water consumption. On average, about 50 percent of domestic usage goes to the garden (Table 7.15), but on peak demand days this rises to around 80 percent. So naturally, water consumption is not evenly distributed throughout the year; nearly 40 percent of annual consumption occurs during three summer months (EWS, 1991).

The water consumption pattern will, however, vary greatly depending on the number, ages and habits of people in the household, the nature of the property (particularly the size and type of garden), the number and type of water using appliances and garden irrigation systems. Within any household, the pattern will vary greatly throughout the year, depending on seasonal factors.

Data was provided by the Asset Management Group of the SA Engineering and Water Supply Department (now SA Water Corporation) for assessment of the spatial and sectoral water consumption characteristics of the Northern Adelaide Plains. Metered water use data were made available for a period of 3 years (1989-1991) for all suburbs in the study area. The data was extracted from the Department's Oracle database, in a format that included the following fields:

- Assessment (property) number
- Land use type (primary and secondary)
- Property location details (house number, street name, suburb)
- Source of supply
- Additional water type
- Date of first supply.

Table 7.15
Typical Domestic Water Usage

Application	Percent	Litres/Person/Day
Garden	50	175
Shower	10	35
Toilet	10	35
Clothes Washing	9	32
Leaks	8	28
Dishwashing	5	18
Bath	4	14
Drinking/Cooking	2	7
Car Washing	1	3
Recreation (pools etc)	1	3
Total	100	350

Table 7.16
NAP Suburbs with Highest Mains Water Consumption(1)

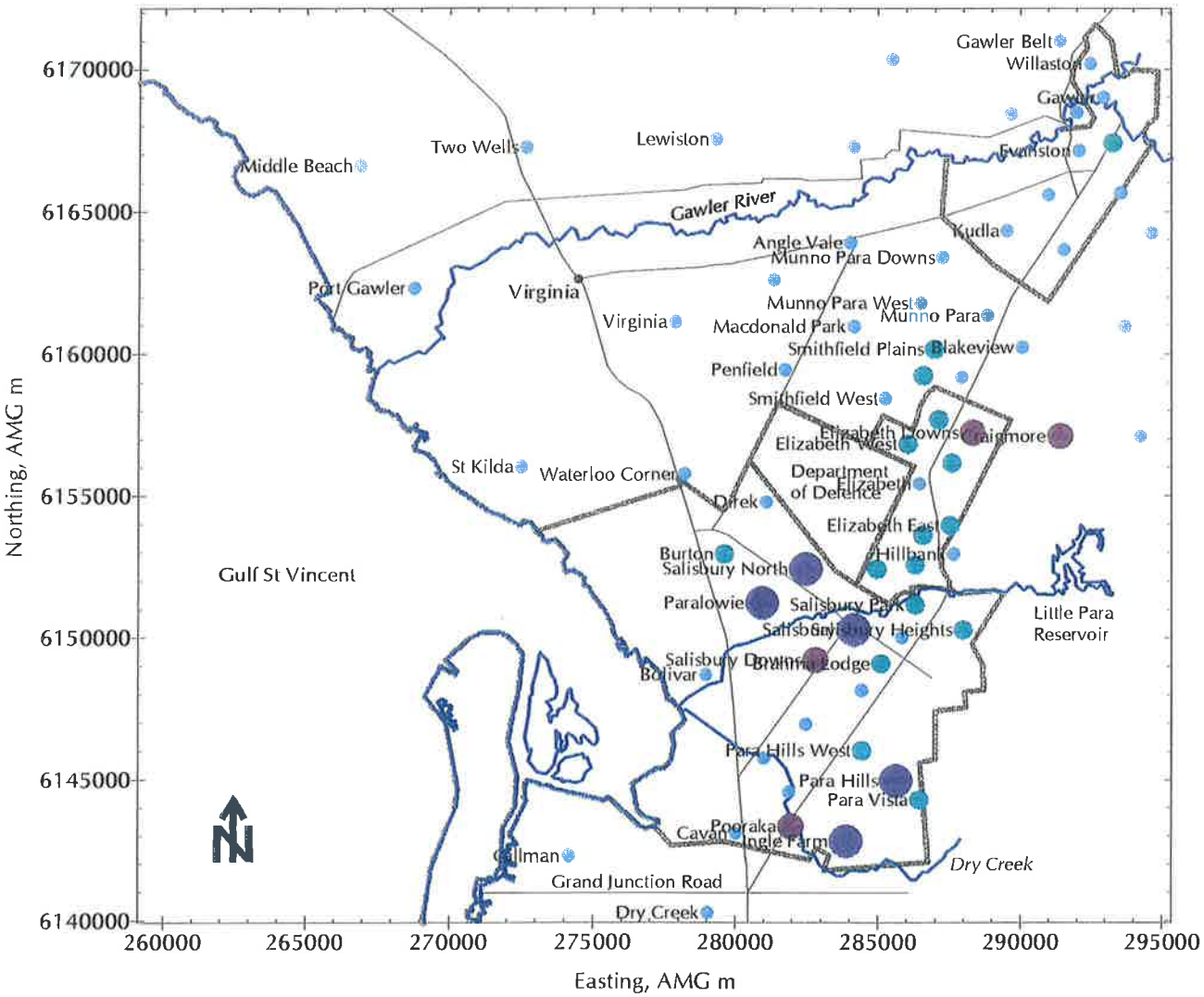
Suburb	Mean Consumption (kL/yr)	Mean Number of Consumers
Parafield Gardens	1,194,422	3,867
Salisbury East	1,115,535	3,291
Salisbury North	962,373	3,277
Ingle Farm	939,977	2,957
Para Hills	914,559	3,041
Paralowie	870,694	3,037
Salisbury	779,854	2,187
Pooraka	595,558	1,734
Elizabeth Downs	544,073	2,004
Salisbury Downs	517,960	1,582
TOTAL	8,435,005	26,977

(1) Consumption, inclusive of all consumer types, for the period 1989-1991

Table 7.17
Summary of Mean Consumption by Land Use Category[1]

Consumer Category	Consumption, kL/yr	No. of Consumers
Commercial	**541,528**	**1,121**
Business services	136,962	281
Construction services	26,931	100
Finance, assurance and real estate services	8,227	53
Personal services	23,144	46
Professional services	15,528	88
Repair services	28,223	141
Retail trade	277,064	364
Wholesale trade	25,449	49
Industrial	**287,957**	**392**
Basic metal industries	5,646	22
Chemicals, petrol, coal, rubber & plastic products	59,609	38
Fabricated metal products, machinery & equipment	89,969	152
Food, beverage, tobacco	47,957	37
Non-metallic mineral products	21,018	31
Other manufacturing industries	16,898	32
Paper and paper products; printing and publishing	2,878	11
Textiles, clothing, leather industries	47,768	19
Wood and wood products	16,214	50
Public Institutions and Utilities	**517,177**	**476**
Amusements and entertainments	18,773	21
Armed services	6,349	4
Cultural activities and nature exhibitions	13,899	14
Educational	365,927	153
Governmental	25,196	20
Medical and health services	21,421	36
Other services	5,971	22
Places of assembly	43,967	145
Social welfare	4,035	28
Gas and electricity	7,252	23
Solid waste disposal	3,954	7
Water, sewage disposal	1,433	4
Residential	**15,311,513**	**17,191**
Double unit (maisonette)	1,994,677	2,598
Flats	319,805	427
Home units	261,005	370
Hostels, private hotels and boarding houses	3,081	6
Hotel and motel accommodation	70,077	62
Institutional residential accommodation	94,611	121
Rural living area	493,156	655
Single unit	12,075,102	12,953
Vacant Land	**476,982**	**780**
Agistment	3,191	10
Car park	163	5
Land used for primary production; not viable unit	101,009	192
Undeveloped reserve	201,105	202
Vacant allotment	171,514	371
Total for all Land Uses	**17,156,159**	**19,960**

(1) Mean consumption assessed over period of available record, 1989-1991



LEGEND

- Council Area Boundary
- Major Road Corridor
- Coastline or River

WATER USE, kL/year

- 0 to 249,999
- 250,000 to 499,999
- 500,000 to 749,999
- 750,000 to 1,000,000

Figure 7.26

Mains Water Use by Suburb and Average Annual Volume Consumed

The mean annual water consumption for the entire study area over the available period of record was 17,156 ML, of which nearly 50 percent was consumed within the 10 suburban areas listed in Table 7.16. The total number of consumers in these suburbs was also equivalent to 50 percent of the total during the same period (consumer count of 53,289).

Figure 7.26 illustrates the water use for all suburbs supplied with mains water within the study region.

The residential sector consumes by far the highest proportion of all water consumed within the Northern Adelaide Plains. On average, 89 percent of water is directed to the residential sector, around 20 percent greater than for Adelaide as a whole, as illustrated by Figure 7.27. This is equivalent to over 15,000 ML per year, around 318 kL per consumer per annum or 870 L/day per consumer. Of this category, over 82 percent of consumers were associated with single, detached dwellings (70% of total consumption), with the next major category being double dwelling or unit style accommodation (at 14.5 percent of consumers and equivalent to 11.4 percent of total consumption).

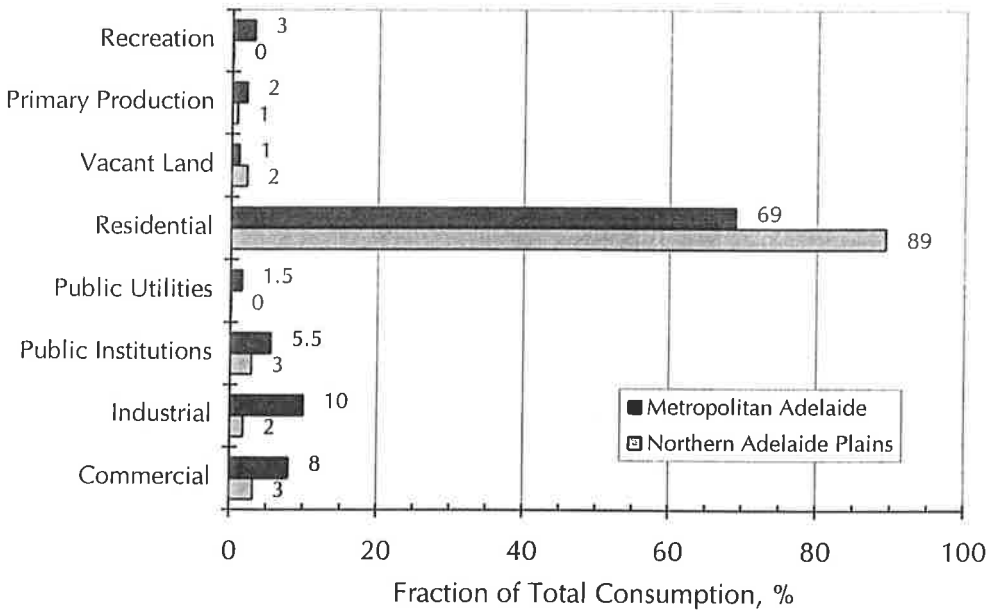


Figure 7.27
Comparison of the Mean Water Consumption Characteristics of Adelaide with the Northern Adelaide Plains

Examining the water consumption characteristics by secondary land use type, five of the top ten consumers groups are associated with residential development. The cumulative water consumption associated with the land use categories of single unit, double unit, rural living, flats, and home units is 15,144 ML (approximately 88 percent of total consumption) with 17,003 consumers. The remaining land use categories associated with high metered water use are (i) educational with 366 ML and 153 consumers, (ii) retail trade with 277 ML and 364 consumers, (iii) business

services with 137 ML and 281 consumers, and (iv) undeveloped reserve and vacant allotments with a cumulative 372 ML and 573 consumers.

Examining the characteristics of independently large water consumers (i.e. those consuming greater than 2,000 kL per year on average), public institutions are found to consume the greatest amount of water, both in total volume and on a per consumer basis. Table 7.18 summarises these findings.

Table 7.18
Characteristics of Consumers Using in Excess of 2000 kL/year

Land Use Category	Total Consumption kL/year	Number of Consumers	Average Consumption per Consumer (kL/yr)
Commercial	171,383	36	3,488
Industrial	216,895	33	7,489
Public Institutions	347,598	48	7,533
Residential	284,475	74	3,835
Vacant Land	230,807	55	4,261

SA Water Corporation also collects and stores information on consumption by a category of user referred to as a "major water user" independently from that presented above. The majority of these major water users are associated with one of three categories: industry, education or irrigation. Data was made available for analysis for the 1990-91 to 1992-93 water years, and is summarised in Table 7.19.

Table 7.19
Consumption of Major Consumers by Category

Category of Consumer	Mean Consumption, kL/yr	Number of Consumers
Education Sector	577,149	26
Industrial Sector	2,615,109	32
Irrigation Sector	1,188,033	46
Total Consumption	4,380,290	104

The education sector consumes a large volume of water, largely for the irrigation of the ovals and grounds of 23 primary and secondary schools; the University of South Australia is also situated within the study area and would consume water in a similar proportion for irrigation, although having other campus applications.

There were numerous industrial applications identified including hardware and masonry, clothing manufacture, quarry and mining activities, food preparation, automotive manufacture, and abbatoirs.

The majority of water used for irrigation was consumed by the city councils within the region at the numerous parks, gardens and ovals. Other water was consumed for irrigation of private sporting facilities and horticultural and nursery activities.

Table 7.20 lists the top ten individual water consumers on the NAP during the 1990-1993 period, which represent 70 percent of the water consumed by all major water users on the NAP. Other major consumers in this regard in terms of their cumulative water consumption at a number of site are the Corporation of Salisbury, who consume around 260 ML per year, and the Education Department who consume in the order of 430 ML per year, both primarily for irrigation purposes. The location of all major users is shown in Figure 7.28.

Table 7.20
Top 10 Major Water Consumers on the NAP, 1990-1993

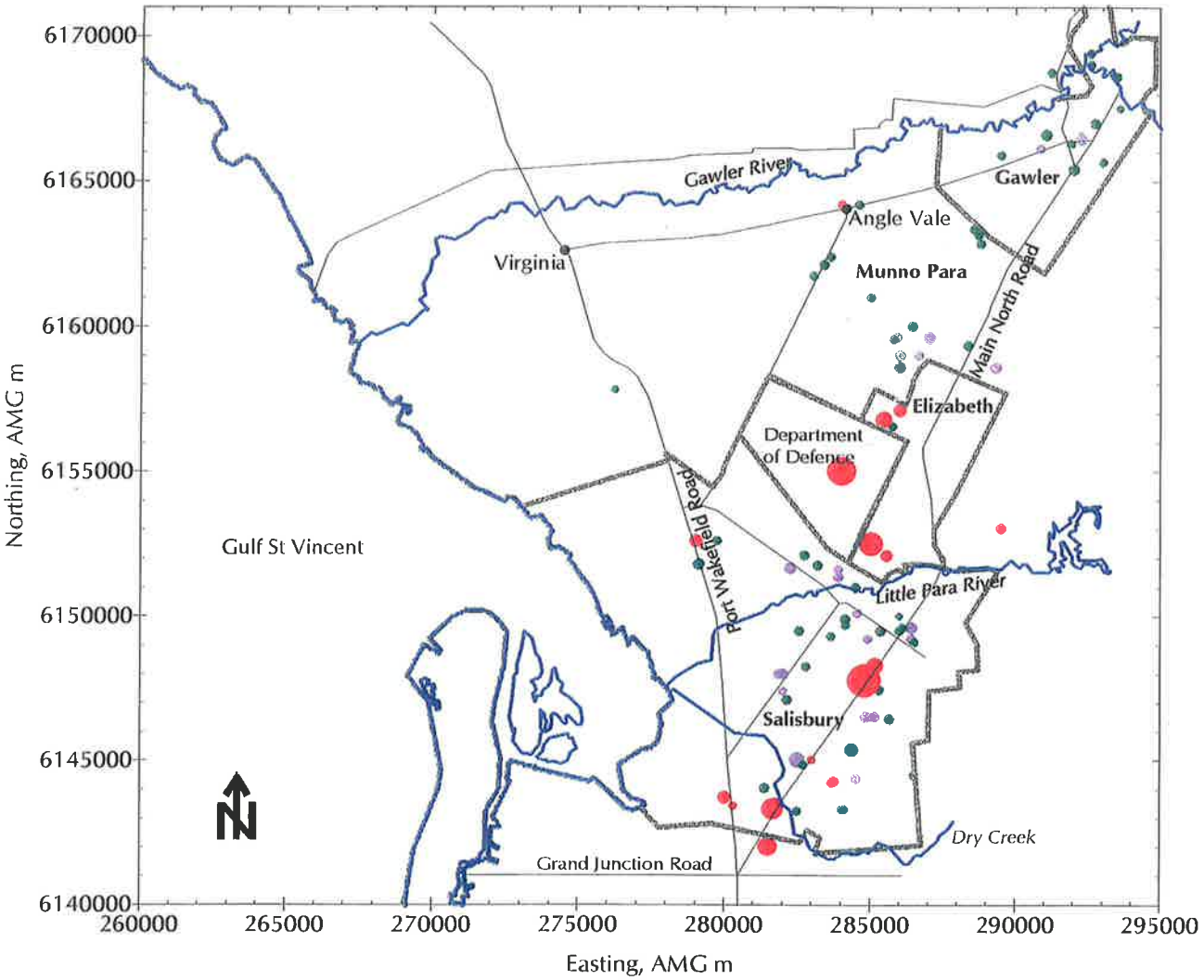
Consumer	Location	kL/yr
Abelia Pty Ltd (GH Michell & Sons Pty Ltd)	Main North Rd, Salisbury South	926,511
DSTO Salisbury, Department of Defence	Commercial Rd, Salisbury	662,735
General Motors Holden	Philip Highway, Elizabeth Vale	400,947
Adelaide Produce Markets	Main North Road, Pooraka	305,471
S.A. Meat Corporation (SAMCOR)	Main North Road, Gepps Cross	229,977
Australian Poultry Ltd (Manos Holdings Pty Ltd)	Ridgeway Road, Elizabeth West	159,394
Bridgestone Australia Pty Ltd	Frost Road, Salisbury South	142,251
University of South Australia	Warrendi Road, The Levels	114,342
Adelaide Malting Co. Pty Ltd	Cardiff Court, Cavan	73,345
Ingham Enterprises Pty Ltd	Port Wakefield Road, Burton	72,250

Given that the majority of water consumed on the Northern Adelaide Plains is associated with residential households, and furthermore that around 50 percent of water in this category is typically used to maintain gardens, it is not unexpected that there is a strong seasonal trend in water consumption in this region. A large proportion of water used by major water consumers is also associated with irrigation activities, and therefore has a very seasonal pattern. (Further information on these characteristics and factors influencing water demand are presented in Chapter 10.)

Furthermore, considering the nature of water use on the Northern Adelaide Plains and more particularly the large application of water for irrigation and general industrial purposes, it would seem that there is considerable potential for utilisation of water of a lesser quality than the potable water from the mains reticulation system.

7.7. Water Recycling

Treated effluent from the Bolivar STW is available for reuse on the Northern Adelaide Plains for certain industrial, recreational, agricultural and irrigation purposes. It is actively encouraged by the Government and pumping sumps are provided along the channel for the effluent to be drawn off. Reclaimed water from the plant has been made available to local landholders for irrigation, with the remaining excess flows transported along a 12 km channel and discharged in a remote part of Gulf St Vincent several kilometres north of St Kilda.



LEGEND

- Industrial Application
- Irrigation Application
- Education Facilities Application
- Council Area Boundary
- Major Road Corridor
- Coastline or River

Figure 7.28

Location of Major Mains Water Users on the Northern Adelaide Plains

Bolivar reclaimed water has been used successfully for agricultural production since 1974. The outfall channel was proclaimed under the Water Resources Act in 1980 and licenses were issued for a total allocation of around 9,340 ML per year, which is additional to groundwater allocations (NAPWRC, 1991).

Effluent from all sewage treatment plants in metropolitan Adelaide totals approximately 100,000 ML per year, with around 5 percent currently being reused for irrigation at Bolivar and 9 percent at Glenelg (Pugh & McIntosh, 1991).

Data provided by the SA Water Corporation has indicated that between 1986 and 1993, on average, 2,400 ML/yr of treated effluent was extracted from the Bolivar STW discharge channel for private use. This is a small proportion of the total volume of effluent produced as can be seen from Figure 7.29. The effluent was utilised for irrigation of a variety of crops including lucerne, vines, pasture, potatoes, cereals, glass house crops, and almonds.

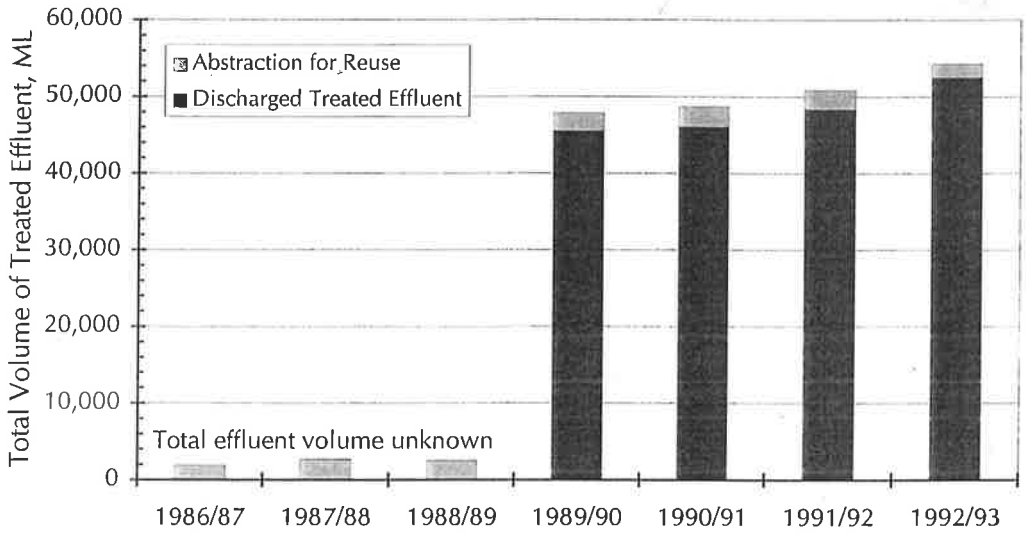


Figure 7.29
Historical Effluent Discharge Volumes for Reuse or to Gulf St Vincent

Reticulation schemes to allow even wider use of the effluent (from Bolivar STW) have frequently been suggested. This question has been investigated in great detail, with comprehensive public consultation and detailed cost-benefit analysis undertaken (EWS, c1980). Unfortunately the idea was found to be highly uneconomic during the past; a reticulation scheme to serve the extensive market garden area centred on Virginia, for example, would have a capital cost of $23 million (1977/78 values) and in addition the operating deficit would be extremely high. Interest in this scheme has been renewed over the past couple of years, and a pipeline from Bolivar to the Virginia area would now seem to have sufficient support and economic viability to ensure its implementation. A comparison of the direct costs of the current and previous pipeline schemes is provided in Table 7.21. Further information on this scheme is provided in Chapter 11.

Table 7.21
Comparison of Historic Costs for Bolivar Effluent Reticulation Schemes[1]

	Capital Cost, $m	Operation & Maintenance Cost, $m/yr
Investigation by Kinnaird Hill deRohan & Young, 1976	69.8	2.980
Current Virginia Pipeline Scheme (after Roger Stokes & Associates, 1995)	41.6	1.045

(1) All costs modified for CPI changes and converted into 1996 dollars.

The collection and reuse of stormwater is occurring at a number of locations, although at a localised level and without general co-ordination between the managing parties or at a regional level. Generally, the stormwater is collected in ponding basins or wetlands that serve multiple roles, those being flood protection, stormwater quality improvement, habitat development and amenity improvement (e.g. The Paddocks Wetland). Typically, reuse of stormwater is for irrigation; there is presently no known reuse of stormwater for industrial or agricultural applications. Artificial recharge of groundwater with stormwater collected and treated in wetlands is under trial at Andrews Farm in Munno Para. Further information is provided in Chapter 8.

7.8. Water Quality Issues

The collection and reuse of wastewaters (sewage effluent, stormwater, etc.) has received considerable attention during recent years and will more so during the future. The quality of water available for reuse is equally important as the quantity. Unfortunately, there has been little data collected on the quality of many wastewater streams in the past. Where data has been collected it has often been difficult to compare due to the use of different sampling methods, timesteps, catchment area characteristics and chemical analytes. Water quality criteria have been similarly lacking for all but drinking water standards, particularly in Australia. Fortunately this situation has been addressed with the release of national water quality guidelines under the National Water Quality Management Strategy programme (ANZECC et al, 1992).

A thorough review of Australian and international literature was undertaken to determine typical characteristics of urban stormwater, given that very little local stormwater quality data was available. The findings are summarised in Table 7.22; further detailed information is presented in Appendix D. The water quality guidelines for water to be used for irrigation are also listed; it is clear that untreated stormwater typically exceeds the guideline concentrations of typical contaminants for irrigation waters.

The quality of raw sewage and treated sewage effluent processed at the Bolivar STW is routinely monitored; a summary of this data is presented in Table 7.23.

Table 7.22
Typical Stormwater Quality Characteristics for Australia

Property	Units	Concentration Range Low	High	Median Concentration	Irrigation Guideline[1]
Suspended Solids	mg/L	20	650	190	NG[2]
Dissolved Solids	mg/L	23	690	152	500
Dissolved Oxygen	mg/L	6	22	14	NG
BOD_5	mg/L	7	60	20	NG
Faecal Coliforms	/100 ml	3,400	5,300,000	2,060,000	1,000
Acidity, pH		6.5	7.5	7.0	4.5-9.0
Oil & Grease	mg/L	1	60	30	NG
Cadmium, Cd	µg/L	6	10	10	0.01
Chromium, Cr	µg/L	20	330	30	1.0
Copper, Cu	µg/L	30	350	40	0.2
Lead, Pb	µg/L	120	440	210	0.2
Mercury, Hg	µg/L	0.1	0.1	0.1	0.002
Nickel, Ni	µg/L	20	110	30	0.2
Zinc, Zn	µg/L	120	3,600	500	2.0
Phosphorous	mg/L	0.01	2.95	1.10	NG
Total Nitrogen	mg/L	0.5	3.0	1.5	NG
Kjeldahl-N	mg/L	2.5	5.1	2.7	NG

(1) ANZECC (1992) Australian Water Quality Guidelines for Fresh and Marine Waters
(2) No Guideline recommended.

There have been a number of investigations into the reuse of reclaimed water from Bolivar STW over the past 20 years (Armstrong, 1972; Matheson, 1972; Matheson & Lobban ,1973; Matheson & Lobban,1974; Cooper et al, 1974; Kinnaird et al, 1976; Desmier, 1987; Schrale et al, 1991; EMS, 1994). All have indicated that the Bolivar effluent can be used for horticulture. In more recent times a more comprehensive database has become available on the existing effluent quality and detailed guidelines have been published on the reuse of reclaimed water (i.e. secondary treated effluent). With respect to the reuse of Bolivar effluent, principal issues are (EMS, 1994):

- **Public Health**: For unrestricted use, and to satisfy irrigators and public perceptions on product quality, reclaimed water should be of a very high quality. In particular, reclaimed water should be free of pathogens and have low levels of toxic materials, including heavy metals and organic compounds. The effluent would need to be disinfected to ensure safety in reuse with regard to faecal coliforms; the data on heavy metals indicates that concentrations are generally low and below guideline levels. Data for organic compounds has been more limited but again indicates very low or non-detectable concentrations.

- **Protection of Soils and Crops**: The chemical quality of effluent is suitable for agricultural reuse and is in line with the available guidelines. As with all typical secondary treated effluents, there are a number of characteristics which require management attention and include (a) salinity; (b) protection of the soil structure; (c) chloride levels; (d) presence of toxic materials; and (e) nutrient levels. Some areas of the NAP have been irrigated with effluent from Bolivar for over 20 years without apparent degradation of the soils.

- **Protection of Groundwater Quality**: Any leaching of irrigation water will be to the upper Quaternary aquifer. This is generally saline and unsuitable as a domestic water supply. Some withdrawals from this aquifer are used for stockwater. Properly managed, there is little risk of contamination. Any movement of salt will have little adverse effect as the Quaternary aquifer is already saline.

Table 7.23
Characteristics of Raw Sewage and Treated Effluent at Bolivar

Property	Units	Raw Sewage[1]		Treated Effluent[2]	
		Conc. Range	Average	Conc. Range	Average
Acidity, pH		6.4 - 8.3	7.4	7.2 - 8.5	7.7
BOD_{total}	mg/L	60 - 810	374	8 - 161	63
Suspended Solids	mg/L	24 - 1,810	475	15 - 448	88
Total Dis. Solids	mg/L	N/A	N/A	930 - 1,600	1,300
Kjeldahl-N	mg/L	33.9 - 93.1	64.4	10.9 - 53.0	40.1
Nitrate + Nitrite	mg/L	N/A	N/A	1.03 - 14.0	6.4
Phosphate, P	mg/L	1.4 - 20.5	12.3	5.6 - 10.0	7.3
Oil & Grease	mg/L	33.0 - 2,240	196	2.4 - 25.0	15.6
Faecal Coliforms	/100 ml			700 - 95,000	17,200
Aluminium, Al	µg/L	1,960 - 19,100	6,820	75 - 989	350
Cadmium, Cd	µg/L	0.2 - 4.0	1.3	0.2 - 1.0	0.3
Chromium, Cr	µg/L	76 - 960	518	5 - 70	27
Copper, Cu	µg/L	24 - 730	347	9 - 58	28
Lead, Pb	µg/L	1 - 550	95	1 - 15	3
Mercury, Hg	µg/L	0.1 - 8.2	1.0	0.1 - 5.5	0.9
Nickel, Ni	µg/L	10 - 220	36	16 - 75	42
Zinc, Zn	µg/L	143 - 1,110	441	16 - 198	67
Magnesium, Mg	mg/L	91 - 280	165	27.9 - 41.1	34.1
Chloride	mg/L	N/A	N/A	373 - 493	432

(1) Hine (1989)
(2) Eco Management Services (1994)

Blesing (1975) also investigated the potential for reuse of treated sewage effluent in industry, and identified that there were a number of high volume industrial water users in close proximity to the Bolivar STW (e.g. Penrice, General Motors Holden). While industrial reuse of the effluent was considered feasible, there was little

economic incentive. In addition to mains water supply, the existing supply of bore water was by far the cheapest source of water at the time, and would continue to be used until long-term aquifer deterioration was proven.

7.9. Summary of Water Resource Availability

Of significance in this study is the availability of local water resources, their spatial and temporal variability, and the capacity to meet local demand. While the preceding discussion has provided an overview of the entire northern metropolitan water supply system and other local water resources, the information summarised concentrates on the water that is generated or is available locally, without diversions of water from other sources (e.g. River Murray).

The tables below present a summary of the temporal availability and consumption of the water resources of the Northern Adelaide Plains. A significant point is that the data presented for each particular resource or consumption category is generally the median value determined from the historical record. Particularly in the case of natural streamflow or runoff, the distribution of flow is typically right-skewed, and therefore the median value is more representative of likely conditions than the mean which is more strongly influenced by a few large or extreme events.

Table 7.24 lists the generation or availability of additional water by month. Only the natural inflow to each of the South Para and Little Para reservoir systems has been provided, acknowledging that the reservoir storage is indeed significantly greater at any particular time (7,700-16,000 ML for the Little Para Reservoir, and 25,600-38,000 ML for the South Para system). The aquifer systems are assumed to behave as large reservoirs where storage exceeds annual consumption; the monthly quota is therefore assumed to be an equal portion of the sustainable yield.

Table 7.24
Estimated Water Resource Availability by Month, ML

Month	Little Para Reservoir(1)	South Para Reservoir(1)	Gawler River	Little Para River(2)	Storm Runoff(3)	Sewage Effluent	Ground-water
January	153	22	0	60	1,129	3,953	500
February	86	25	0	30	817	4,080	500
March	87	57	0	25	1,031	4,154	500
April	80	150	0	30	2,025	3,840	500
May	122	239	0	37	3,211	3,999	500
June	477	494	35	45	4,472	3,900	500
July	1,633	2,321	375	52	6,111	4,185	500
August	2,327	4,567	3,089	62	7,024	4,309	500
September	1,382	2,547	7,162	72	6,395	4,170	500
October	432	566	5,502	75	5,606	4,495	500
November	229	216	1,066	70	2,746	4,440	500
December	185	107	83	60	1,801	4,185	500
Total	7,190	11,309	17,313	618	42,367	49,710	6,000

(1) Natural inflow as runoff from reservoir catchments only.
(2) Estimated; refer to following discussion.
(3) Based on an urban area of 10,524 ha and a rural area of 54,585 ha.

The available discharge in the Little Para River has been estimated as the difference between recorded discharges from the Little Para Reservoir for the purpose of groundwater recharge, and those measured at a downstream gauging station.

The volume of stormwater generated from the study area has been calculated on the basis of the volumetric runoff coefficients developed as part of this research (refer to Chapter 10), mean monthly rainfall, and data on the fractions of the region that are urban and rural in nature.

The water consumption data presented in Table 7.25 is derived from historical records as discussed in previous sections. Data was not available to indicate the magnitude of withdrawals from the Gawler or Little Para Rivers, or the use of harvested stormwater. While some withdrawal of surface water from the Gawler River is known to occur, with pumping to surface storages during periods of flood, the volume of water used as a proportion of the total flow is likely to be very low. Therefore, for the purposes of this study, it has been assumed that effectively no water is presently withdrawn from these sources.

Table 7.25
Estimated Water Consumption by Month, ML[1]

Month	Little Para Reservoir	South Para Reservoir	Gawler River	Little Para River	Storm Runoff	Sewage Effluent	Ground-water
January	1,968	1,924	-	-	-	337	2,336
February	1,755	1,598	-	-	-	328	2,271
March	1,356	1,687	-	-	-	290	2,012
April	796	1,212	-	-	-	187	1,298
May	16	1,184	-	-	-	112	779
June	0	982	-	-	-	66	454
July	0	993	-	-	-	56	389
August	0	1,012	-	-	-	75	519
September	0	1,019	-	-	-	169	1,168
October	438	1,308	-	-	-	253	1,752
November	1,361	1,678	-	-	-	309	2,141
December	1,735	1,691	-	-	-	337	2,336
Total	9,424	16,284	-	-	-	2,520	17,455

(1) Magnitude of consumption of stormwater or flow from rivers is unknown although considered to be insignificant in comparison to total availability. Stormwater consumption is likely to be less than 1% of total annual runoff.

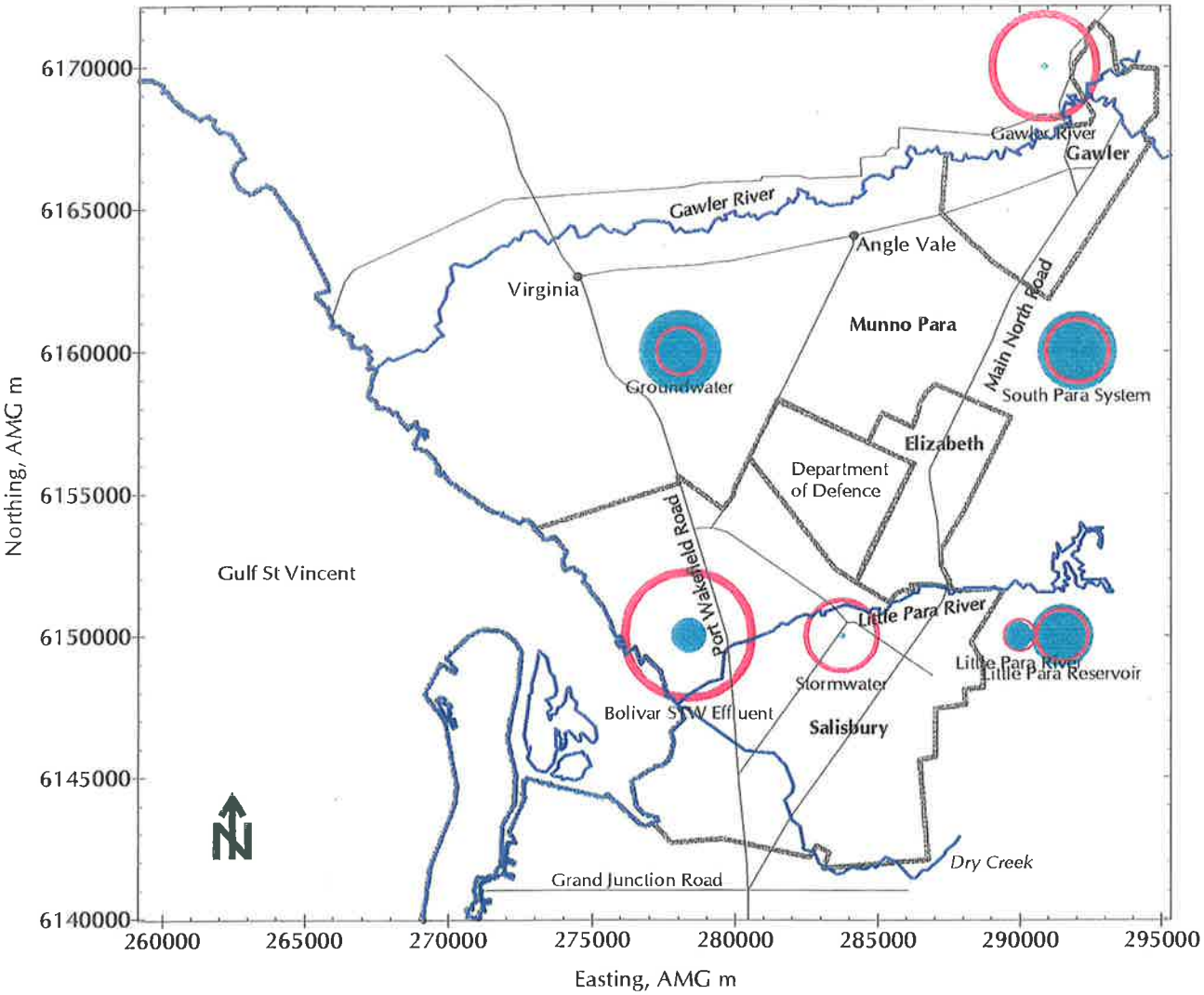
A more detailed summary of this data and its derivation (where applicable) is contained in Appendix E.

A comparison of the total available volume of water with total demand is made in Table 7.26, and is illustrated in Figure 7.30. Putting aside the not insignificant issues of location and water quality, at a purely temporal scale it is clear that in all but 3 months of the year the availability of water exceeds demand, outstripping demand by between 60% and 950%! On an annual basis, the quantity of available water is typically 2.3 times greater than demand.

Table 7.26
Comparison of Water Availability and Consumption Patterns

Month	Availability, ML	Consumption, ML	Excess Avail., ML
January	5,322	6,565	-1,243
February	5,221	5,952	-731
March	5,399	5,345	54
April	5,680	3,493	2,187
May	6,465	2,091	4,374
June	7,154	1,502	5,652
July	10,927	1,438	9,489
August	16,765	1,606	15,159
September	17,506	2,356	15,150
October	13,082	3,751	9,331
November	7,497	5,489	2,008
December	5,855	6,099	-244
Total	106,873	45,683	61,186

It is therefore clear that with appropriate storage and distribution facilities, and water treatment appropriate to the final application of the water, there is significant opportunity for development of the water resources for more sustainable use. It may also be possible to largely eliminate the dependency of northern Adelaide on the River Murray. These issues are explored further in following chapters.



LEGEND

- Median Annual Water Resource Consumption
- Median Annual Water Resource Availability
- Council Area Boundary
- Major Road Corridor
- Coastline or River

Figure 7.30

Availability and Consumption of Water Resources on the Northern Adelaide Plains

8

Water Conservation, Reclamation and Reuse

8.1. Urban Water Systems

The development of South Australia's infrastructure for water supply and wastewater treatment has traditionally focussed upon a 'once through' use of water. Water is supplied from large reservoirs or high yielding groundwater basins. Following filtration and chemical treatment, the high quality drinking (or potable) water is distributed through an extensive reticulation system to domestic, industrial, commercial and agricultural consumers.

Much of the water that is supplied is not effectively utilised and consumed in the production of another good (e.g. foodstuffs, or for irrigation of crops), but is used as a cleaning and transport medium – for the removal and transport of 'wastes'. These wastes are many and varied and include oils, food scraps or faeces from domestic and commercial sites, and heat, chemical and solid wastes from construction activities and heavy industry. These wastewaters are commonly discharged into the pipe network of the sewerage system, and some level of waste removal is conducted at a sewage or wastewater treatment plant prior to disposal of the treated effluent.

Reticulated drinking water is also frequently used in the outdoor environment for irrigation, in construction, and for washing of vehicles and paved or built surfaces. These activities can introduce a variety of pollutants into the water such as nutrients, bacteria, oil and grease, heavy metals and so on. Some of this contaminated water will also enter the sewerage system, although much of it will run into the storm drainage network which may be piped underground, or flow along open channels or a natural creek system. Stormwater generated through the runoff of rainfall in urban areas can also be highly contaminated, and some pollutants have been found in concentrations that are comparable to that of raw sewage (Dowsett, 1995).

Sewage effluent and stormwater are typically discharged to the sea or some major water body, and adverse effects upon the natural environment are well documented (refer to Chapters 5 and 7), even though sewage is often treated prior to disposal.

The 'once through' approach to the supply, use and disposal of an initially high quality water can therefore be seen to be operationally ineffective and harmful to the environment. Not only is the supply of potable quality water for all uses

financially expensive, it is also costly in terms of the damage caused to ecosystems upon which important industries (such as fisheries) depend.

The information presented in Table 8.1 demonstrates that a 'once through' use of potable water has been allowed to occur in circumstances of relative water scarcity. Adelaide's groundwater resources are reported to be over-exploited, and the surface water collected in the Mt Lofty Ranges is insufficient in all but the wetter years to meet the demand for potable water. Yet there are alternative sources that could meet a portion of the demand for water. The estimated volume of stormwater discharged annually to the Gulf St Vincent is almost equivalent to Adelaide's total water consumption. Alternatively, further treatment and redistribution of the sewage effluent could meet around 50% of Adelaide's potable water needs, although at some considerable additional expense.

Table 8.1
Water Availability and Use in Metropolitan Adelaide and Environs[1]

Water Resource	Available Resource (ML/yr)	Actual Consumption (ML/yr)	Excess Resource (ML/yr)
Reticulated Potable Water	150,000	185,500	-35,500[2]
Groundwater	28,000	32,000	-4,000
Treated Sewage Effluent	91,000	6,700	84,300
Stormwater	211,200	200	211,000
Total	480,200	224,400	255,800

(1) Sources: ECA (1991), EWS (1991), EWS (1993) and DENR (1995)
(2) Shortfall is typically met through pumping and treatment of water from the River Murray.

The comparison of the volume of available water with demand on an annual basis is somewhat superficial as it ignores the issues of storage of seasonal flows, wastewater treatment, long term environment and public health risks, economic viability, and political and public acceptability. Nevertheless, it is clear that to meet existing and future demands for water and to relieve the stress on the natural environment, some innovative and alternative water management measures will need to be introduced. Indeed, in many regions of the world, wastewater treatment and reuse has been occurring for many years. These existing technologies coupled with water conservation and demand management measures hold considerable promise.

8.2. Water Conservation and Demand Management

Water sources are becoming fully developed as populations expand, with a resultant increase in treatment and energy costs and negative impacts upon the environment. Interest is therefore intensifying in methods that reduce urban water demand, and conservation and demand modification measures are becoming important elements of water resource management strategies in many regions.

Water conservation involves the modification of demand and consumption patterns to make more efficient use of existing water supplies. Methods available to facilitate and encourage water conservation include:

- **Structural Methods**: can be implemented by the water utility and the individual home owner. Water utilities can introduce flow control (pressure reducing) devices and wastewater recycling systems. The consumer can install water-saving devices, flow controllers and household grey water recycling systems. Outside water use can also be reduced by adopting alternative gardening practices – both physical (native vegetation, irrigation, etc) or operational (frequency of irrigation).

- **Operational Methods**: generally fall within the control of the utility. Leakage detection, repair of pipe systems and facilities, and water use restrictions are the primary methods. In some utilities, pressure reduction has been shown to reduce usage and also leakage.

- **Economic Methods**: Economic means of demand reduction can be accomplished solely through utility actions. These include various pricing policies, incentives and penalties and consumption metering.

- **Socio-Political Methods**: include building code modifications to legally mandate the use of low water consuming plumbing fixtures or maximum lawn areas, as well as public education which is essential to develop a conservation ethic (Flack, 1982).

There are many benefits to be had from reducing the demand for water. Water utilities benefit through reduced pumping costs, deferment of system expansion, increased life of present supplies and facilities, and reduced hydraulic loading on sewers and sewage treatment facilities. Both water and wastewater treatment facilities experience additional benefits in reduced energy and chemical costs and reduced disposal costs due to lower residual sludge volumes. In addition, the attenuation of peak demands allows lower system investment costs resulting from scaled-down designs for water treatment facilities, pumping plants, and storage and piping in the distribution system. Significantly, money saved by the water authority and government can be channelled into development and expansion of other community facilities and services. The home owner also benefits through reduced energy costs for water heating.

An extensive investigation of the benefits of water conservation measures has been undertaken in Western Australia, who now lead Australia in terms of a system-wide approach to water efficiency with the implementation of many initiatives in Perth and the Kalgoorlie-Boulder region (English & Schlafrig, 1996; Botica & White, 1996).

8.2.1. Residential Water Conservation

Water conservation measures have received limited attention from Australian water authorities in the past when compared to that in Israel and also the south-western states of the USA, and California in particular. Many of the water companies in the US have distributed water saving retrofit kits which include a low volume shower

head, toilet displacement device, tap aerators, leak detection dye tablets, and instruction manuals, all at no cost to every residential customer (Vickers, 1991).

Australian water authorities have run extensive advertising campaigns encouraging water conservation since the late 1970s, however the authorities have not matched the efforts of some North American authorities where economic incentives have been provided for conservation, or domestic fittings changed at no cost. The relative lack of action on the part of water authorities belies the potential for significant benefits to be accrued through residential water conservation in Australia. There is considerable scope for improving the efficiency of water use in a traditional household. A reduction in the volume of water consumed in each household might not provide large cost savings to the occupants at the present time, however it is likely that the price of water will rise in future with increased financial benefit. The benefits to the community as a whole can be far greater.

Given that residential water consumption is the most significant component of water use on the NAP, any reduction in domestic water use can provide numerous benefits to the community, such as:

- a reduced load upon the existing infrastructure resulting in less wear;
- decrease in the volume of water pumped the River Murray;
- less energy and chemical use at water purification plants;
- reduced flow of sewage to wastewater treatment plants;
- reduced maintenance and operating costs;
- postponement or elimination of the need for further infrastructure development,
- reduced impact on degraded environments (e.g. seagrass and marine environment of the Gulf); and
- preservation of natural environments that might otherwise be destroyed (e.g. through the construction of new reservoirs and pipelines).

It is estimated that for every dollar spent supplying treated water to a house, it costs 3 dollars for its removal and treatment (Archer, 1991).

Household water use can be reduced in many ways including having shorter showers, repairing leaking tap washers, but also by using water efficient appliances such as aerators on taps, low flow shower heads, low volume flush toilets, water efficient washing machines, and similar appliances. Simple changes in everyday habits can also make real differences.

A breakdown of typical domestic consumption in metropolitan Adelaide is provided in Table 8.2, with the estimated water savings that could be achieved by using existing devices or water conserving practices.

Toilet flushing accounts for about a quarter of all internal domestic water usage, so it offers great potential for saving water, money and resources. A major advance has been the dual flush cistern, with its low volume flush for the times when the toilet is used only as a urinal. Used properly, these toilets can save around 40 to 50 percent on water normally used for the toilet, although a more conservative estimate has been used as part of this research.

Composting toilets are the most efficient and environmentally appropriate option as they use no water at all. These break down human and kitchen wastes into pathogen-free compost, which can safely be used to enrich garden soils. There are a number of composting toilets now used in Australia, the cost of installation being similar to that of a septic system (Archer, 1991; French & Sullivan, 1994).

Table 8.2
Breakdown of Domestic Water Consumption[1]

Breakdown of Domestic Water Use	Water Demand, l/p/day			Description of Changes or Appliances Used
	Existing Use	Efficient Use	Reduction %	
Clothes washing	32	18	44	Typical 'Top 10' washer[2]
Toilet flushing	35	27	23	Standard dual flush toilet[3]
Kitchen for				
- Dish washing	18	18	0	Hand washing
- Drinking & cooking	7	6	14	
Bath	7	7	0	No change
Shower	35	30	14	Low flow shower rose
Hand basin	7	4	43	Aerating tap
Total Indoor Consump.	141	110	22	
Outdoor				
Car washing	3	2	33	Bucket & sponge over lawn
Pools & contact rec.	3	3	0	Volume used unchanged
Lawn/plant irrigation	125	50	60	Smaller individ. garden area
Vegetable irrigation	5	5	0	Volume used unchanged
Total Outdoor Cons.[4]	136	60	56	
Losses due to leakage	28	14	50	Leak detection and elimination
Total Consumption	305	184	40	

(1) Data sources included AmWWA (1983); EWS (1987); Archer (1991); EWS (1991); KDJV (1991); EWS (1992); Saldinger (1992); Thomas et al (1994); Choice Magazine of Feb '89, April & Dec '95; van der Wel & McIntosh (1996).
(2) Assumes 75 litres/cycle with a total of 5 full-water cycles/week for a household of 3 persons
(3) Assumes toilet is used 5 times daily per person, 4 times as urinal with reduced volume flush.
(4) Total outdoor consumption derived from historical consumption, consumer and dwelling occupancy data.

8.2.2. Conservation Measures for Open Space, Parks and Gardens

Conserving water by changing horticultural and irrigation practices can significantly reduce municipal water use for individual homes and for city parks and recreation areas. Such changes can be accomplished in at least 3 different areas: plant choices, landscape design, and watering methods.

The general environment that is created in a residential garden can help to minimise demands. Buildings, fences, walls and big trees can be used to screen wind and sun from planting areas, thereby limiting evapotranspiration. Intense irrigation should be limited, but when used the benefits should be targeted toward the most visible and intensively used parts of the site (Ferguson, 1987). Types of plants and soil covers must also be chosen to fit the allocated moisture levels. Many native trees, shrubs and ground covers have adapted to low unreliable rainfall and require very different watering and minimal maintenance. When incorporated into a residential

garden, savings in water use be about 50 percent (EWS, 1987) when compared to more thirsty exotic plants.

Improved irrigation practices and technologies developed over recent years (such as moisture sensors and micro/drip irrigation) can usually reduce outdoor consumption by at least 30 and up to 60 percent (*Choice*, Dec. 1987; EWS, 1987; Farwell, 1993; Chandler, 1996; Kourik, 1993 in Jeppesen & Solley, 1994). A study conducted in 1985 documented average water savings of 54% for sample households that used efficient landscape designs and maintenance practices (Ferguson, 1987).

The combination of reduced lawn areas, careful garden design and plant selection (including the selective use of native plants), and improved irrigation efficiency can thus readily provide a reduction in water use of around 60 percent.

8.2.3. Commercial and Industrial Water Conservation

Commercial and industrial water consumers constitute the majority of the largest individual users of water in urban areas, although the total consumption within these sectors is often less than that of the residential sector. These consumers often do not require a high quality water for their applications, and therefore considerable potential exists in these sectors for water conservation or substitution with sub-potable sources. However, difficulties arise in identifying opportunities for the conservation of water, particularly in industry, due to the diversity of processes and the imperative of profitability (Manzione *et al*, 1991).

Industrial water systems are typically key components of any larger industrial process. Managers are therefore sometimes reluctant to take the risk of modifying equipment or operations to conserve water. There are several good reasons to implement water conservation measures in industry:

- conservation can improve operational efficiency and reduce costs;
- cheaper manufacturing or processing costs translate into a stronger position in the market place;
- business stability is improved through a reduced susceptibility to water rationing during drought periods; and
- goodwill can be gained through positive contributions to the community.

Water use by industrial or commercial consumers has three fundamental purposes: heat transfer, materials transfer (e.g. ore processing or rinsing), and as an ingredient in manufacture of a product such as food-stuffs (after Ploeser *et al*, 1992).

Water for cooling represents one of the largest water uses. Water is used to cool heat-generating equipment or to condense gases in a thermodynamic cycle. The most water intensive cooling method used in industrial applications is once-through cooling, in which water contacts and lowers the temperature of a heat source and then is discharged (USEPA, 1996). In contrast, cooling towers conserve water by reusing or recycling water, reducing the usage of cooling water and wastewater discharge by as much as 97 percent (MNTAP, 1996).

Recycled or reclaimed water can be used as cooling tower make-up water. Experience shows that tertiary treated municipal effluent is adequate for cooling tower make-up water if bleed-off occurs frequently (Ploeser *et al*, 1992). The water is uncontaminated and can be reused for landscape irrigation, site cleanup and other purposes (Vickers, 1991).

Another common use of water by industry is the application of deionised water for removal of contaminants from products or equipment. Historically, industries have used excessive quantities of deionised water rinsing, which can be reduced by converting the rinse baths from continuous to intermittent flow systems. This water can be reused for a different application, because it is often more pure after its initial use than municipal water (USEPA, 1996).

Car washes, car dealerships, trucking companies and other facilities with large fleets may use significant volumes of water for vehicle washing that can be reused. Additional conservation opportunities exist at other operations where large volumes of water are consumed, including commercial laundries, kitchens, cafeterias, fume scrubbers, construction sites, landscape watering, and materials transport (Ploeser *et al*, 1992).

Techniques for industrial water conservation can thus be broadly grouped into:

- water-use monitoring for process improvement,
- reuse of cooling tower water,
- other water recycling and reuse,
- equipment and process modification,
- employee education, and
- improved landscape irrigation.

Climate is typically only a variable that affects water consumption at commercial or industrial facilities if large amounts of water are used for cooling or landscape watering.

Studies by Vickers (1991), Manzione *et al* (1991) and Ploeser *et al* (1992) have found that cost effective industrial water conservation measures typically save between 25 and 40 percent, but can be as high as 90 percent of the original water use. Most savings in the commercial sector arise through the use of toilet and faucet devices, recycling of water, and reduction in landscape irrigation, with savings in the range of 5 to 10 percent (Maddaus & Feuerstein, 1979).

Table 8.3 presents the estimated fractions of water consumed within the industrial, commercial, and public institution and utilities sectors on the Northern Adelaide Plains according to water application. Historical water use data supplied by SA Water enabled the determination of water use according to a range of consumer types within each of these sectors. This information was combined with data indicating the fractions of water consumed for different applications by a range of major business and industry groups, public institutions and utilities, sourced from publications such as those of MMBW (1980), Environment Canada (1986, 1996), Ploeser *et al* (1992), AWWA (1993), USEPA (1996) and MNTAP (1996).

It is clear from this data that domestic uses, cooling and heating, process water and landscape irrigation are likely to comprise the largest components and over 70 percent of all commercial and industrial water use on the NAP. For most of these applications, considerable potential exists for water conservation either through use reduction measures or the reuse or recycling of water.

Table 8.3
NAP Water Usage and Potential Savings via Conservation

Water Application	Use as a Fraction of Total Consumption, %			Conservation Potential as a Fraction of Use, %
	Industrial	Commercial	Public Utilities	
Domestic uses	9.9	39.1	39.9	28
Landscape	1.9	20.8	21.6	40
Cooling and heating	23.4	30.2	16.9	12
Process water	36.4	4.1	5.3	15
Cleaning & sanitation	20.8	0.4	3.8	12
Laundries & kitchens	0.4	1.5	9.2	32
Misc. uses and leaks	7.2	3.9	3.3	47

8.2.4. Consumption Metering and Water Pricing

Studies of water consumption and conservation measures have generally found that metering is an effective measure to encourage water conservation. Metering provides a strong incentive for customers to use less water more than if they are billed on a flat rate. Data gathered in the USA between 1980 and 1982 showed that metered households use about 20 percent less water annually than unmetered households, and a consumer survey has indicated that consumers generally consider metering to be a fair and equitable system of charging for use (Flack & Greenburg, 1987; Maddaus, 1987). Sub-metering should also be adopted where multiple dwellings are situated on a common site to encourage water conservation, control unaccounted-for water (because small meters are more sensitive) and for leak detection (Rathnau, 1991).

The characteristic of the relationship between market demand for water and price is 'price elasticity'. Price elasticity is defined as the percentage change in the quantity of a product or service demanded divided by the percentage change in price, or:

$$\text{Price Elasticity of Demand, } \varepsilon = \frac{\Delta Q}{Q} \cdot \frac{P}{\Delta P} = \frac{\%\text{ change in demand}}{\%\text{ change in price}} \qquad (8.1)$$

where Q is the quantity demanded and P is the price. For a downward sloping demand curve such as that in Figure 8.1, price elasticity of demand is negative. If the value of ε is between -1 and 0 the percentage fall in use is less than the percentage increase in price, demand is inelastic and revenue will increase if the price increases. Alternatively, if ε is less than -1 (e.g. -1.5) the percentage fall in use is greater than the percentage increase in price. In this case, demand is elastic and revenue will fall if the price increases (Metropolitan Water Authority, 1985).

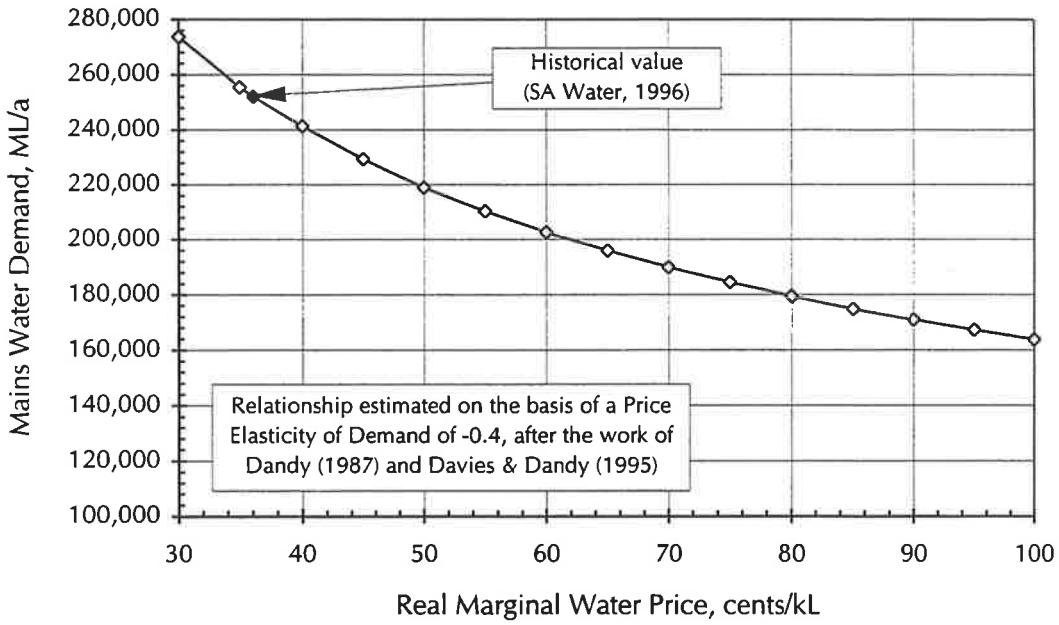


Figure 8.1
Theoretical Variation of South Australian Mains Water Consumption with Price

Many studies have examined the effect of price on residential water consumption, which have been summarised by Davies (1992). A selection of these elasticity values for different locations around the world have been provided in Table 8.4; the findings of Dandy (1987) for metropolitan Adelaide are also included.

Table 8.4
Summary of Price Elasticity of Demand Estimates

Location	Elasticity Value	Component	Price[1]	Notes	Source
USA Eastern USA Western USA	-0.23 -1.57 -0.73	Inhouse Sprinkling	MP	–	Howe & Linaweaver, 1967
Kuwait	-0.771 to -0.976	Residential	–	–	Al-Qunaibet & Johnston, 1985
Oahu, Honolulu	-0.032 to -0.517 -0.100 to -0.683	Residential	MP	Short-run Long-run	Moncur, 1987
Manila, Philippines	-0.287	Annual residential	MP + D	Includes block rate structure	Palencia, 1988
Perth, Western Australia	-0.11 -0.18 -0.05 -0.31	Annual residential Household use Domestic indoor Domestic outdoor			Metropolitan Water Authority, 1985
Adelaide, South Australia	-0.10 -0.35 to -0.47	Residential: excess water consumers	MP	Short-run Long-run	Dandy, 1987

(1) Price variables: MP = marginal price, D = bill difference

The price elasticities of demand are typically found to lie between -1 and 0 for residential use. Given that residential use typically comprises a large share of total water consumption in urban areas, particularly in Australia, water authorities could increase the price of water for cost recovery or demand management purposes without loss of revenue.

Studies also show that price increases will reduce outdoor water use more than indoor water use. For this reason, some cities have focussed on seasonal pricing structures because the relationship between cost and use is most sensitive during peak periods of summer when outdoor use increases (Grisham & Fleming, 1989).

Broad (1992) found that with the introduction of a 'user pays', two part water pricing system to the Hunter Valley region in New South Wales, water consumption was reduced by 30 percent when compared with the trend that previously existed. All properties attracted a fixed service charged based upon the service capacity provided, plus a variable charge for all water consumed and sewage generated. Average residential consumption was significantly reduced, with the higher level consumers reducing their consumption the most under restrictions and the 'user pays' scheme. Peaks in water demand during summer were only half as large as those previously recorded.

8.2.5. Recycling

The re-use of water can also reduce the demand for potable water. Wastewater can be used directly in irrigation, industry and for some non-potable residential applications. A survey conducted in the United States during the 1970s indicated that 358 municipalities, located primarily in the south-west, re-used wastewater for such purposes (Schmidt, 1975).

While wastewater re-use is common in some parts of the United States and in arid countries such as Israel, the possible long term effects of ingestion of low levels of viruses, organics and heavy metals that may be present have not been determined. A clear distinction between potable and non-potable residential use has therefore been advocated due to these health uncertainties.

Further information on water recycling, particularly wastewater reclamation and reuse, is provided in Section 8.3.

8.2.6. Leak Detection and Repair

Unaccounted-for water can result from meter inaccuracies, underground leaks, illegal connections, reservoir evaporation and seepage, inaccurate accounting methods, and unmetered uses such as fire fighting, and flushing of water and sewer pipes.

Water leaks, which occur in almost all water distribution systems are responsible for a large percentage of water losses. The extent of leakage depends on the condition

of the pipes, the quality and pressure of the water, the type of soil, and the degree to which the water system is maintained. In metropolitan Adelaide, leaks are estimated to account for approximately 8 percent of all residential water use which comprises around 70 percent of total mains water consumption (EWS, 1991).

8.2.7. Conclusions

Water conservation can be achieved through a variety of methods that normally involve structural and operational changes to the water system, or to water supply policy and pricing. Many of the measures for water conservation are targeted at domestic water users because the residential sector typically consumes more than other urban water user groups (such as industrial and commercial).

There are numerous devices for saving water within the home which are technologically well developed and can be cost effective. However, the amount of saving to the home owner can be low in relation to other household costs and widespread use may therefore not occur. Increasing water service prices will make these devices more attractive.

The biggest savings in residential water use can be made in the garden. Many landscaping and watering systems have been developed that are capable of using water more efficiently than current practices. Horticultural changes are also found to be an effective means of further reducing lawn sprinkling demands. The amount of water saving that can be achieved depends on the degree to which the public will accept horticultural changes.

Metering is effective in reducing, domestic usage and peak demands. Pricing methods appear to be the key for customer adoption of many conservation methods. Greater emphasis on this method as a demand modification tool appears possible.

Many of the suggestions for residential water conservation are applicable to commercial and industrial users. Difficulties arise in identifying opportunities for the conservation of water in industry, however, due to the diversity of processes and the imperative of profitability. The greatest water savings in industry may be achieved through the substitution of potable water with sub-potable sources.

Unfortunately, while many water conservation alternatives have been demonstrated to be technologically feasible, public acceptance in Australia will continue to be slow because of the long pay-back period and small economic return. Higher prices for water are likely to provide sufficient incentive to alter this situation.

8.3. Wastewater Reclamation and Reuse

Urbanisation is increasing rapidly with an increasing proportion of the world's population is living in cities. Along with population, the per capita water consumption is projected to increase, particularly in the developing nations in Asia, Africa and Latin America. An inevitable consequence of this urban growth and demand is the inadequacy of water resources for public supply, which is

exacerbated in times of drought. Additional sources are often not available to expand water supply or can only be developed at high cost. In many cases, there will also be competition for the water between the cities and agricultural applications.

With increasing water consumption comes a proportional increase in the generation of wastewater. Following conventional western development practices, this wastewater would be treated at a sewage treatment plant and disposed to land, a river or the sea. Environmental degradation often results. As succinctly stated by Shelef (1991), "The conclusion that the solution to pollution is dilution is ... an illusion". In recognition of this fact, environmental protection agencies around the world are progressively imposing tighter controls upon effluent discharges.

In highly industrialised countries, the problems is therefore one of providing adequate supply and wastewater disposal, while in developing countries it is that of developing low cost, appropriate technology methods of acquiring new supplies while protecting existing sources from pollution (after Asano, 1991). But as Niemczynowicz (1992) so appropriately declared, water scarcity *per se* should not create large problems, because water is (practically) indestructible and can be (theoretically) used an infinite number of times. Thus, the issue of water scarcity should be looked upon in the perspective of possibilities to improve the efficiency of use and to *treat and reuse water.*

Water reuse is a term generally used in relation to the treatment of wastewater generated by one activity to be used as the water supply for another (Swayne *et al*, 1979). The reuse of wastewater, and provision of water at a quality 'fit for purpose' is not a new concept though. In the late 1950s, the United Nations Economic and Social Council stated that "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade" (UN, 1958). While not a new concept, it is perhaps more relevant today than ever before.

Water reuse can take three forms: (i) internal recycling primarily by industries; (ii) indirect reuse by discharge of treated effluents into water courses or infiltration into aquifers; and (iii) direct reuse of treated effluents for either potable, industrial or agricultural application (Odendaal, 1991). Ideally, water reuse should be coupled with water conservation programs to reduce the volume of wastewaters and effluent generated.

The major pathways of water reuse include irrigation, industrial use, surface water replenishment and artificial groundwater recharge.

8.3.1. Water Quality Requirements

The degree of treatment required prior to wastewater reuse varies according to the specific reuse application and associated water quality requirements.

The contaminants in wastewater that are of potential health significance include biological pathogens such as helminths, protozoa and enteric viruses. Persistent anthropogenic chemical agents are also of concern, and with many chemicals there

is an insufficient pool of knowledge upon which to base any conclusions as to potential health effects. For these reasons, reuse of wastewater has traditionally been restricted to non-contact or at least non-potable applications.

Nevertheless, for almost all applications it is essential to produce virtually virus-free effluent due to the potential for human exposure or contact in many reuse applications, such as spray irrigation for food crops (eaten uncooked), spray irrigation for parks and playgrounds, and unrestricted recreational impoundments where swimming may take place.

The non-potable water delivered to residential premises must meet stringent standards for human health and safety, as well as a quality generally suited to lawn and garden irrigation (Haney & Beatty, 1977).

There are no national standards for the reuse of water in the United States. However Arizona, California, Florida, Texas, Oregon, Colorado, Nevada and Hawaii all have extensive regulations or guidelines the prescribe requirements for a wide range of end uses of reclaimed water (Rowe & Abdel-Magid, 1995).

The State of California pioneered efforts to promote water reclamation and reuse and the first reuse regulations were promulgated in 1918 (Asano & Levine, 1996). These have become the oldest and most tested standards, with a focus upon specification of the treatment process rather than performance standards for the treated water.

Shuval (1991) felt that Californian wastewater irrigation standards were flawed by being illogical, inconsistent and unreasonably strict. Few, if any of the natural rivers in the United States or Europe could ever meet the coliform count requirement (< 23/100 ml), yet in 1973, the USEPA recommended that river water be considered safe for unrestricted agricultural irrigation if its mean coliform count did not exceed 1000/100 ml! Furthermore, most US states allow bathing in water with coliform counts of 1000/100 ml.

The WHO considered California's guidelines were too strict, however, and recommended that instead of complex tertiary treatment, wastewater be given primary and secondary treatment and at times disinfected prior to irrigation of crops eaten raw (Gregory *et al*, 1996).

The most important quality objective is that the water be adequately disinfected, so a chlorine residual should always be present. Conventional wastewater treatment plants, with the exception of disinfection, are not effective for the removal of pathogens from sewage, rarely achieving 90-95% pathogen reduction.

Table 8.5 provides the standards for irrigation with reclaimed effluent based upon extensive experience in the application of wastewater in Israel and the USA.

The reuse of effluent for irrigation has been practised for many years in St Petersburg, Florida. Conclusions drawn from a study of the public health and water quality facets of the operation of the St Petersburg reclaimed water distribution facility were (Johnson, 1991):

Table 8.5
Quality Criteria of Treated Wastewater Effluent to be Reused for Agricultural Irrigation (after Shelef, 1991)

Group of crops	A	B	C	D
Principal crops	Cotton, sugar beet, cereals, dry fodder, seeds, forest irrigation	Green fodder, olives, peanuts, citrus, bananas, almonds, nuts, etc.	Deciduous fruits(1), conserved veg., cooked and peeled vegetables, green belts, football fields and golf courses	Unrestricted crops, including vegetables eaten raw, parks and lawns
Effluent quality	*Requirements should be met in at least 80% of the samples taken.*			
Total BOD_5, mg/l	60*	45(2)	35	15
Dissolved BOD_5, mg/l	-	-	20	10
Suspended solids, mg/l	50*	40(2)	30	15
Dissolved oxygen, mg/l	0.5	0.5	0.5	0.5
Coliform count/100 ml	-	-	250	12
Residual chlorine, mg/l	-	-	0.15	0.5
Mandatory treatment				
Sand filt. or equivalent	-	-	-	Required
Chlorine contact, min.	-	-	60	120
Distances, metres				
From residential areas	300	250	-	-
From paved road	30	25	-	-

(1) Irrigation must stop two weeks before fruit picking; no fruit should be picked from the ground.
(2) Different standards will be set for stabilisation ponds with retention time of at least 15 days.

- There is no evidence of increased enteric diseases in urban areas irrigated with treated reclaimed wastewater using coagulation, filtration and disinfection.
- There is no evidence of significant risks of transmission of viral or microbial diseases as a result of exposure to effluent aerosols from spray irrigation with reclaimed water.
- The recommended turbidity standard is a average of 2.0 NTU during any 24-hour period. Continuous on-line turbidity monitoring should be provided.
- The recommended standard for faecal coliform is an average of 2.2/100 ml with an upper limit of 23/100 ml in not more than 10 per cent of the samples, while maintaining a 4.0 mg/l chlorine residual.

It was also found that product quality must be continuously monitored. This is not only necessary from a technical and operational perspective, but also to instil customer confidence in the product water, which is necessary if the scheme is to be successful (Johnson, 1991).

8.3.2. Wastewater Treatment

The treatment of municipal sewage to produce an effluent for reuse is most frequently achieved using conventional primary and secondary level wastewater treatment technologies, followed by filtration and disinfection. These technologies

are well established and are not discussed further here. The reader is referred to Metcalf & Eddy (1979) or similar references for further information. The treatment processes typically recommended to meet the water quality requirements of various reuse applications are summarised in Tables 8.6 and 8.7.

An emerging trend in the treatment of wastewaters for reuse is the decentralisation of treatment facilities. Decentralised wastewater management may be defined as the collection, treatment, and disposal or reuse of wastewater from individual homes, clusters of homes, or communities, industries or institutional facilities. Tchobanoglous & Angelakis (1996) suggest that greater emphasis upon decentralised wastewater management provides more opportunities for localised reclamation and reuse, but the desire for local reuse may also be a reason for establishment of local treatment facilities.

A number of technologies exist for treatment of sewage for unsewered areas or localised reuse, including septic tanks, sand filters, trickling filters, or pre-engineered and constructed 'package plants' for small communities. Disinfection, where required, is by means of chemical addition (e.g. chlorine and related compounds) or ultraviolet (UV) radiation (Tchobanoglous & Angelakis, 1996).

A number of constructed wetlands are used in New Zealand for the treatment of domestic wastewater from small communities for secondary treatment and pathogen removal. These systems were found to be effective, low cost alternatives to conventional treatment processes (Jantrania, 1993). Wastewater treatment ponds and wetlands are also attracting attention in the research fields in Australia for their potential for cost effective and high quality treatment of municipal and industrial effluents from small communities up to 20,000 EP (Keller, 1996; Bavor, 1996).

Stabilisation lagoons have long been recognised as valuable treatment processes, particularly in developing countries, with the attraction of low cost and simple operational needs, while providing superior effluent quality with regard to algae, nutrient and pathogen removal (Banks, 1991; Bartone, 1991, Mara *et al*, 1992).

In Australia, more advanced forms of treatment are required though to meet the stringent human health and environmental quality requirements. Decentralised treatment remains attractive for practitioners who perceive local treatment plants as the vehicle for savings on investment in pipes and infrastructure for storage and disposal into treatment facilities, making wastewater reuse more economically viable. Butler & MacCormick (1996) demonstrate that this can be achieved using advanced membrane technologies such as microfiltration and reverse osmosis. Indeed, membrane microfiltration is gaining increasing acceptance, particularly for smaller scale applications, such as the tertiary treatment of municipal effluent at Blackheath (in the Blue Mountains) and at Coffs Harbour in New South Wales (Day *et al*, 1991; Armstrong & Butler, 1996; Day, 1996).

Table 8.6
Consumptive Use of Reclaimed Wastewaters and Water Quality Requirements (Shelef, 1991)

Consumptive Use	Removal of pathogens	Chlorine residual or other disinfection	Removal of suspended solids and turbidity	Presence of dissolved oxygen	Removal of BOD and COD	Removal of nutrients	Removal of taste, odour and colour	Removal of trace organics & metals	Removal of excess salinity
Landscape and forest irrigation	x	-	x	x	x	-	x	x	-
Irrigation of restricted crops (Groups A & B)	x	-	x	x	x	-	x	x	-
Irrigation of limited crops (Group C)	xx	xx	xx	xx	xx	-	x	xx	x
Irrigation of all crops & produce (Group D)	xxx	xxx	xxx	xx	xxx	-	xx	xxx	x
Groundwater recharge	xxx	xx	xxx	xx	xxx	xxx	xxx	xxxx	
Industrial reuse	xx	xx	xxx	xxx	xxx	xxx	xxx	xx	xx
Dual urban systems - toilet flushing and gardening	xxxx	xxxx	xxxx	xxxx	xxxx	xxx	xxxx	xxxx	xx
Potable reuse	xxxxx	xxxxx	xxxxx	xxxx	xxxxx	xxxx	xxxxx	xxxxx	xxx

A blank indicates no need for treatment; (x) slight need; (xx) moderate need; (xxx) strong need; (xxxx) stringent requirements; (xxxxx) very stringent requirements.

Table 8.7
Treatment Unit Train[1] of Various Wastewater Reuses (Shelef, 1991)

Consumption	**Irrigation** (refer to Table 8.6)				**Dual Systems**		**Potable Reuse**	
Treatment	Group A	Group B	Group C	Group D	Alt. 1	Alt. 2	Alt. 1	Alt. 2
Anaerobic ponds	x	x						
Facultative ponds	x	xx						
Primary treatment			x	xx	xx		xx	xx
Biological secondary treatment			xx	xxx	xxx		xxxx	xxxx
Stabilisation reservoirs	xxx	xxx	xxx	xxxx				
Nitrification-denitrification					xx		xxx	
Lime treatment						xxx		xxx
Ammonia removal						xx		xxx
Recarbonation						xx		xx
Flocculation					xx	xx	xxx	xxx
Filtration				xx	xxx	xxx	xxxx	xxxx
Chlorination			xx	xxx	xxxx	xxxx	xxxxx	xxxxx
Activated carbon					xx	x	xxxx	xxxx
Ozonation					xx	xx	xxx	xxx
Reverse osmosis							xxx	xxx
Air stripping					x	x	xx	xx

(1) The exact order of the units in the train can be altered, some units can be omitted, while some processes can be applied more than one time. x, xx, xxx, etc. denotes the importance or intensity of a given treatment process.

Many of the treatment systems used for individual homes, household clusters and small systems perform at a level equal or better than comparable large scale centralised systems (Fastenau *et al*, 1990; Tchobanoglous & Angelakis, 1996). However, the treatment of grey-water to make it safe for human contact is expensive to achieve on an individual household basis both in Australia (Jeppesen, 1996) and other industrialised countries. It is also difficult to ensure that treatment systems are maintained. Surveys in Australia (Khalifé & Dharmappa, 1996) and the US (Campbell *et al*, 1995) have found that 60-80% of 'on-site domestic wastewater treatment plants' are not maintained adequately. Decentralised treatment facilities at a community scale are more likely to be acceptable in Australia for some years due to the concern of water authorities over the maintenance and health issues associated with localised treatment facilities, and their resistance to change. The provision of many, small scale and localised treatment facilities is not likely to be economically viable, and that the optimal treatment plant capacity is somewhat larger than a household or small community, as demonstrated in Chapter 10.

8.3.3. Dual Water Supply Systems

Only a small portion of the total community water supply is required for drinking, cooking and other uses that demand high purity. The other applications of water could be met with some other sub-potable source of water. Dual water systems aim to meet these needs.

In a dual or multiple water supply system, two or more qualities of water, one potable and the other non-potable, would be supplied through separate distribution systems. The quality, quantity and pressure available in each system are functions of the intended uses for each grade of water (Haney & Beatty, 1977; Deb, 1980).

Separate non-potable supplies are used for golf courses, public parks and industry, but the largest use is for irrigation (McDonald, 1980; Okun, 1983).

A limited number of dual supplies have been operated successfully over many years. Dual systems continue to be implemented and there is evidence that in the highly developed countries the impetus towards such supplies is increasing.

The first dual system in the United States was installed in Grand Canyon Village in 1926, with reclaimed water still used today for most non-potable purposes including landscape irrigation and toilet flushing. Construction of dual systems in conventional municipalities commenced in the 1970s. Two good examples of this practice are the Irvine Ranch Water District in semi-arid southern California, and the city of St Petersburg in humid Florida (USEPA, 1992).

The major objections to dual water system proposals related to cross-connections and cost. In the past, cross connections have permitted inter-mingling of two supplies to the detriment of consumers (McDonald, 1980). The fear exists that regardless of laws, rules, regulations and constant surveillance, the two systems will be cross-connected resulting in water consumers receiving contaminated water through pipes intended only for water of drinking quality. However, cross connection problems can be adequately resolved by establishing proper plumbing codes and ensuring adequate supervision of construction (Okun, 1973). The implementation of such codes has resolved many of the problems as demonstrated by years of successful operation in United States.

Historical studies of the cost of these distribution systems have indicated that when installed in new or redevelopments they would only be about 20 percent higher than conventional systems. Furthermore, where construction consists of high-rise family dwellings, the cost increment would be considerably less.

The fact that dual supply systems have been constructed overseas, and have begun to be built in Australia is the best demonstration of the increasingly cost-effective nature of dual distribution systems. In most cases, lower cost water sources have already been developed and the cost of treatment of polluted sources is increasing. In Hong Kong, sea water and treated waste water is used widely as a secondary source of water, mainly in the flushing of toilets.

8.3.4. Wastewater Reuse in Industry

The reuse of wastewater within industry offers another opportunity to substantially reduce potable water demand. Reuse of sewage effluent by industry has been demonstrated to be economically viable and implemented in many countries including Israel, USA, South Africa, Japan, UK, Saudi Arabia, Singapore (Taylor & Denner, 1984; Ng & Chia, 1991) and Australia (Hartley *et al*, 1991; Wijesinghe *et al*, 1996).

One of the most promising alternative sources of water for industry is municipal sewage effluent. In terms of quantity it can be the most stable and dependable source of supply. Where better quality water is required, some additional pre-treatment is provided by the industrial consumers to meet their own needs. The main use of the reclaimed water is for cooling and other low-grade applications. Reuse in industrial sectors such as food, drink and pharmaceuticals is usually avoided for reasons of hygiene (Taylor & Denner, 1984).

The major users of cooling water are thermal power stations and the heavy industry sectors such as iron, steel and other basic metals production. In the USA, sewage effluent has been used for cooling water at many power stations (Taylor & Denner, 1984). More recently in Australia, up to 4 ML/day of reclaimed effluent has been successfully reused following on-site tertiary treatment at the Eraring Power Station in New South Wales (Craig, 1996).

Wastewater has also been reused in aquaculture for many years. The use of wastewater for fertilisation of fish ponds was developed in Germany in the late 1800s and independently in Calcutta in 1930, which by the mid 1980s had the largest wastewater-fed aquaculture system in the world (Edwards, 1985). By the early 1990s, aquaculture employing reclaimed municipal sewage was established in numerous countries including India, Germany and Hungary, although the extent to which enteric viruses were transferred to the fish and then human consumers is unknown. A study conducted in South Africa has found that fillets from fish grown in stabilisation ponds were completely safe for human consumption, provided that simple precautions were taken in food handling and processing and that ponds are restricted to domestic wastes (Odendaal, 1991).

In practice, substituting purified sewage for the mains water supply for industrial purposes has been difficult in our existing large cities. The main problem has been the costs to pipe the treated water from the WWTP to industrial sites which are often separated far apart (Anon., 1975; Blesing, 1975). Decentralised wastewater treatment facilities do offer some potential to overcome this problem.

8.3.5. Reuse for Irrigation

The large scale reuse of urban sewage for irrigation is common-place in many arid and semi-arid regions of the world. In Israel, reclaimed wastewater constitutes 11 percent of all irrigation water, and in Santiago and Mexico City around 70 to 80 percent in a dry season (Bartone, 1991). Irrigation with purified sewage effluent has

also been practised in South Africa for many years without any obvious harmful effects on crops, soils or consumers (Odendaal, 1991).

Official standards for irrigation with sewage effluent are often a compromise between what is theoretically desirable to safeguard the public health and what is practically achievable. In general, most effluents from predominantly residential areas meet the agronomic requirements for unrestricted irrigation.

Main considerations are salinity and the reduction of potentially toxic ions such as boron. Chlorine added as a disinfectant is not considered to adversely affect plants at usual levels of dosage (Banks, 1991). Nutrient removal is not required because the addition of artificial fertilisers can be greatly reduced or even eliminated, which can provide an substantial cost saving to farmers in developing countries.

Irrigation techniques are chosen to minimise the contact between the irrigation operators and wastewater. On-surface and sub-surface drip irrigation with effluent is a promising technology not only to satisfy the non-contact requirement but to simultaneously address water shortage and pollution problems (Oron *et al*, 1991; Gearing & Riddell, 1992). Flood, drip and sprinkler irrigation methods can be used, but the closed conduit systems of drip or trickle irrigation are preferable because flood irrigation or sprinklers can contaminate crops or fruit trees, and disperse a harmful wastewater aerosol.

Disease outbreaks attributable to the controlled use of treated sewage are virtually unknown (Thomas & Kowarsky, 1992; Asano & Levine, 1996). Health effects have only been reported where salad vegetables were irrigated with raw effluent.

The reuse or disposal of wastewater using irrigated woodlots is gaining increasing attention in Australia, particularly with the commitment of State Governments to eliminate the disposal of sewage effluent to inland rivers (such as the Murray) or marine waters wherever economically feasible. A considerable research effort has been directed toward the identification of suitable species and operating conditions for the maximum uptake of effluent water, as reported by Sweeney & Frahn (1992), Gardner (1992) and Baker (1992). Furthermore, woodlots, extensive areas of wetlands and open space irrigation will form the major components of reclaimed water utilisation for the inland city of Albury, NSW (Larkin & McGregor, 1991). There is also interest in the use of native woodlots for the land disposal of winery effluents (Kennedy, 1992), while some wineries and orchards are in fact investigating the use of these effluents for crop irrigation (Kayaalp, 1997).

Land based application of effluent via irrigation of crops or native woodlots has also been proposed for wastewater disposal from Adelaide's largest wastewater treatment plant at Bolivar. Investigations into the viability of irrigation with effluent focussed upon issues of soil suitability. Armstrong (1972) and Matheson & Lobbon (1972-1975) found that irrigation with secondary effluent was possible for salt tolerant crops such as onions and potatoes. The salinity effects of saline effluent on heavy soils over a highly saline water table was of concern however. Since that time, limited irrigation with effluent has taken place. Growing evidence of degradation of the marine environment due to effluent discharge has now prompted the South Australian government to re-consider land based disposal options. As a result, the

Hardwood Irrigation Afforestation Trial (HIAT) was established in 1990 to investigate the potential for using the treated effluent to irrigate a native hardwood tree plantation. Early results indicate that although there were high levels of timber production – providing saleable forest products – the annual water use was unlikely to the exceed annual evaporation achievable from ponds (Hanna *et al*, 1992; Shaw *et al*, 1996). The trials ceased, with the focus turning to an alternative irrigation scheme, the Virginia Pipeline Scheme (which is discussed in detail in Chapter 11).

8.3.6. * Reuse for Potable Supply

Most people find the idea of drinking purified sewage revolting. Until recent years, direct potable reuse has not been seriously considered in the US with Arber (1991) citing the following reasons: the negative public perception, potential for human health effects, and perhaps more importantly, the potential liabilities associated with direct potable reuse. But undoubtedly as new sources of water become more scarce or difficult to develop, the potable reuse of wastewater must eventuate, especially in arid regions. This is particularly well demonstrated in the Middle East where there is substantial financial investment in the production of drinking water via desalination; the marginal cost of further treatment and distribution for reuse becomes comparatively small compared with the total cost of wastewater (Banks, 1991).

While there are only a few examples of direct reuse of wastewater for potable purposes, many examples of indirect potable reuse can be found throughout the world, the most common being the result of upstream disposal of wastewater and subsequent reuse via withdrawals downstream. Some of the more notable examples include the River Thames in the United Kingdom (Harper, 1992), the River Rhine in Europe, the Ohio River in USA, and the Hennops River in South Africa where it is possible for effluent to represent up to 80 percent of the raw water intake for potable supply. By the early 1970s, about one third of the total population of the United States used water that was in part made up of wastewaters that only hours earlier were discharged from municipal or industrial sewers.

The River Murray provides an example from Australia; the effluent from many inland wastewater treatment plants has historically been discharged within the Murray-Darling Basin and extracted downstream for irrigation. In South Australia, around half of metropolitan Adelaide's water supply is sourced from the River Murray thereby constituting an indirect reuse of wastewater. The upstream states of New South Wales and Victoria have accepted disposal of wastewaters into water courses used as raw water sources for water supply, so long as there is dilution of at least 1 part in 19 and a distance of 400–800 metres between the discharge point and water supply off-take. Hamilton & Greenfield (1991) are unaware of any scientific basis to these legislative requirements, however.

The 60,000-plus inhabitants of Windhoek – a city located at the edge of the Kalahari Desert in Namibia in south-west Africa – have become quite used to drinking purified effluent. Because of a severe water shortage they drank largely purified sewage for 4 years from 1969 (Anon., 1975). Since that time the plant has been upgraded several times and is still operating according to need. Studies have shown that the quality produced at the Windhoek and other plants in South Africa (at Cape

Town and Pretoria) is of a consistently high quality (Isaäcson & Sayed, 1987) and perfectly potable by virological standards (Hodgkiss *et al*, 1989).

In July 1985, a substantial research effort was initiated by the City of San Diego to determine the possible health risks of direct reuse of reclaimed wastewater. The research included the consideration of infectious disease agents and potentially toxic chemicals, with screening for mutagenicity and bioaccumulation. The study indicated that processes already existed that could reliably produce a water of equal or better quality than the raw water supply used at that time by San Diego. Based on this study, the San Diego region is actively considering potable reuse of treated effluent by discharge to a reservoir at a scale greater than 76 ML per day (Olivieri *et al*, 1996).

This situation is characteristic of the nature of wastewater reuse plans world-wide. The technology for advanced treatment is available and epidemiological studies indicate that the risk is comparatively insignificant (Hamilton & Greenfield, 1991). It appears that the economics and public acceptability of direct reuse are the only barriers to be overcome.

The reuse of wastewater for non-potable applications is rapidly gaining acceptance in Australia, with numerous schemes of various scales implemented in recent years (refer to Section 8.3.8). This is likely to lead to further inquiry into direct potable reuse, with some researchers and practitioners already proposing such use. Law (1997) suggests that there are many reasons why water managers should move on from dual systems to seriously consider and plan the implementation of potable reuse, submitting that advanced water treatment can produce reclaimed water that can be safely distributed for potable reuse. Past experience in the USA and South Africa confirms that consumers are often ready to accept potable reuse after is has been successfully demonstrated in potable or near potable applications such as swimming (Hamilton & Greenfield, 1991).

A survey in Australia by Hamilton (1993) found that the majority of respondents were prepared to consider potable reuse if convinced of the need and the adequacy of safe-guards.

The economics of potable wastewater reuse are also likely to be conclusively proven in the coming decades. As more stringent water quality criteria are imposed upon treated effluent in response to environmental concerns, combined with the scarcity and expense of developing new sources, the incremental cost of new water supplies and wastewater treatment is likely to make advanced wastewater treatment for potable reuse economically attractive. Cases are beginning to emerge to support this proposition. Anderson (1995) has shown that in the long term, potable reuse is likely to be less costly than non-potable reuse. Law (1993) showed that the implementation of potable reuse was comparable with the cost of the domestic non-potable reuse scheme at Rouse Hill, NSW. Furthermore, MacCormick & Johnson (1996) note that recent developments in membrane technology can lower the cost of producing potable quality reclaimed water.

8.3.7. Australian Experience of Wastewater Reuse

Water recycling is still in its infancy in Australia, but the notion of wastewater reuse is rapidly gaining increased attention. Numerous researchers are exploring and promoting reuse options, as conferences are dedicated to the theme and a few major reuse schemes have emerged since the early 1990s. Anderson (1996a) notes that there is now a strong perception in the community, born of concern for the environment, that wastewater and stormwater should be recycled rather than discharged to rivers or the ocean.

Wastewater reuse has been practised in Australia in an indirect way for many years, however. Land based disposal of effluent was originally practised at sewage farms at Werribee near Melbourne, and Islington in Adelaide, for example. The use of effluent as a supplementary source to conventional water supplies in a planned, productive manner has only been seriously promoted since the mid 1970s, when reuse of reclaimed water from metropolitan wastewater treatment plants for irrigation commenced.

In 1979, the National Health and Medical Research Council (NHMRC) and the Australian Water Resources Council (AWRC) jointly prepared guidelines for the use of reclaimed water. These guidelines were revised in 1987, and another review commenced in 1991 in order to accommodate changes in reuse practices, technical advances and an increasing understanding of the risks and benefits inherent in the use of reclaimed water (Gregory *et al*, 1996). While work is progressing to develop the revised national guidelines, South Australian guidelines are being prepared for reuse of reclaimed water (Kayaalp, 1996). A number of guidelines have emerged from government and non-government organisations, as summarised in Table 8.8.

McDonald (1980) reviewed past experience with dual water supplies in Australia. There are a number of limited dual water supplies in Australia, such as in Canberra; Rottnest Island in Western Australia; Longreach and St George in Queensland; Glenelg in South Australia; and Broken Hill, Bourke, Brewarrina, Walgert, Warren and Finley in New South Wales.

McDonald (1980) also investigated the feasibility of dual water supply systems for country towns in New South Wales. Indoor domestic water requirements were to be met via the conventional potable water supply system; all other needs would be supplied with non-potable water. A variety of system configurations and discount rates were analysed for a design life of 40 years. Dual systems were found to be some 10 percent more costly at best. As treatment costs increased, dual systems would become more feasible. In addition, for areas where outside water use was high, dual systems were favourable.

An extensive study of alternatives to ocean disposal of treated effluent for the major wastewater treatment plants in Western Australia found that the five options with the greatest potential for implementation on a cost and environmental impact basis included: irrigation of woodlots, groundwater recharge via borehole injection, dual reticulation, potable reuse, and the irrigation of urban parklands (van Oorschot & French, 1996).

Table 8.8
Recent Australian Guidelines on Wastewater Management and Reuse

Source	Details
AWRC	*Draft Guidelines for Sewerage Systems: Effluent Management* (1992) focussing upon land based disposal or discharge to receiving water bodies.
NSW WRC	In 1993, the NSW Water Coordination Committee published the *NSW Guidelines for Urban and Residential Use of Reclaimed Water* to promote the non-potable reuse of effluent from community WWTPs.
CSIRO	From the Division of Foresty, the guidelines *Effluent Irrigated Plantations: Design and Management* (1995) provide advice on all aspects of effluent treatment, reuse, plantation design and management.
Friends of the Earth	*Not Just Down the Drain* is a guide funded by the Melbourne Water Corporation and published to inform the general community, to provide ideas and methods for on-site conservation and reuse of grey-water (McQuire, 1995).
Victorian EPA	*Guidelines for Wastewater Irrigation* (Thomas, 1992); and the *Guidelines for Wastewater Reuse* (Vic EPA, 1996) providing guidelines for non-licensed, performance based, non-potable reuse.
NHMRC, ARMCANZ and ANZECC	The *Draft Guidelines for Sewerage Systems: Use of Reclaimed Water* (1996) providing guidance on the reclamation and reuse of effluent from community wastewater treatment plants. Discharges from particular industries including piggeries, tanneries, wineries and wool scouring are addressed in separate guidelines.
SA Health Commission	*Guidelines for the Use of Reclaimed Water in South Australia* - guidelines under development for the non-potable reuse of municipal effluent, primarily for irrigation applications (SAHC, 1996).

Towns along the River Murray with WWTPs now dispose their wastewater on land where it was previously discharged to the river. Country towns with sewage treatment and effluent drainage schemes (STEDS) and the metropolitan WWTPs utilise part of the reclaimed water for irrigating sports fields, golf courses and some crops. Kayaalp (1997) reports that there are 22 townships in South Australia currently recycling effluent from STED schemes for irrigation of golf courses, ovals, woodlots or vineyards. A further 8 townships make productive use of effluent from package treatment plants.

Effluent from Adelaide's Glenelg wastewater treatment plant has been used for irrigating public lawns and gardens for more than 60 years (Anon., 1975). Since that time some form of effluent reuse is practised at almost all major treatment plants in South Australia (Anon, 1993).

Large scale reuse of sewage effluent has been suggested for the Bolivar Sewage Treatment Works in Adelaide since the 1960s. In 1975, Blesing investigated the potential for reuse of Bolivar effluent in industry but found that there was little economic incentive for the numerous large water users in the region due to the low cost of fresh mains water. Only recently has the reuse of effluent for irrigation of horticultural crops proven economically viable (refer to Chapter 11 for further information on the Virginia Pipeline Scheme).

Wastewater reuse has been applied extensively in a new residential development near the port of Adelaide, called New Haven Village. The development was

supported by the MFP Development Corporation, who gained government approval for the use of reclaimed water, after ultraviolet disinfection, for irrigation of residential gardens and an adjacent oval, as well as for toilet flushing. The South Australian draft guidelines for effluent reuse were adopted (Kayaalp, 1996).

A more substantial initiative of the MFP Development Corporation is the construction of a major urban development implementing advanced technologies, particularly for water cycle management. The development, to be called 'Mawson Lakes' and be situated at Greater Levels in northern metropolitan Adelaide, will include wastewater treatment for full on-site reuse involving dual reticulation, wetlands and open space irrigation. This development is nearing the end of planning stages with construction scheduled to begin before the year 2000 (after Thomas *et al*, 1994).

The Rouse Hill development in the north-west of Sydney is Australia's first full scale application of domestic non-potable reuse, with the sewage treatment plant and the dual water distribution system being commissioned in late 1994. This urban development, which will eventually accommodate around 300,000 people, incorporates a dual water system with sediment traps, detention basins and wetlands as measures to reduce the cost of water supply and the environmental impact of such a large development in the sensitive environment of the Hawkesbury River catchment (McNeill, 1994; Law, 1996).

The latest developments in reuse technology such as mains interception sewage treatment (MIST) are already in evidence with projects such as the ACTEW South Park Water Mining Project (Butler & MacCormick, 1996). Wastewater is extracted directly from existing sewers, treated to the required standard, and reused for irrigation. The treatment plant is ideally suited to a residential setting, occupying only 180 m^2 of land, while incorporating primary screening, secondary biological reactors, dissolved air flotation followed by membrane filtration and UV disinfection (Barnett, 1996).

McIntosh (1996) suggests that the costs associated with retro-fitting dual water supply systems to existing developments is unlikely to be an attractive option for some time. The implementation of dual supply systems in new developments or renewed urban areas does appear to be feasible however, given the emergence of such schemes in various parts of Australia, although Anderson (1996a) considers that some further development of the technologies is needed to bring down the cost of water quality improvement and recycling.

8.3.8. Conclusions

In many industrialised nations there are growing problems associated with developing adequate water supplies in an environmentally sound manner. In addition, the costs of municipal and industrial wastewater disposal for water quality protection and pollution abatement are increasing. In developing countries, particularly those in arid regions of the world, reliable low cost, low technology methods are needed for acquiring new water supplies and protecting existing water sources from pollution. In the planning and implementation of water reclamation

and reuse the intended water reuse applications dictate the extent of wastewater treatment required, the quality of the finished water, and the method of distribution and application. As technology improves and the reliability of water reuse systems is demonstrated, it is likely that water reuse will continue to expand in the future (Asano & Levine, 1996).

To date, the majority of reclaimed water has been applied in the areas of agricultural and landscape irrigation, industrial uses (primarily cooling towers), in-building applications such as toilet flushing, and groundwater recharge.

Such use of reclaimed wastewaters for non-potable purposes in a planned water resource program can provide numerous benefits (Okun, 1973; Dworkin, 1975) including:

- wastewater reuse for non-potable purposes relieves the pressure on limited high-quality water sources, so that these can serve larger populations;
- the costs of providing reclaimed water would be far less, in many instances, than the cost of developing additional high quality freshwater sources;
- wastewater reuse reduces the burden of pollution on the receiving body of water, thus reducing water pollution control costs and environmental damage;
- the risk to the population of ingesting the contaminants in polluted waters is reduced;
- the advantage that availability of supply is almost assured, even in drought years, since the effluent originates mostly from households;
- saves on potable water use;
- saves the environment;
- has nutrient value in irrigation;
- can reduce the asset replacement burden; and
- the capacity of reuse systems can often be implemented or expanded much faster than developing new surface water or groundwater sources.

A drawback of non-potable recycling is often the cost of establishing a second reticulation network and a second system of household plumbing with safe-guards against cross-connection (Anderson, 1996b). However, significant financial savings have been found to be possible from modular infrastructure development.

The focus of wastewater management is changing from constructing regional sewerage systems to decentralised wastewater reclamation facilities (Tchobanoglous, 1996). Only infrastructure essential for an entire development site need be developed up front, with all other infrastructure including wetlands developed on a staged basis (MacCormick, 1995).

The greatest benefit from wastewater reclamation could be gained through direct potable reuse. While potable reuse is unlikely to eventuate in Australia in the foreseeable future, dual supply schemes are being developed and a treatment plant is being constructed to develop and demonstrate the technology for the treatment of effluent to a potable standard.

8.4. Stormwater Management

The management of stormwater has traditionally been driven by the fear of flooding and the costs in terms of property damage, economic dislocation, injury and death. The response has been the development of engineered drainage systems to convey the storm runoff away from developed areas as quickly as possible, discharging into streams or the ocean.

It is clear that the increase in impervious surface with the development of rural areas has greatly increased the volume of storm runoff. With increasing urbanisation and renewal of urban areas with higher density housing, the problems associated with conventional urban development will be exacerbated:

- An increasing burden upon lakes and rivers and their ecology to accept the pollutants and rubbish contained in urban storm runoff.
- An increase in the peak rate of storm runoff, and a reduction in the time of concentration of runoff. The faster flows will scour and erode the bed of natural channels.
- An increase in non-seasonal baseflow to streams due to leaks from water mains and irrigation runoff, carrying pollutants from streets and gardens.
- Continuing decline in sea-grasses and marine ecosystems with adverse impacts on fisheries, further coastal erosion and a decline in the recreational amenity of beaches, creeks and waterbodies.

While many Australian cities have been spared the impacts of significant flooding, a catchment perspective to stormwater management has often been lacking. A major contributor to this inadequacy has been the failure of existing planning systems and building controls to recognise stormwater as a metropolitan-wide issue that can be addressed to a large extent through effective control over the nature of land use and forms of development and its capacity to both generate and limit runoff (ECA, 1991). The result has often been a lack of coordination in stormwater management, inequitable and ill-timed allocation of funding for construction of stormwater control facilities, and a failure to address the environmental impacts of stormwater.

It is now recognised that stormwater management is larger than the issue of flooding alone. Environmental protection, urban amenity and the resource potential of stormwater should be addressed along with the issue of flooding in an holistic way.

Multi-objective stormwater management, rather than stormwater drainage, is gaining unprecedented interest in Australia (Cullen, 1995), particularly since the early 1990s, with Australian researchers and practitioners perhaps at the forefront of technology development for stormwater harvesting and reuse. Hence, this discussion tends to have a focus upon Australian conditions and experience.

8.4.1. Urban Stormwater as a Resource

The planning for urban stormwater management has emerged over the last decade into a much broader development context, that of addressing how urban communities and infrastructure can meet the goals of sustainable development. In this context, the sources of water and technologies used for the provision of water supply and sewerage services have come under scrutiny. Some of the key points and main areas of concern that have emanated from this period of deliberation are:

- the quality of many surface water resources used for supply is being degraded;
- some groundwater resources are being polluted or over-exploited;
- the costs of water and wastewater treatment are rising;
- much of the water infrastructure is falling due to replacement;
- the prices being charged to consumers do not reflect, and in some instances do not cover, the true costs of service provision;
- discharge of sewage effluent and polluted stormwater to rivers and the sea is causing serious environmental harm; and
- much of the water consumed in the urban environment does not need to be of a potable quality.

Under these circumstances, stormwater began to be perceived as a resource rather than a nuisance, capable of meeting some of the non-potable water needs, reducing the load upon the potable water distribution system, while providing numerous social and environmental benefits.

Momentum has progressively grown behind the push for greater development of stormwater as a resource, following the early work of Lawrence & Goyen (1987), Fisher & Clark (1989), WSUDRG (1990), Mouritz & Newman (1991), ECA (1991) and Clark (1992). Today, stormwater is now clearly recognised and quantified as a resource alongside surface waters, groundwater and treated sewage effluent in such resource statements as the strategic water plan entitled *South Australia: Our Water, Our Future* (DENR, 1995).

It is apparent from experience in Canberra, ACT that well designed and integrated urban stormwater systems can provide numerous benefits to the community, including:

- removal of excess water and prevention of flooding of property and the associated impacts of flooding community facilities;
- protection of downstream water bodies from the contaminants in urban runoff;
- aesthetic value within the urban landscape;
- recreational facilities on water bodies;
- nature conservation habitat in urban areas for birds and other valued species;
- a community education resource;
- recreational and wildlife corridors along drainage lines; and
- a second class water resource for other appropriate uses (Cullen, 1995).

To achieve many of the outcomes desirable from multi-objective stormwater management, some form or combinations of intervention is often required.

Structural inventions for water quantity and quality management are discussed further below.

8.4.2. Runoff and Pollution Control Technologies

There are a wide range of measures that may be employed to improve the quality and resource value of urban stormwater. There are structural measures that can be applied to either reduce the volume of stormwater generated at the source site, or improve its quality prior to discharge from the generating site. Other measures aim to reduce the impacts of high flows upon receiving water bodies, often providing water quality improvement at the same time. In a multi-objective stormwater management strategy, both measures are equally important.

A variety of stormwater management measures that are available to control the quantity and quality of runoff from urban areas. These range from local or on-site measures to technologies suitable at the catchment or regional scale.

Many of the stormwater control measures discussed below aim to detain or retain the stormwater for water quality improvement. This is because many of the pollutants in stormwater are associated with particulate matter, and as such sedimentation or retention of stormwater over an extended period provides an effective means by which water quality can be improved.

Further detailed information on the design, implementation and operation of the following measures can be obtained from Mein (1982), Degroot (1982), Phillips (1991), Beca Carter Hollings & Furner (1992), EWS (1992), and Debo & Reece (1995). Guidance on the integration of the available technologies in the residential and urban landscape can be sought from WSURDRG (1990) and NCPA (1993).

8.4.2.1. Paved Area Minimisation

Most runoff within urban areas is generated from paved surfaces and roofs. A reduction in the amount of paved and impervious surface area will therefore have an effect in decreasing runoff and the quantity of stormwater available for the capture and transport of pollutants (BC Tonkin, c1992).

8.4.2.2. Erosion and Sediment Control

Sediment control measures are usually most relevant for construction sites or disturbed land areas that are prone to erosion. There area a range of measures that can be applied depending upon the particular circumstances, including:

- *Mulching and revegetation*: to protect soils disturbed by earthworks.
- *Hay bales*: placed around the inlets to pits or across minor drainage swales to capture sediment laden flow.
- *Sediment traps and basins*: to capture and detain sediment laden runoff prior to discharge from the site.

8.4.2.3. On-Site Detention and Retention

A number of methods are available for the temporary or longer-term storage of stormwater runoff on the generating site. On-site retention can be achieved using infiltration trenches or pits, most often filled with gravel and designed to serve individual allotments. Flow in excess of the capacity of these systems is diverted back to the municipal drainage system. They have been shown to be effective even in heavy soils for reducing peak flows for storms of up to 5 year ARI (Allen & Argue, 1992). At the New Brompton Estate in Adelaide, a gravel filled stormwater retention trench captures runoff from 15 residential allotments, using the water for recharge of a shallow aquifer, with the recharged water extracted during summer months for landscape irrigation (Hopkins & Argue, 1993). There are also a variety of on-site or local stormwater detention facilities offered by the manufacturers of pipes and drainage products.

8.4.2.4. Swale Drains & Grassed Waterways

Replacing conventional roadside kerb and gutter systems with grassed swales can reduce and slow runoff and improve runoff water quality. Vegetation in the swale system accumulates vehicular and airborne pollutants captured in the runoff and filters them out. Swales have been demonstrated to operate as an excellent entrance channel providing substantial water quality improvements to urban runoff draining into an artificial wetlands (Tomlinson *et al*, 1993; Williams & Daniell, 1996).

8.4.2.5. Trash Racks

Trash racks are structures comprised of steel grates or mesh bags placed across the path of a drainage line to capture floating debris in stormwater. They are used to protect downstream drainage lines from blockage and to improve the visual aesthetics of receiving waters by removal of this debris. Racks require regular cleaning and maintenance to remain effective. When partly blocked, they can provide a significant obstruction to flow, with potential flooding affects.

8.4.2.6. Gross Pollutant Traps

Gross pollutant traps are structures that combine a trash rack and sedimentation basin designed to not only remove floating debris but a large proportion of the suspended particles. Small or minor traps are generally placed to capture sediment at the outlet of underground drainage systems which discharge to main drainage lines. Major traps are used on main streams, usually just upstream of wetlands and wet retention basins to protect these pondages from silt and debris accumulation (BC Tonkin, c1992).

8.4.2.7. Detention and Retention Basins

The use of stormwater detention basins is becoming a relatively common technique, whereby stormwater runoff from a large area is captured in a basin, temporarily held and discharged either through a pipe or over a spillway to a downstream drainage line. As a result of the temporary storage of water within the basin, the peak outflow from these structures is less than the peak inflow. Basins require a large area of land and fill relatively infrequently, but therefore provide the opportunity for conjunctive

use as car parking or recreational areas (BC Tonkin, c1992). The overall effectiveness of the detention basin in runoff water quality control is poor due to the short residence time and the potential for re-suspension of materials deposited on the basin floor.

Retention systems are usually constructed at the outlet of major drainage lines prior to discharge into receiving waters. These wet basins store runoff for an extended period, allowing physical, chemical and biological processes to remove pollutants from stormwater. The basins can require little maintenance and can be landscaped to enhanced amenity and increased land values. Additional advantages include the storage of water for irrigation and aquifer recharge (Manning, 1996).

8.4.2.8. Artificial Wetlands

Wetland basins or reed ponds are wet retention basins also situated at the outlet of major drainage lines, but they differ in that they are purposely designed to provide more of the characteristics of natural wetlands. Areas of submerged and emergent macrophytes are provided, along with bank vegetation and a viable fauna population, particularly fish.

Wetlands provide an efficient mechanism for the removal of a wide range of pollutants including suspended solids, nutrients, micro-organisms and heavy metals. Quantitative data on the performance of detention, retention and wetland systems clearly demonstrates that wetlands are the most efficient water quality improvement systems if properly designed. Residence time is one of the most important factors in determining the size of wetlands (Walker, 1996), however the configuration of the ponds and long term maintenance is also very important.

Artificial wetlands have become particularly popular stormwater control devices in Australia, in a large part due to their amenity, landscape and habitat value. In fact, not only can open channel, swales and wetlands reduce the overall costs of stormwater drainage (with cost reductions of up to 70% estimated for Canberra), they can also dramatically enhance land values of blocks abutting or with views of these facilities (Cullen, 1995).

8.4.2.9. Other Stormwater and Pollutant Control Devices

Over recent years a number of new devices have been developed for the removal of litter and fines from stormwater flows. These devices range from small litter traps, often as simple as a wire mesh basket designed to work with side entry pits (Rose, 1995; Ecosol, 1996) to larger, engineered devices that can service a small urban catchment.

The Continuous Deflection Separation (CDS) system developed by Pollutec Ltd is perhaps the most well known device for stormwater quality improvement currently available in Australia. The CDS system is an on-line unit consisting of a stainless steel perforated and deformed separation plate placed in an hydraulically balanced separation chamber. Solids in the flow are deflected away from the main stream of flow and concentrated by vortex action in the centre of the unit, periodically removed as part of a regular maintenance program. The water filters through the separation plate in a direction opposite to the flow and is diverted back into the

stormwater drainage network (SIA, 1995; Wong & Wootton, 1995; Allison *et al*, 1996).

8.4.3. Stormwater Capture for Reuse

The previous discussion has concentrated upon urban stormwater management for the achievement of water quality improvement, reduced environmental impact and improved urban amenity. In most cases, measures to achieve these goals are introduced to the existing stormwater drainage network without a substantial departure from the conventional systems of stormwater drainage. This reflects the conventional approach to stormwater management in Australia.

Some have suggested that stormwater should be considered within a far more integrated water management framework, even as a source for potable water supply. Bergman (1992) suggests that such an alternative approach might involve the replacement of 'conveyance' systems with smaller scale water resource management systems that are integrated into local communities. This approach would reduce demand upon mains water supplies, allow harvesting of stormwater and better treatment of waste. Cullen (1995) considers from a water quality perspective that it may well be more appropriate to look at treatment of urban runoff rather than sewage to provide additional potable supplies.

It is often reported that urban runoff has a greater pollutant load than sewage (Dowsett, 1995), but Cullen (1995) points out that in the case of phosphorus – a key nutrient causing eutrophication of water bodies – this is certainly not the case. Indeed, a comparison of water quality data for similar volumes of sewage with stormwater invariably demonstrates that sewage effluent contains much higher concentrations of faecal coliforms and nutrients, whereas stormwater exhibits higher concentrations of suspended solids and heavy metals. From this simple perspective, stormwater may appear to be the more appropriate source if potable reuse were to be considered. In the temperate and semi-arid climates that characterise the majority of the southern and urban areas of Australia, it is not quality but the ability to capture stormwater that presents the greatest problem.

A natural consequence of the traditional approach to stormwater management is a lack of reliable data on the quantity of runoff and potential yield for stormwater collection and use. The majority of information available relating to stormwater flows has tended to be generated via hydrological design studies that have focussed on the issue of flooding and the design of stormwater drainage systems, and therefore relates to flood flows rather than potential stormwater yield. Since that time little has changed, with only a small number of catchments have urban flow components being gauged, typically for research purposes and at this stage with a short period of record that is often plagued by unreliability or important data gaps.

The ability to capture urban stormwater in sufficient quantities to make it useful as a potable water source is the challenge. Aquifer storage and recovery technologies do offer considerable potential to effectively expand the available storage capacity for stormwater, as well as provide water quality improvement.

It therefore seems that in the foreseeable future, stormwater will be managed in a multi-objective way but with the focus upon environmental enhancement and re-use for applications such as open space irrigation or possibly industrial applications where the opportunities present themselves. Such applications can effectively make significantly more potable water available through substitution as has been the experience in Canberra in the Australian Capital Territory. The city of Canberra now meets 6 percent of its total water needs by recycling water from stormwater detention basins for non-potable uses (Anderson, 1996b). These initiatives are likely to be keenly supported by the general community.

8.4.4. Community Values and Participation

Urban stormwater has come out of the shadows and is now a major public issue (Cullen, 1995). Concerns about untreated or partly treated sewage polluting Australian waterways and beaches is now seen by the community as more important than flooding (CEPA, 1993).

These attitudes toward water quality have been reflected in the results of a recent public opinion survey conducted in major Australian cities. Nancarrow *et al* (1995a; 1995b) found that environmental values were consistent across cities. From the community's perspective, the major criteria for setting water quality standards are cleanliness (health); protection of the environment/ecosystem in general; and suitability for human activities. The maintenance or restoration of a pristine water was also a desirable goal. This has indicated that the community requires high standards of water quality for their waterways throughout Australia. Indeed, the people interviewed clearly indicated that they perceived quite a large public good component to stormwater quality management and considered this aspect to be more important than stormwater quantity management. This was further evident from the responses to willingness to pay questions, with over 50 percent of respondents indicating their willingness to pay for pollution abatement measures.

In 1996, a survey of local government in the Adelaide metropolitan area revealed that the vast majority of respondents were strongly in support of the statement "the public will readily accept the recycling of stormwater runoff for irrigation water supplies." There was less support however for the use of treated sewage effluent for irrigation (Dillon, 1996). Consultation and market research carried out in the ACT also found that from a human health perspective the community was less concerned about the use of stormwater than wastewater (ACTEW, 1994).

The interest of the community in water quality and stormwater issues is also clearly reflected by their participation in the community-based Waterwatch program, and attendance at community consultation meetings associated with development of Catchment Management Plans. It seems that the future of integrated stormwater management, rather than stormwater drainage, is assured.

8.5. Aquifer Storage and Recovery

8.5.1. Aquifers and Groundwater

An *aquifer* is a water bearing earth material, which is not only a reservoir for containment of groundwater, but also the conduit for transmission. Most groundwater reservoirs contain far more water in storage than the volume that passes through them annually (Oaksford, 1985).

Aquifers can be close to the land surface, with continuous layers of materials of high permeability extending from the land surface to the base of the aquifer. Such an aquifer is termed a water table aquifer or an *unconfined aquifer;* refer to Figure 8.2. Natural recharge of the aquifer is accomplished by direct percolation through the vadose (unsaturated) zone; infiltration via stream beds; sub-surface lateral groundwater inflow from surrounding formations; or upward seepage from underlying strata (Fetter, 1988; Helweg, 1985).

Some aquifers, called *confined* or artesian aquifers, are overlain by a confining layer (Figure 8.3). A *confining layer* is a geologic unit having little or no intrinsic permeability. Groundwater moves through most confining layers, although the rate of movement is very slow (Fetter, 1988). Recharge to confined aquifers typically occurs horizontally with inflow from a recharge area where the aquifer crops out, or by slow downward leakage through a leaky confining layer.

The potentiometric surface for a confined aquifer is the surface representative of the level to which water will rise in a well cased to the aquifer. If the potentiometric surface of the aquifer is above the land surface, a flowing *artesian well* may occur (Fetter, 1988).

8.5.2. Artificial Groundwater Recharge

Artificial recharge of groundwater has a central role in groundwater basin management. Groundwater recharge has the potential to maximise the available water supply, and enhance the capacity to conjunctively use, integrate and conserve the existing groundwater and surface water resources (Lehr, 1983). Artificial groundwater recharge techniques have been used for a variety of purposes, including (Harpaz, 1971; Lehr, 1983; Oaksford, 1985; Gerges & Howles, 1996):

- storage of stream waters during periods of high or excess flow;
- storage of fresh water to reduce costs of pumping and piping;
- storage of water during cold seasons for use during the growing seasons;
- development of water storages where the topography is otherwise unsuitable for large surface reservoirs;
- conservation and disposal of storm runoff and flood waters;
- augmentation of the amount of available groundwater by the replenishment of depleted aquifers (allowing renewed use of wells that had previously become unproductive);
- decreasing the size of areas needed for water supply systems;
- improving quality by earth filtration of suspended solids from the water;

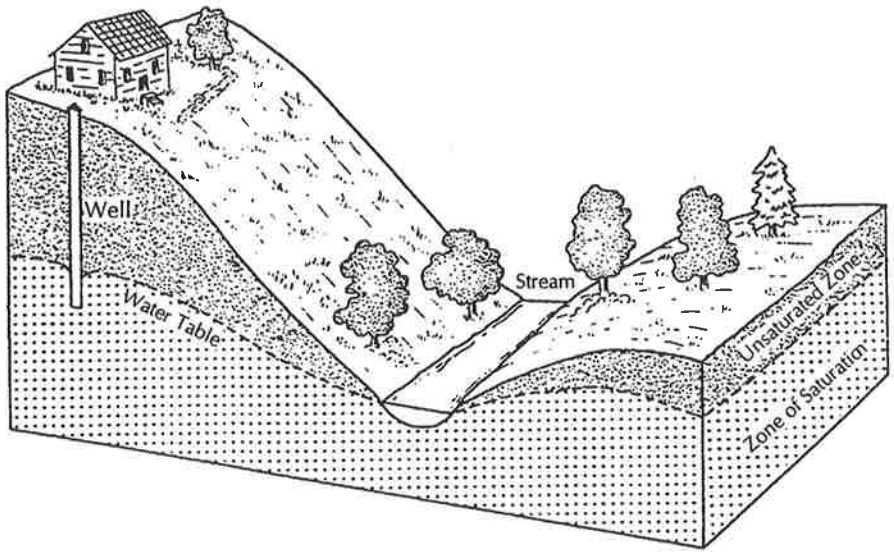


Figure 8.2
The Nature of an Unconfined Aquifer (after Fetter, 1998)

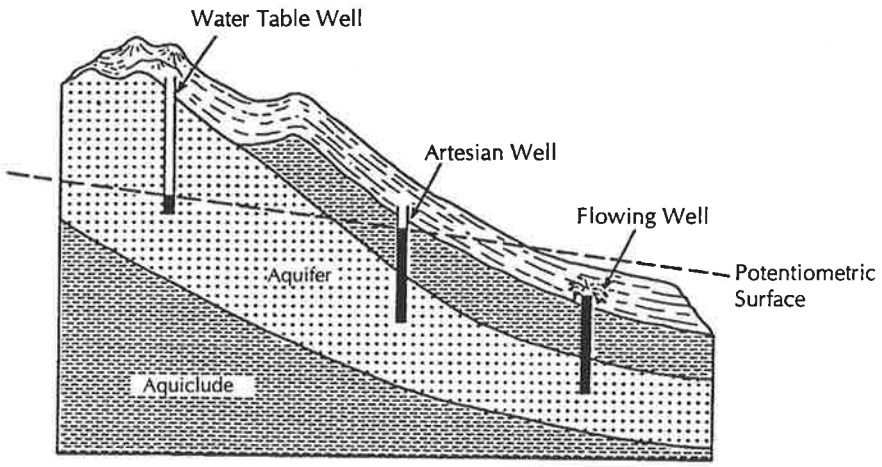


Figure 8.3
The Nature of a Confined Aquifer (after Fetter, 1998)

- purification and reclamation of effluents;
- reduction in the salinity of groundwater where it has traditionally been unsuitable for irrigation;
- protection of aquifers from saline intrusion through the formation of pressure barriers;
- reducing the cost and improving the effectiveness of flood mitigation;
- well field management;
- reduction of land subsidence;
- increasing stream flow;
- secondary recovery of oil; and
- conserving energy in groundwater geothermal applications.

Surface reservoirs have the advantage of straightforward operation and management. High construction costs are the prime disadvantage, and these costs can vary significantly depending upon land availability, site characteristics, storage volume, and regulatory and other factors (Guymon & Welch, 1990). When compared to surface water storage, groundwater storage is advantageous because groundwater reservoirs (Roberts, 1980; Oaksford, 1985; Bouwer *et al*, 1990; Helweg, 1985):

- undergo little or no evaporation;
- require minimal construction;
- have large storage capacities;
- ameliorate land subsidence;
- provide additional treatment of reclaimed water;
- offer inexpensive transmission;
- cause no interference with surface land use (if appropriately implemented);
- reduce or eliminate odour and mosquito problems inherent with surface storage of treated wastewater;
- provide a 'loss of identity' of recharged water such as treated effluent; and
- are less vulnerable to drought.

Although the advantages of artificial recharge are many, there may be instances where they are outweighed by the disadvantages such as (Oaksford, 1985):

- the area required for operation and maintenance of a groundwater supply system may be larger than for a surface water supply system;
- not all water may be recovered;
- sudden water supply demand may not be met because groundwater reservoirs are not as easily drained as their surface water counterparts;
- salts of calcium, magnesium, iron and other elements in the recharge water cannot be readily removed;
- clogging of aquifers can be difficult to remedy; and
- expansion of public groundwater supply systems may be costly.

8.5.3. The Methods of Artificial Recharge

Artificial recharge is a concept. Nearly every application of artificial recharge is a uniquely designed complex of works and operational rules, but which possess four fundamental elements (Schuurmans *et al*, 1983):

- the supply of water;
- the infiltration of water into the subsoil;
- the passage through the subsoil; and
- the recovery of recharged (and natural) groundwater.

While each recharge operation is site specific, there are a few basic techniques that are most commonly adopted, such as surface spreading, pits and shafts, and injection wells.

Sub-surface recharge (via natural openings, injection wells, pits and shafts) is generally used when a semipermeable confining stratum separates the source of recharge water from the aquifer requiring replenishment. Pits and shafts are usually employed where a confining layer is at or near the land surface, whereas injection wells are used to replenish groundwater when an aquifer is deep and separated by materials of low permeability (Oaksford, 1985).

Direct surface techniques are among the simplest, oldest and most widely applied methods of artificial recharge. Surface spreading of polluted water has been practised for more than a century in European countries. Major surface recharge operations have also been carried out for several decades using impounded stormwater or imported waters in California. The use of treated waste water has considerable appeal because of its constant assured flow and reasonable consistent quality (Mathew *et al*, 1982).

Recharge or spreading basins are frequently used to recharge unconfined aquifers, especially where land costs are high. Basins are advantageous in that a substantial hydraulic head can be maintained in order to increase the infiltration rate. Recharge basins concentrate a large volume of infiltrating water in a small area. As a result, a ground-water mound forms beneath the basin (Figure 8.4). As the recharge starts, the mound begins to grow; when the recharge ceases, the mound decays and the water spreads through the aquifer. The infiltration capacity of recharge basins is initially high and then declines as recharge progresses. This is due to surface clogging by fine sediments and biological growths in the uppermost few inches of soil. It has been found that the operation of recharge basins with alternate flooding and drying-out periods will maintain the best infiltration rates (Fetter, 1988).

When hydrogeologic conditions permit groundwater recharge with surface infiltration facilities, considerable water quality improvement can be obtained by the movement of the wastewater through the soil, vadose zone, and aquifer. Surface spreading is also considered to be more preferable to injection because clogging is more easily remedied.

Where aquifers are confined or semi-confined by overlying clays, recharge ponds and channels are ineffective and injection wells are required to achieve economical recharge rates. In these systems, injection of water may have a rapid influence on piezometric pressures for a radius of several kilometres and the aquifer provides storage and pressure transmission. In such aquifers, groundwater protection normally provided by the confining layer is breached by the injection well, and groundwater quality protection becomes a major responsibility for the operator of the facility (Dillon *et al*, 1994).

While large volumes of water can often be stored in aquifers at far lower costs than reservoirs or tanks, economics is a key constraint to artificial recharge along with site geological conditions. Surface recharge is by far the least cost approach, and the resulting soil-aquifer treatment costs have been found to be less than 40% of the costs of equivalent in-plant treatment (Bouwer *et al*, 1990; Bouwer, 1991). Recharge can be disadvantaged by the land costs for surface or pit recharge, and the energy, operation and capital costs for injection wells (Helweg, 1985).

The costs of using injection wells are associated with (i) well establishment, (ii) the cost of recharge water, (iii) water distribution or conveyance systems, and (iv) operation and maintenance costs (Harpaz, 1971). Dual purpose or injection-and-recovery wells have an economic advantage over purely injection wells, and generally have a longer life because the problem of clogging can be addressed more efficiently.

8.5.4. Water Quality Requirements and Treatment for Recharge

The quality of recharge water is a primary concern. Unless a water source (such as a local river or imported water) of high quality is used for aquifer recharge, the injectant (usually a wastewater) can require significant treatment prior to use. A high degree of treatment is usually required prior to recharge, often with the objective of approaching a drinking water quality (Treweek, 1985). In the USA, all water to be recharged must comply with USEPA drinking water standards or similar criteria, and detailed suites of analysis are required. In Switzerland, however, only a few water quality parameters need be monitored, however strict standards must be met (Dillon *et al*, 1994).

The main concerns governing the acceptability of groundwater recharge projects are that adverse health effects could result from the introduction of pathogens or toxic chemicals into groundwater that is consumed by the public. Extreme caution is warranted because of the difficulty in restoring a groundwater basin once it is contaminated (Asano, 1993).

The wastewater treatment requirements are therefore designed to provide assurance that reclaimed water is essentially pathogen-free prior to extraction from the groundwater.

Wastewater should be pretreated to the extent that its addition to the groundwater system will not degrade this water source with respect to its potential uses. To prevent clogging of the aquifer around an injection well, all suspended solids, BOD and micro-organisms should be removed from the water. Chlorination of waters for recharge has been a long standing recommendation, although concern has been raised about the formation of disinfection byproducts (Bouwer, 1996). Singer *et al* (1993) have shown that disinfection byproducts can be biodegraded in the aquifer, so that chlorination or other disinfection may not be objectionable.

It is preferable to reserve recharged groundwater derived from reclaimed wastewater for uses where water quality requirements are less stringent, such as irrigation. Water reclamation for groundwater recharge where potable use is envisaged usually entails further treatment following conventional secondary treatment (Roberts, 1980).

Effluent that is surface spread, generally only receives secondary biological treatment. Those facilities that provide effluent for groundwater injection include primary, secondary, and full tertiary treatment, invariably including filtration, air stripping, and granular-activated carbon adsorption prior to injection (Treweek, 1985). These processes are illustrated in Figures 8.5 and 8.6.

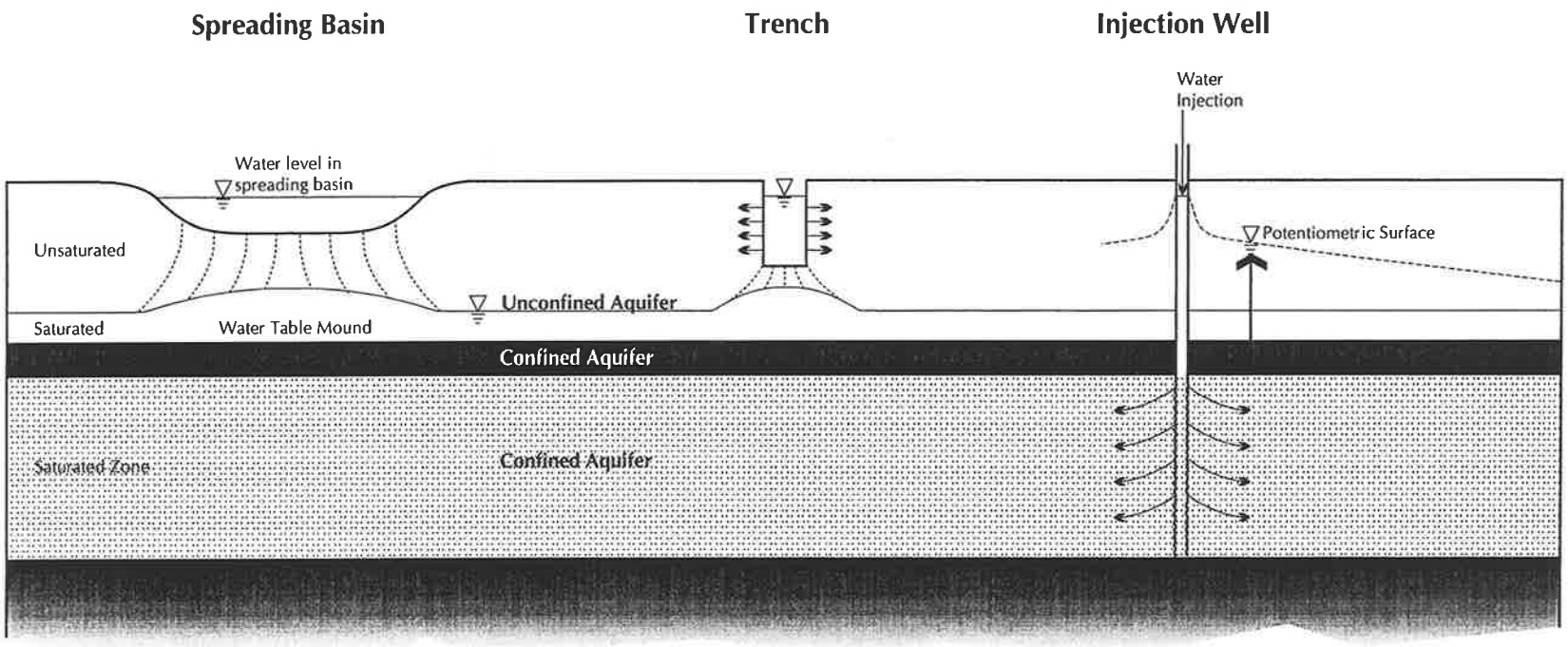


Figure 8.4
Methods of Artificial Recharge

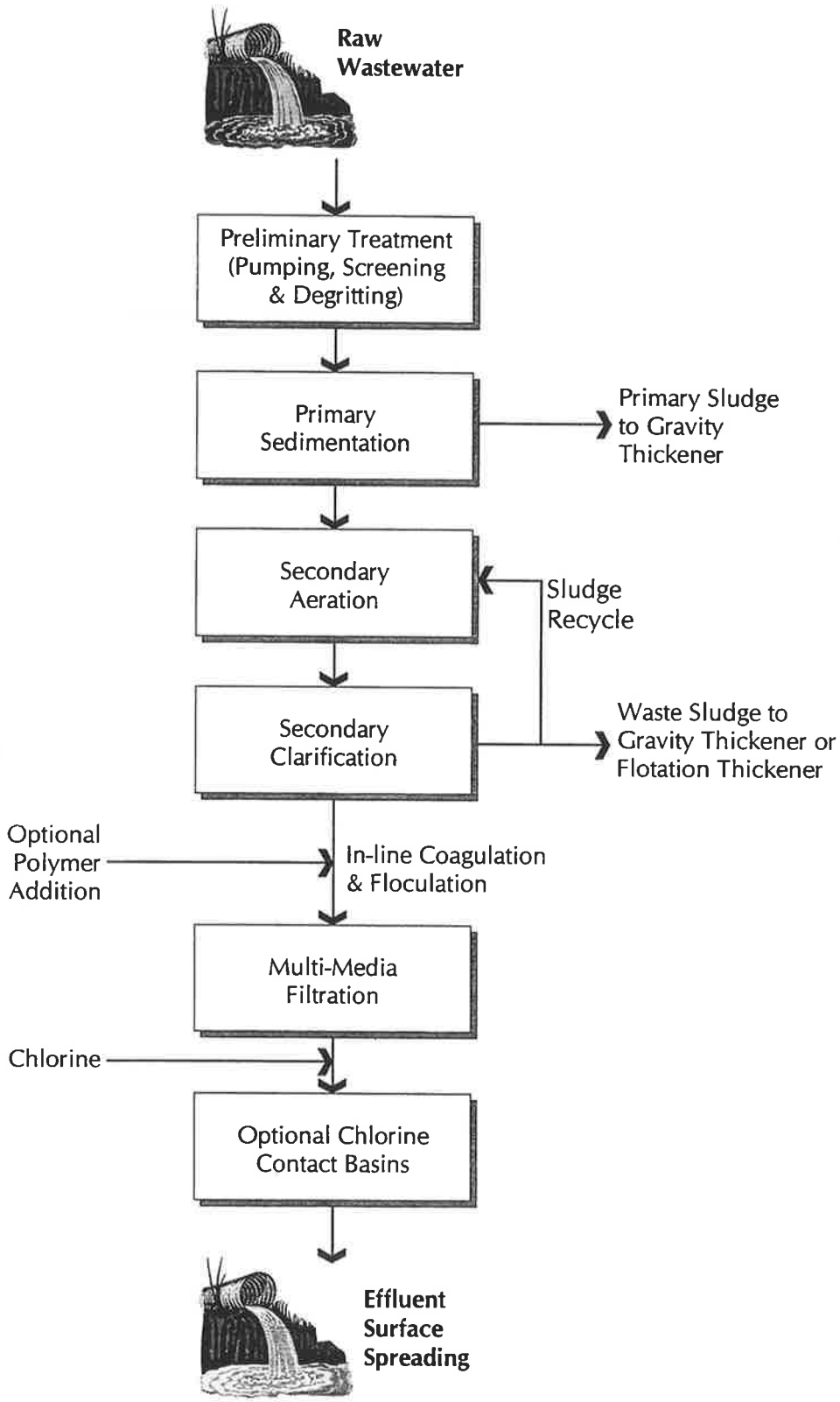


Figure 8.5

Typical Process for Treating Raw Wastewater Prior to Surface Spreading for Aquifer Recharge

(After Treweek, 1985)

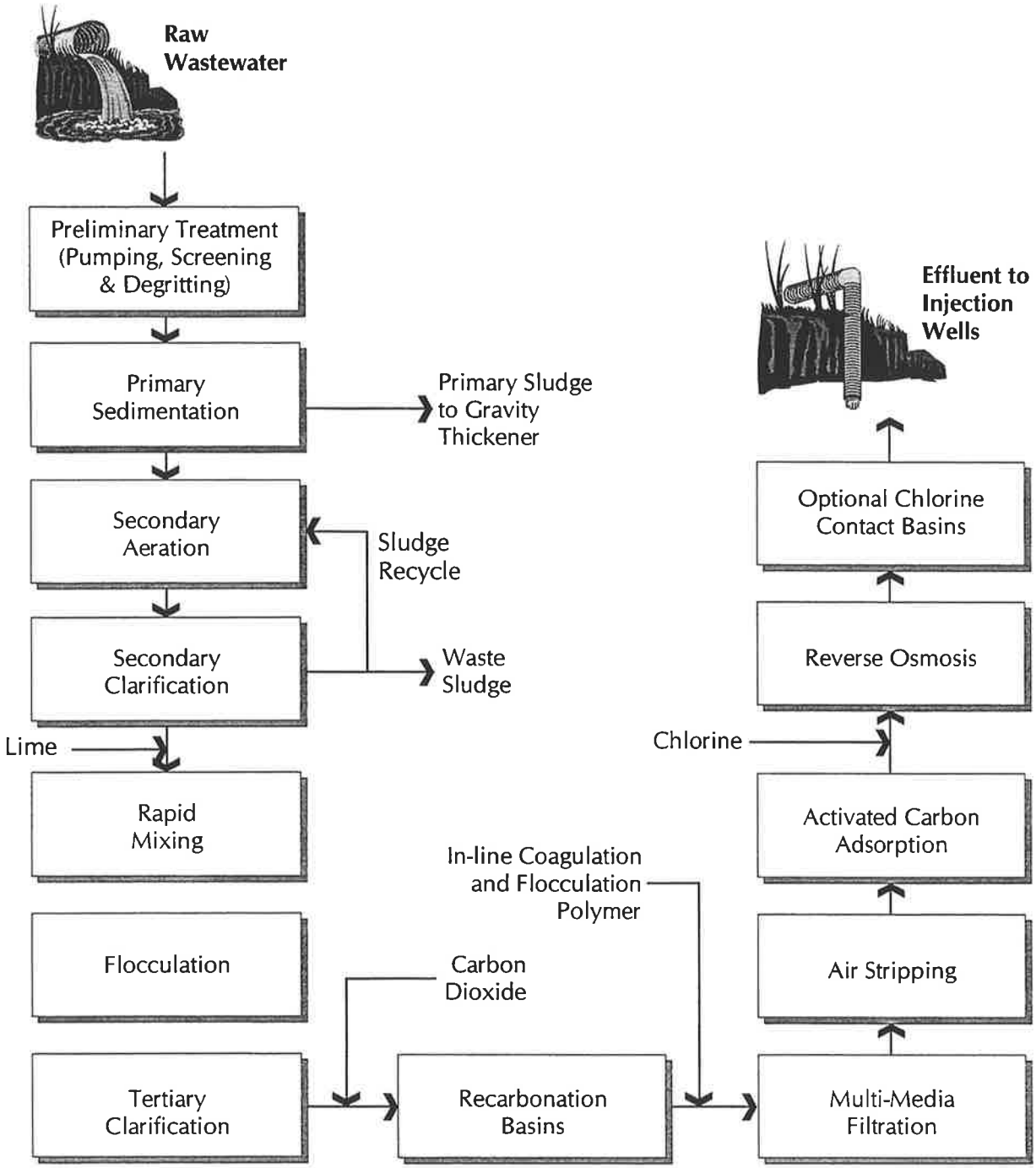


Figure 8.6

Typical Process for Treating Raw Wastewater Prior to Well Injection for Aquifer Recharge

(After Treweek, 1985)

8.5.5. Experience with Recharge Around the World

The use of wastewater for aquifer recharge is reported in the United States as early as 1948 (Johnson, 1948), where spent water from air conditioners was returned to the aquifer via several hundred injection wells. More recent aquifer recharge projects in the US have made use of treated wastewater (see Oberdorfer & Peterson, 1985; Guyon & Welch, 1990). Dillon *et al* (1994) report that aquifer injection using water and treated wastewater is now operating in many other parts of the world, including Israel, the Netherlands, England, Germany, Switzerland, Thailand and Australia.

Underground water storage has been an integral part of Israel's national water supply system for many years (Harpaz, 1971). Part of the artificial recharge is connected with flood water utilisation and wastewater reclamation. However, the majority of the recharge operations were directed towards replenishing over-exploited aquifers, preventing seawater intrusion, and seasonal and perennial water storage. Surface storage was found to be unsuitable, and when water of drinking quality is used for recharge, well injection was preferred over surface spreading (Rebhun & Schwarz, 1968). Well injection recharge is most widely practised, and the majority of wells are dual purpose, with recharge typically occurring over a 100-150 day period during the winter when water is not required for irrigation (Harpaz, 1971).

8.5.6. Australian Experience with Aquifer Recharge

While the term Aquifer Storage and Recovery (ASR) is currently in vogue in Australia and is generating a great deal of interest with water resource users and managers (Sibenaler, 1996). The use of wells or basins for groundwater recharge is not new though. Stormwater has been drained via bores to the karstic aquifer underlying, and providing water supply to, the city of Mt Gambier in South Australia for over 100 years (Telfer, 1994). There is also substantial experience in artificial recharge through land spreading in areas such as the Burdekin Delta in Queensland. Australian efforts in ASR are in their infancy, however, with only 6 studies identified in Australia, 5 of which are occurring in South Australia (Dillon & Pavelic, 1995).

The town of Newman, Western Australia, and mining operations of Mt Newman Mining Co. Pty Ltd are solely dependent upon groundwater for industrial and municipal needs. The forecast water demand is 12,000 ML per annum, which compares with the long-term safe yield of the aquifers of only 3,000 ML per annum. The continuing overdraft on the unconfined alluvial aquifers resulted in a long term commitment to rectify and re-establish the water balance by construction of a dam and recharge facilities. Four excavated recharge ponds, two river basins and an open earth canal are used for recharge. The recharge water quality is superior to the water extracted from the production bores; results have shown substantial improvements in water quality in many of the bores, particularly those closest to the recharge facilities. These facilities are expected to meet the long-term water requirement, with in excess of 7,000 ML to be recharged to the aquifer each year (Clark & Kneeshaw, 1983).

The city of Perth in Western Australia is also highly dependent upon groundwater resources to meet in excess of 60 percent of total water demand. With increasing pressures upon the quality and availability of the resource, aquifer storage and recovery technologies are an element of the strategy to remedy this situation. Stormwater and treated wastewater will be both injected to aquifers and used as a substitute for potable water, thereby relieving some of the pressure upon the regional aquifer systems (WAWA, 1987). Sewer mining for ASR is also being considered (SKM, 1996).

In South Australia, approximately 25,000 ML is pumped annually from the Angas-Bremer confined aquifer to irrigate a variety of crops. The extraction exceeded the rate of natural replenishment, and therefore a cone of depression resulted which did not disappear each winter. While depletion of the groundwater was not considered to be a problem, the reduced flushing of salts combined with the lateral inflow of saline water was resulting in the deterioration of the groundwater quality. Artificial recharge of the aquifer using River Murray water or flows from the Angas or Bremer rivers was therefore proposed (Cobb & Beal, 1987). Gravity infiltration bores were initially constructed, although many injection bores are now used. From the mid 1980s to early 1990s, recharge volumes increased from 400 ML/a to over 1,200 ML/a through about 25 bores (Sibenaler, 1996). This recharge program has restored the quality and availability of an important water resource.

Elsewhere in South Australia, and particularly since the early 1990s, aquifer storage and recovery has experienced a revival, with numerous ASR systems either operational, under trial or proposed for implementation (refer to Table 8.9 and Figure 8.7). To identify the potential for implementation of further ASR schemes, maps have been prepared illustrating areas within metropolitan Adelaide that area suitable for implementation of ASR.

Table 8.9
Summary of Aquifer Injection Operations in South Australia (Sibenaler, 1996)

Site	Aquifer Type[1]	Salinity, mg/L	Source of Water	No. of Recharge Wells	Bore Recharge Rate, l/s[2]	Annual Recharge Volume, ML
Mt Gambier	TL		Stormwater	300		
Andrews Farm, Adelaide	TLC	2,200	Stormwater	1	20 (G)	100
Greenfields, Adelaide	TLC	2,100	Stormwater	1	10-15 (G)	100
The Paddocks, Adelaide	TLC	1,900	Stormwater	1	8 (I)	75
Angas Bremer	TLC	<3,000	River flow	30	5-40 (G)	1,000
Clayton	TLC	30,000	River flow	1	40 (I)	70
Northfield, Adelaide	FR	2,500	Stormwater	1	10-15 (G)	40
Torrens Park (Scotch College), Adelaide	FR	2,100	River flow	1	15 (G)	40
'Mawson Lakes, Adelaide (proposed)	TLC	2,200	Stormwater	1	20 (I)	

(1) TL-C: Tertiary limestone - confined; FR: fractured rock
(2) G: gravity feed, I: injection.

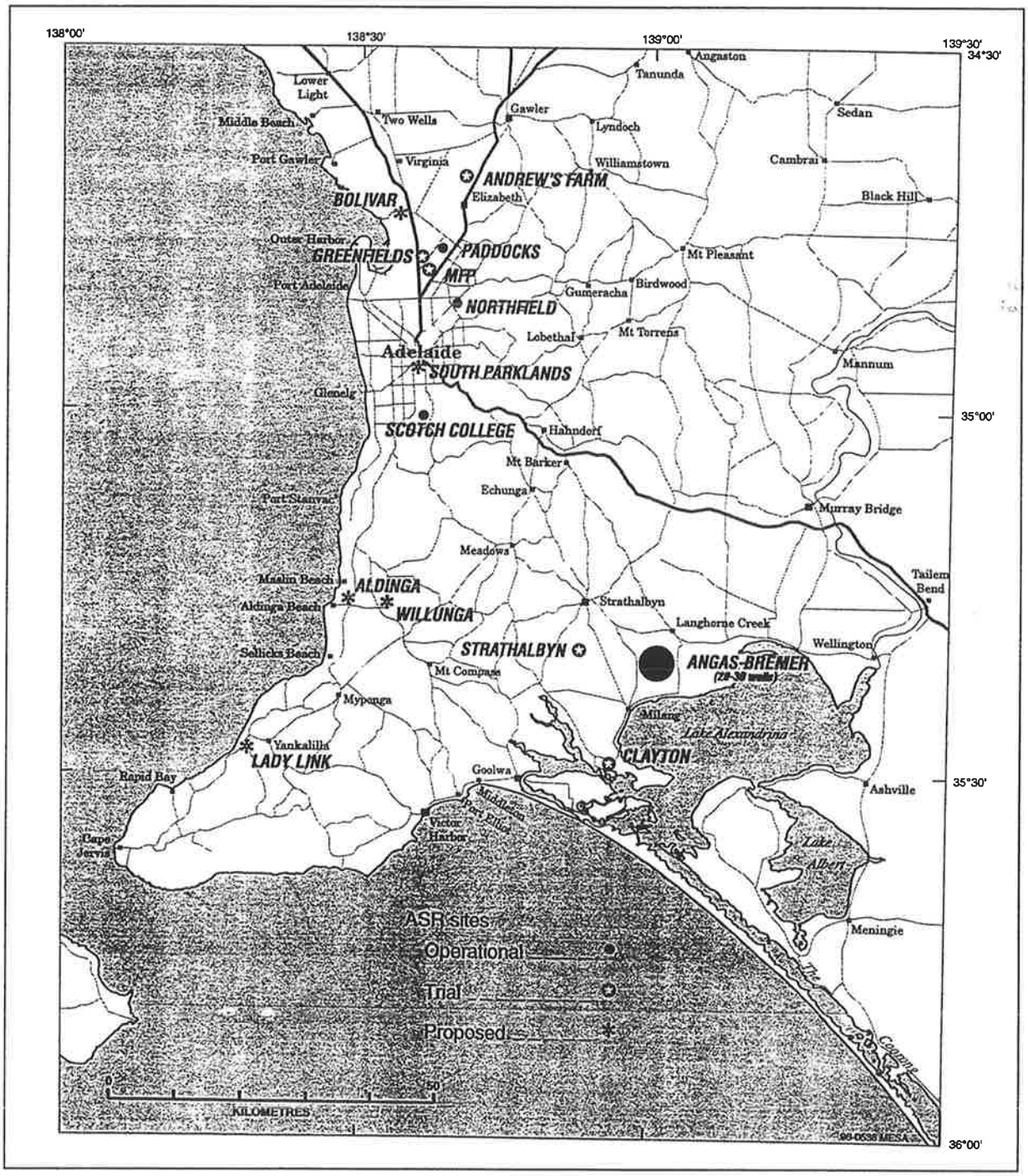


Figure 8.7
Aquifer Storage and Recovery Sites in the Adelaide Region (after Sibenaler, 1996)

Pavelic *et al* (1992) prepared ASR suitability maps for around 530 km² of metropolitan Adelaide, based upon the suitability of the upper Quaternary groundwater system for storage and reuse of stormwater runoff (Figure 8.8). The hydrogeological parameters identified to be critical included groundwater salinity, bore yield and depth to watertable. It was shown that the groundwaters of the upper Quaternary aquifer provide an abundant and accessible non-potable water resource, capable of meeting at least one third of the garden irrigation demand in the metropolitan area. The maximum storage capacity of the Quaternary aquifer was estimated to be 50,000 ML, with the capacity to store a further 2,000 ML above the existing water table. Caution should be exercised, however, given Adelaide's heavy and expansive clay soils. Excessive recharge could cause soil swelling, cracking and salt damp in houses, and flooding. Excessive dewatering may also have implications for land subsidence.

The viability of groundwater recharge and reuse using stormwater from residential allotments was examined by Caretti *et al* (1993) for Adelaide's eastern suburbs. It was found that under the 'user-pays' pricing system for mains water introduced to South Australia in 1991, on-site recharge of stormwater was neither economically feasible or environmentally desirable. This position is confirmed by Dillon (1996) who states that the costs of ASR are generally prohibitive for domestic users who are capable of recharging a quantity of water which is in equilibrium with use. It was found by simple economic analysis that break-even periods for domestic scale facilities were likely to exceed 10 years, compared with municipal scale facilities which could be providing a return in around 4 years. An exception to this is coastal dunes where domestic wellpoints could be installed by water jetting which is a very cheap form of well construction. Dillon (1996) concluded that there were ample opportunities to implement ASR facilities at the scale of municipal or large industrial water supplies, where potability standards were not required.

The economics, technical and environmental sustainability of the reuse of wastewater via ASR are yet to be proven. The use of wastewater for recharge has the advantage of a consistent flow and quality when compared to stormwater, although the treatment costs may be higher, particularly if new treatment facilities must be constructed. The injection of treated wastewater for inter-season storage is being considered as part of the Virginia Pipeline Scheme, which involves the distribution of treated effluent from the Bolivar WWTP for horticultural irrigation (refer to Chapter 11). Because of the seasonality of demand for irrigation water and the approximately constant supply of treated effluent, there is a shortfall of supply in summer of 9,500 ML. This shortfall exceeds the predicted sustainable yield of the groundwater system which is already under severe stress. To avoid continuing aquifer stress as the horticultural area becomes fully developed, ASR could be implemented to provide inter-season storage of the excess effluent available during winter. To store the required volume, a system of approximately 50 injection-and-recovery wells operating at a rate of 1.5 ML/day would be required at a capital cost of $4.0 million and an operating cost of $276,000 per annum (KME, 1996).

Perhaps the most significant work in the field of ASR is centred around the Andrews Farm wetland site at Munno Para in the north of metropolitan Adelaide. To date, a major barrier to the storage of reclaimed waters in aquifers via injection wells has been a lack of scientifically based guidelines for the quality of water to be injected.

The trials conducted at this site have been integral in the development of draft guidelines as a first step to providing a sound basis for the injection of non-potable waters into aquifers for a range of beneficial uses. In the process of developing the draft guidelines, Dillon & Pavelic (1995) undertook a review of Australian and international guidelines for the management of groundwater and use of wastewaters; the quality of stormwater; suitable pretreatment processes; the nature of well clogging and methods to overcome it; and the interaction of contaminants with aquifers. The guidelines are unique in that while they adhere to widely accepted scientific and policy principles they are quite different from those adopted elsewhere in the world, as they do not presume potability as an essential objective and allow for treatment of water by natural processes in the aquifer. Having established the theoretical basis for the guidelines, a pilot study was established to evaluate the technical and economic viability and the environmental sustainability of injecting stormwater into a brackish aquifer to create an irrigation water supply. Stormwater from an urban and rural catchment covering 55 km^2 is provided passive pretreatment in a series of 3 detention basins prior to injection into a deep Tertiary aquifer. Clogging by sediments and micro-organisms did occur, but was overcome by periodic redevelopment of the injection well. The pilot study demonstrated that by following the proposed guidelines, an irrigation water supply could be developed from an otherwise unsuitable groundwater source. The extracted water met the relevant national guidelines for irrigation (except for faecal coliforms in isolated instances). The guidelines were finalised and published in July 1996 (Dillon & Pavelic, 1996).

8.6. Conclusions

Historically, water management has had a focus upon water development – building dams, channels, pipelines and treatment plants – to supply water wherever and in whatever amount was demanded. However, the changing realities of today's world are forcing the emergence of new water management strategies that that place greater emphasis on demand management and recycling than the historical orientation toward source development.

In arid regions or where the cost of developing new water sources is prohibitive, water authorities have recognised the value and potential of water conservation programs and have implemented pricing policies and aided retrofitting of domestic appliances to reduce water consumption. Elsewhere, the adoption of water conservation strategies has been slower. This is often due to the large investments of water authorities in water supply infrastructure, and their vested interest in selling water from the existing reservoirs. This has acted as a strong disincentive for conservation or the development of urban stormwater and wastewater as an urban water resources.

Because residential water consumption normally accounts for a high proportion of urban water use, and due to the nature of domestic use, there is considerable potential for savings through domestic water conservation. However, this potential is often unmatched by the willingness of individuals to utilise water conservation measures. Walski *et al* (1985) report that measures are seldom universally implemented in a region, with only 10 to 25 percent coverage (or less) during non

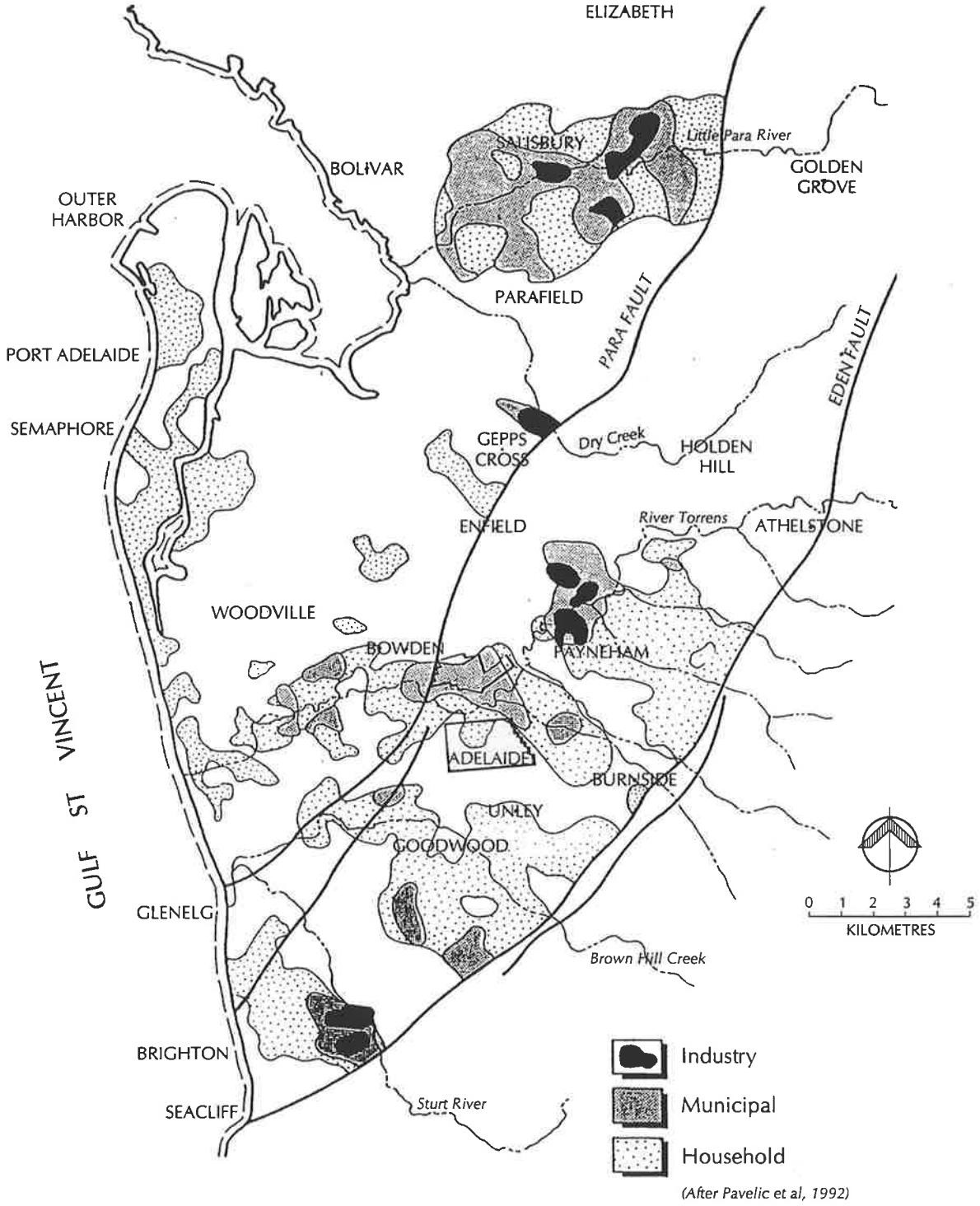


Figure 8.8

Areas Favourable for Stormwater Recharge and Reuse

drought periods, up to around 90 percent during rationing. Some conservation will help delay construction of capital intensive additional capacity, thereby reducing effects on the environment, saving money and giving utilities more time to develop long-term supply plans. However, demand side management and conservation measures alone will not be a replacement for new source development.

Water scarcity must be looked upon in the perspective of opportunities to treat and reuse wastewater (Niemczynowicz, 1992). The capture and reuse of stormwater and wastewaters can be the promising new 'sources' for development. Standards for discharge of wastewater are becoming increasingly stringent, while fresh water resources are becoming increasingly stressed. Treatment for reuse may well be more economical than treatment for disposal, and is highly attractive where a high degree of treatment needs to be provided for pollution control. Furthermore, the additional cost of reclamation facilities and dual distribution systems for new urban areas will often be less costly than constructing facilities for bringing in additional freshwater sources.

Aquifer storage and recovery (ASR) technologies can also form a large part of the solution to the water treatment and supply problem. Experience has shown that the use of aquifers for water storage has many benefits. There are no construction costs for a large storage capacity that is not subject to evaporation losses, and the aquifer can be the distribution system for the water, providing additional treatment in the process. There is a considerable body of knowledge relating to the use of spreading basins and trenches for recharge of water table aquifers. By comparison, aquifer storage and recovery using injection wells is in its infancy. However, work to date suggests that both forms of recharge have a promising future as wastewater and stormwater reuse schemes flourish.

In the future, it is possible that the most economic and environmentally effective water management strategy for urban centres will involve potable reuse of wastewater. At the present, there is only one documented case of wastewater reclamation for direct potable water use; this operates in Windhoek, the capital of Namibia. While it seems that general acceptance of potable reuse by the public is some way off, there is growing interest in potable reuse of wastewater.

Law (1997) considers that there are many environmental, economic and health reasons why we should now move on from the dual water systems and seriously consider and plan for the implementation of potable reuse. A greater saving in potable water would be expected if potable reuse were practised – and any reclaimed water that is discharged to the environment would be of a superior quality.

Recent developments in membrane technology and a greater understanding of appropriate technologies look like driving down the cost of producing reclaimed water that is suitable for potable reuse, be it for indirect or direct purposes. MacCormick & Johnson (1996) predict that in Australia, the incremental cost of treating a secondary quality effluent to a potable quality reclaimed water could drop to some 54 ¢/kL by the turn of the century, making it very competitive with the price of potable water. It is also noted that as effluent discharge requirements become

more stringent, the difference between the quality for discharge and that for potable reuse will reduce, which in turn will reduce the costs of potable reuse.

There has already been an example in Australia where the cost of potable reuse was similar to that of a dual supply system – this was the case at Rouse Hill near Sydney. It was shown that implementing potable reuse would have been comparable with the cost of the domestic non-potable reuse scheme (Law, 1993) and that in the long term potable reuse is likely to be less costly than non-potable reuse (Anderson, 1995).

Technology does not pose a constraint to greater reuse of stormwater and wastewater, and the economics of reuse are rapidly becoming favourable. It remains to be seen how quickly the public and perhaps more importantly, the politicians and water managers, are prepared to implement more advanced, integrated water strategies.

9

Redirecting Urban Development for Sustainability

9.1. Our Current Cities Are Unsustainable

Currently, about 40 percent of the world's people live in urban areas (WRI, 1990), and urban populations are growing rapidly, predominantly in the developing countries in Asia, Africa and Latin America. Rural towns are growing very slowly, if at all, thereby intensifying the need for basic services and infrastructure in large urban areas. By the turn of the century nearly half the world's population will live in urban areas (WCED, 1987).

While cities offer great opportunity for economic development, technological innovation, social and cultural interaction, and advanced learning, it is an unfortunate fact that cities in their present form are causing serious and un-necessary destruction of the natural ecosystems that support all life on Earth.

Cities are often characterised by sprawling residential suburbs that reinforce a high dependency on the car for transit. Extensive and complicated water, sewerage, electricity, transport and communication systems are required to service these vast areas. Pollution, social disintegration and increasing problems of infrastructure maintenance are symptoms of this urban form. The mounting environmental crises present a challenge for innovation in the design, development and management of infrastructure. There is now increasing recognition that conventional patterns of urban development are leading to environmental, and ultimately economic and social, destruction if changes are not made.

Many of the changes that are required to pursue more sustainable living must occur in our political and economic systems. There is also a need to develop new technologies and practices for urban development. Developed countries have a clear role to play in this regard. The industrialised nations typically set the standard to which the less developed countries aspire. Therefore, the industrialised countries need to establish new models for sustainable living, and provide assistance to developing countries to identify urban patterns appropriate to their own environments. The way our urban areas develop and re-develop will determine whether environmental challenges are met and progress is made toward more sustainable lifestyles.

9.2. The Australian Urban Form

Australia is no less vulnerable to the environmental, economic and social problems typical of cities in other industrialised countries. Although Australia has a very small population per unit area relative to many other nations, the majority of Australians live in large, sprawling and highly urbanised cities.

Indeed, Australia is one of the most urbanised countries in the world. Although an outsider may regard a population in excess of 18.3 million (ABS, 1997) in an area of 7,687,000 km² as representing a low density, it is the way the population is distributed that contributes to the highly urbanised nature. The requirements for flat land, fresh water, closeness to coastal ports, closeness to agriculturally productive land and a defendable position has meant that most of Australia's major urban centres are concentrated along the south-eastern coastline. Around 85 percent of the population now lives in cities, with 63 percent in the major urban centres, in less than 0.1 percent of the total area of Australia (Maher, 1982).

Historically, the development of Australian cities was linked to the patterns of investment that occurred in response to awareness of Australia's rich resource base. The early investment went into the establishment of urban services, particularly roads, drainage and railways. This rapid development contributed significantly to suburban sprawl, as housing followed the tramlines (Young, 1991).

The advent of public transport, principally rail and tramway, and then later automobiles, increased the mobility of the population. Employees were able (and eventually forced by economic circumstances) to live further from their place of work. This increased mobility coupled with the assumption of endless, cheap energy and land, meant communities grew unchecked and inefficiently, and have become dependent upon lengthy distribution systems. The wealthier classes could indulge their desire for detached housing on large blocks of land while maintaining close links with the city core. The less affluent would move further afield to construct the family home on the 'quarter acre block', fostering an addiction to the car and increasing the separation of homes from workplaces.

In more recent years, the majority of new households have been formed either by young people leaving the parental home or by arriving immigrants. Both the rate of household formation and size of households is decreasing. During the period 1947 to 1986, the average number of persons per dwelling dropped from 3.87 to 2.67 (ABS, 1992). Despite decreasing average household size, there is a trend towards increased dwelling size. If current trends continue, by 2006 almost 50 percent of all households will consist of single persons or childless couples over 35 years. Yet 80 percent of Australia's housing is essentially family style single detached housing (PCA, 1992).

Australian cities are now typically characterised by small city centres – central business districts – surrounded by sprawling, low density suburbs consisting of a high percentage of single detached dwellings. The main city centres generally accommodate commercial, service and some manufacturing industries with little

Table 9.1
Profile of Australian Cities as Characterised by Melbourne
(1981 data; after Newman *et al*, 1992)

Housing Location	Housing & Urban Form Patterns				Transport Patterns (to Work)		
	Urban density, people/ha	Housing density[1]	Employment, jobs/ha	Land use mix	Private car	Public transport	Walking or cycling
CORE AREAS: Old city areas near CBD, heavily commercial with some housing	20 - 60 Avg 35	25 - 45 Avg 37	15 - 75 Avg 40	Very highly mixed, residential sparse in places (extremely self sufficient)	52%	32%	16%
INNER AREAS: loss of industry, some redevelopment occurring, population decline reversing	25 - 40 Avg 32	15 - 25 Avg 19	5 - 20 Avg 11	Highly mixed in some areas; most have some mixture (high degree of self sufficiency)	65%	27%	8%
MIDDLE SUBURBS: ageing, occupancy declining, population declining	15 - 35 Avg 25	10 - 15 Avg 12	5 - 15 Avg 7	Pockets of mixed land use but mostly zoned (low self sufficiency)	73%	21%	6%
OUTER SUBURBS: developed, young families dominant	10 - 20 Avg 14	5 - 15 Avg 10	2 - 7 Avg 4	Virtually no mix, highly zoned (little self sufficiency)	79%	16%	5%
FRINGE AREAS: to be developed, opposition from semi-rural inhabitants and environmentalists	5 - 15 Avg 8	3 - 10 Avg 5	1 - 5 Avg 2	Rural and some urban mixtures (some self sufficiency)	84%	9%	7% - 18%

(1) Housing density is gross residential dwelling density per hectare (i.e. includes most roads)

mix in land use and pockets of residential development (Manning, 1978). Major residential areas and retail outlets are spread throughout the surrounding suburbs.

Australia's urban form has therefore become, and *could* continue to be, dominated by high concentrations of people in metropolitan cities, but at a very low density.

This postwar pattern of development involving continual, unchecked growth 'at the fringe' of a city should be scrutinised. Urban sprawl has costs in environmental, economic and social terms, most notably in the pollution generated by private vehicles, the costs of delivering sewerage and water, and access to services. Governments are finding an increasing gap between the amount of money they can direct towards the extension of suburban infrastructure and the amount of investment required. Land is also recognised as a finite resource and supplies in desirable and accessible locations can no longer be guaranteed.

There are many other problems associated with urban sprawl, characteristic not only to Australian cities, which include:

- Transport systems are inefficient and costly to operate. Our needs for transportation arise directly from the way that land is used in our communities. The low density of population means that there is a dependence on the automobile and reluctance or inability to use a public transport system that struggles to deliver an adequate service to all areas of the city.

- High dependency upon the automobile and high per capita emissions, resulting in related problems including the formation of smog; generation of greenhouse gases; traffic congestion; pollution of stormwater; and high fuel consumption.

- The high cost of providing physical infrastructure (utilities, pipes, transmission lines, roads), particularly incremental additions at the fringe of cities. Governments are faced with the enormous problem of paying for maintenance and upgrading of existing infrastructure, let alone new construction or extension of existing facilities.

- High social infrastructure costs, as cars are often required for participation in social life. There is social isolation and clustering of disadvantaged groups. Also, because of the highly dispersed nature of the population, there is often a lack of community, with women and youth being most disadvantaged. Research shows that one of the most frustrated population groups in low density suburbia is adolescents. Getting together with friends and going shopping are made difficult by the paucity of public transport, the separation of housing from retail areas, and the large distances of separation. Consequently, teenagers become bored and are more often involved in anti-social behaviour (Cooper-Marcus & Sarkissian, 1986).

- Lack of community services. The provision of community services often lags behind residential development, and often in areas where the services are most needed.

- Generally inefficient use of building materials and other resources. Spacious family homes are of typically low thermal and energy efficiency. Energy consumption for domestic heating is high due to the lack of a shared insulating effect when buildings are grouped. Energy usage and thus consumption costs are high. Per capita consumption of highly treated water is also very high, much of it used in maintaining large lawn areas or for toilet flushing (neither of which require water of drinking quality), with minimal incentives through government pricing schemes or other measures to save water.

- Degradation of water resources. Waterways and marine ecosystems are damaged by polluted stormwater carrying contaminants from road surfaces, sewer overflows, fertilisers from lawns, and so on. Groundwater is also often polluted beneath industrial sites, or is being used unsustainably for irrigation or industrial applications.

- Poor recycling rates due to the large cost involved in collection compared to a compact housing system (European cities have 4 to 6 times the recycling rates of North America).

- Loss of most productive agricultural land and valuable habitat, ecosystems and biodiversity. Land use planning and management regulations often ignore the agricultural and productive value of areas of land. Low density development and the associated high land requirements in both the block size and the road system required to service it quickly consume large areas. (Road provision is much greater in low density areas than in medium density areas.)

- Negative impacts upon economic activity and employment. Low development density also makes it difficult for local shops to have sufficient population within walking distance of houses, with the result that the shops cluster on road intersections or on major roads and then need to be reached by car (UDTF, 1994).

Urban consolidation has been suggested as a potential solution to the problems of sprawl. Urban consolidation can be thought of as comprising: redevelopment of previous industrial sites for housing infill development; and new housing subdivisions adopting smaller lot sizes (Hillier, Yiftachel & Bentham, 1991). It has received attention in Australia since the late 1970s, but there has been little forthcoming in the way of a coordinated response or national position on the issue.

The question is whether the main objectives which urban consolidation is meant to achieve are best met by striving to achieve arbitrary definitions of spatial densities, or by improving on the present system of urban expansion through the incorporation of environmental and social costs in prices and charges.

By charging less than the full cost of servicing new land, governments have subsidised the provision of residential land, on the fringe on the justification that it is delivering a social good. However, changing these strategies raises serious questions, including that of equity. Making consumers pay the full cost of "greenfield" developments (raw land development at the fringe) could:

- send the 'right message' and cause a reduction in demand for fringe land; or
- send people further afield seeking even cheaper sources of land for development.

Although the cost of new infrastructure provision is increasingly being recouped on a user pays/cost recovery basis, the costs of subsequent use and maintenance of services is generally still charged to consumers on the basis of average property values. The need for infrastructure arises from population growth and per capita consumption. Better demand management can reduce consumption, extend the life of existing assets and reduce the costs to fringe buyers by deferring the need to augment existing infrastructure. It is even possible that reductions in consumption by existing users will result in savings to new users.

However there are many conflicting views as to the benefits of higher urban densities, for two main reasons:

- unlike most other countries, Australia does not have a definite, strong, national urban and regional strategy, and
- there is no adequate collection of research data on which to base significant analysis.

Troy (1992) has suggested that there are inequities and inefficiencies in the way we presently order and service our cities, and although we might be able to agree that we generate unacceptable environmental stresses in the way we behave in them, that is not a *prime facie* reason for changing the whole system.

Urban consolidation is therefore not a panacea for urban problems. While it is true that more compact cities will offer environmental benefits, the evidence does not suggest that the current approach to urban consolidation will succeed in containing cities. Nor will it produce a shift from private to public transport – this depends upon a number of variables, not just the price and accessibility of a service. Many urban inefficiencies arise from inappropriate pricing policies, and their reform offers the prospect for great efficiency gains.

What is important is the recognition that there needs to be significant changes in the design and administration of urban areas. Urban consolidation does not provide the whole answer because it does not alter the basic fabric of the city. Instead, the density of population is increased in small pockets with benefits often limited many respects. Indeed, it has been suggested that current policies of urban consolidation in Australia have failed; uninspiring unit and town house developments, often ill-matched with the surrounding street-scapes, have simply reinforced community resistance to denser living (Newman, Kenworthy & Robinson, 1992).

Nevertheless, while there are differing views on the benefits of urban consolidation, it does appear to be widely accepted that a more condensed urban form is inherently more efficient and environmentally benign, particularly in the provision of services and housing. Indeed, governments are now advocating density levels higher than the previously accepted standard of 8-10 dwellings per hectare, in all suburbs from core to fringe.

Only very recently have some more bold and positive initiatives occurred in the area of residential development. The Australian Urban Design Task Force (UDTF, 1994) have observed promising developments in water and liquid waste management, that point towards the evolution of more self sufficient sub-regional supply and treatment systems. These changes, like new work patterns, appear to be sympathetic to emerging ideas about the evolution of urban and regional 'village' networks within Australian metropolitan areas. New Haven Village in Adelaide, South Australia, and more significantly Rouse Hill in Sydney, New South Wales are two examples of more integrated urban planning, development and management.

9.3. Principles for Developing an Adaptable and Enduring City

Over the centuries, there have been many ideas and examples of the development of new towns. Most have been aimed at solving a variety of problems associated with city life. But none of these experiments or utopias seemed to have had a major lasting influence on urban development. Ashworth (1954) suggests this is because they tended to focus too much on single aspects of new town development, particularly where they were based on a single industry and were vulnerable to trade shifts. All new plans were confronted by "... the hard, impenetrable and unclimbable wall called - *will it pay?*".

The issues of economics were amply discussed by Ebenezer Howard in his book *Tomorrow: A Peaceful Path to Real Reform*, first published in 1898. With further evidence and argument in favour of his proposed 'garden city', Howard published a second, revised edition in 1902 entitled *Garden Cities of Tomorrow*. The book was mainly about urban economics, estate management, and theories of urban growth. Howard suggested that instead of thinking in terms of a polarisation of town and country, there should be a merger between the two, to create a 'town-country' element which possessed the advantages of both and the disadvantages of neither. His arguments are summarised in the diagram representing the three magnets in Figure 9.1 (Thomas & Cresswell, 1973). The major features emphasised in Howard's proposal were:

- The town would be built on agricultural land acquired at low cost.
- Ownership of the estate would be held in trust by 'gentlemen of undoubted probity and honour', and land rents would cover the expenses of town operation.
- The town itself would have a population of 30,000. It would have a good variety of employment and a full range of public facilities and buildings.
- The town estate would have associated agricultural activities – including large farms, smallholdings, allotments, cow pastures – which would utilise the refuse of the town, and which would have a population of about 2,000.
- The process of growth would be by establishing another new town next to the original new town and directly connected by rail and road (see Figure 9.2).

While Ebenezer Howard's ideal of combining the best of the urban with the best of the rural has never been realised, it seems that modern technologies are opening the real possibilities toward some form of 'garden city' that is relevant to the needs of today and tomorrow.

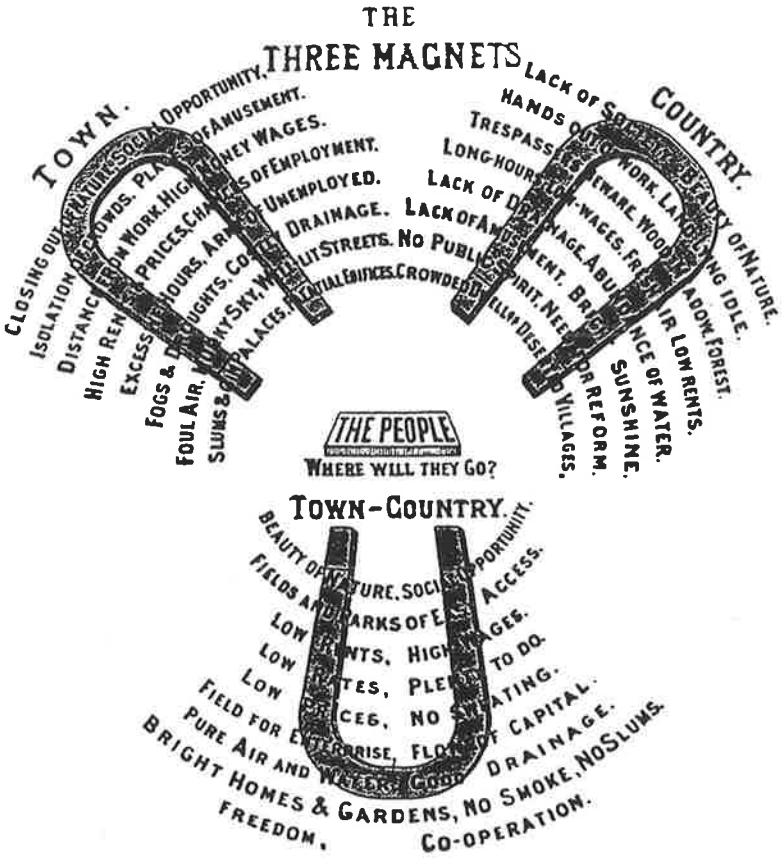


Figure 9.1 Howard's Three Magnets (Thomas & Cresswell, 1973)

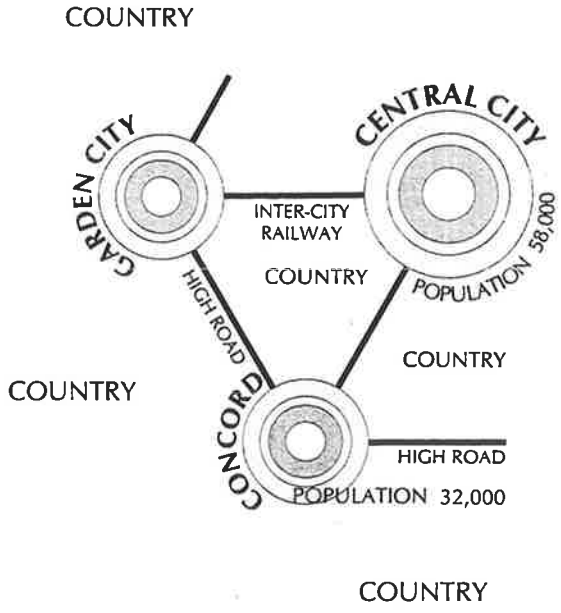


Figure 9.2 Howard's Principles of City Growth
(Thomas & Cresswell, 1973)

Miller *et al* (1972) envisage that the dwelling of the future as the nerve centre of daily life. Business, education, shopping and entertainment, as well as participation in community decision making and voting, would be possible from the home. But such a capability, together with economical home energy and waste utilities, raises serious questions about the need for social distance and the need for proximity to municipal pipelines and wires of various kinds.

According to Miller *et al* (1972), modern technology could provide two, quite opposite scenarios of how people would be able to live. One scenario is described as 'nature first', where the new community would be developed at a very low dwelling density to maximise interaction with the natural environment as well as privacy, with transportation networks being a secondary consideration. While there would be some activities within walking distance, there would be a strong centralised activity centre that is highly urban providing the majority of commercial, public and retail services. Access from the home to the outside world would be made using modern communications or cars.

The second scenario is of the 'urban city'. These are places where 'the action is', where residents value close social proximity. Agglomeration patterns of the dwellings are dense and complex. Individual dwellings themselves have a high degree of privacy and amenity, including small quiet gardens, but can be grouped so that some common element is shared by several dwellings for living arrangements. Stepping out of the dwelling one is in the midst of urban activity and the excitement of the city. The zoning is multi-use so that there are layered zones of activity that cover the site. Servicing this configuration are networks of utility channels that are grouped in horizontal and vertical utility tubes and in some places physically integrated with the automated transportation guideways. Every dwelling is in easy walking distance of an activity centre that contains most of the services used on a daily or weekly basis. This is a sensual city; the touches, sounds and smells unique to cities are experienced from walking to home or activities.

It seems that somewhere in the middle of these scenarios, or a suitable combination of them, lies contemporary suburbia. Yet for either or both of these prototype communities to occur, highly efficient and responsive public service systems are required. This condition, in turn, requires an uncommon degree of entrepreneurial management and design skills, as well as a high degree of commitment from both public and private participants in the community development process. Whatever the case, it is clear that for sustainable development to occur, a new set of urban design principles must be adopted, where the natural environment becomes an important and integral component of the urban fabric.

Good urban design is essential to creating settlements that minimise environmental damage. The key is to design *practical* urban spaces, where White (1994) considers practicality means an urban form that is in tune with nature. Therefore, principles to guide development, to make it more sustainable, include:

- Implement policies and practices to ensure integrated natural resource management.
- Eliminate the pollution of air, water and soils, and remediate existing problems.
- Encourage greater use of renewable energy sources.

- Develop closed loop or minimal waste production processes, and maximise recycling and reuse.
- Develop and adopt appropriate technologies, ensuring flexible and with recyclable materials.
- Ensure a more efficient distribution of the population for housing and employment.
- Provide improved and more accessible education and social welfare services.
- Provide more freedom and diversity of choice.

Newman (1990) considers that social organisation for sustainability will need to reverse the settlement pattern of the recent era, that of low density suburbs. Cities should be made more urban and the countryside more rural. This can be accomplished by re-urbanising city centres and sub-centres, re-orienting transport infrastructure away from the automobile, and providing a more community oriented urban culture, assisted by attractive urban design. City centres should be redeveloped, encouraging greater density through multiple unit residential developments; integrating work, residence and shopping in mixed used development, and by encouraging residential clustering (FCM, 1990). The countryside can be made more rural by means such as protecting and encouraging sustainable agriculture in rural areas, and adopting the catchment area as a whole in management initiatives.

The City of San Jose (1991) in California has adopted a number of initiatives for planning or redevelopment of urban areas:

- Planning, implementation and operation of energy efficient infrastructure for major water, wastewater and solid waste management systems.
- Regulation of energy use through local land use policies that effect the patterns of residential, commercial and industrial development.
- Stringent enforcement of the energy efficiency standards of building codes.
- Establishment of energy efficiency programs (such as climate control systems and appliance efficiency) aimed at various community sectors.
- Education of local residents and businesses by providing information on energy efficient technologies, service providers, and financing opportunities.
- Adoption of site standards for renewable and alternative energy resources.
- Use of renewable resources such as solar, geothermal, hydroelectric, biomass, and wind at City owned facilities.
- Encouragement and assistance in the development and implementation of energy policies and programs by utilities and other levels of government.

While there has been little debate over whether the consumption of fossil fuels is a poor use of the resources, it is clear that use of fossil fuels by existing technologies (such as coal in power plants, and petrol in automobiles) is having a serious and adverse effect upon the environment. It is therefore desirable to minimise the use of fossil fuels through programs to reduce automobile dependency, and adoption of energy efficient design and appliances in building construction.

In order to reduce reliance upon the automobile, attractive options must be provided for movement and transit, and easy access to services and facilities. That is, mass transit should be more easy and movement less necessary. Figure 9.3

illustrates the potential of more compact cities to reduce petrol consumption. Australia must make the choice of whether to continue to follow the American example of suburban sprawl and high energy use, or plan for higher density cities that may tend to follow the European style.

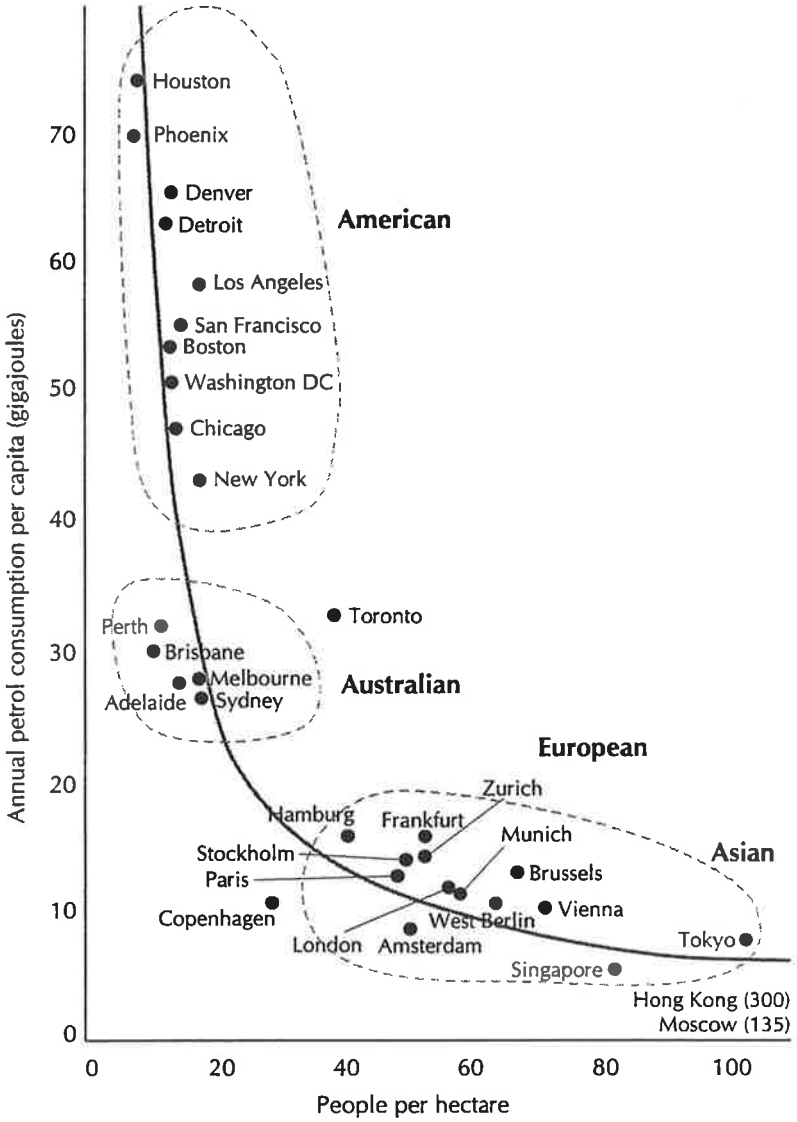


Figure 9.3
Petrol Consumption and Urban Density in 32 Cities of the Developed World
(Using 1980 data; from Newman, Kenworthy & Robinson, 1992)

To pursue a more European style of development that is less dependent upon the automobile and suitable to Australian conditions, a number of initiatives are required:

- implement planning controls to prevent strip development and urban sprawl;
- provide zoning for higher density development along established transit routes;
- encouraging the infilling development of existing vacant land in built-up areas;

- decentralise commercial and community services to reduce travel distances;
- create self contained communities with a better balance between employment and population;
- encourage the development of high quality walking and bicycling facilities; and
- ensuring that major public facilities have provision for walking and bicycling access to transit (FCM, 1990).

Serious environmental problems have been well known for decades before action is taken, and it has been recognised that among the obstacles to action is the lack of congruence between ecosystem boundaries – such as coastlines and watersheds – and administrative boundaries, both local and international. Failure to align political and jurisdictional boundaries (i.e. municipal council areas) with natural boundaries (e.g. water catchments) has meant that land, water and natural resource management initiatives have been fragmented and less effective than would be the case with a coordinated approach. Integrated catchment management should become the primary water and land management tool.

Measures are required to raise consciousness of the role and importance of watersheds and other natural systems, and to take these issues into account in land use planning and management. There is a need to work with nature in adjusting jurisdictional boundaries, and to use the topography of the land to determine the appropriate shape of the urban form. The protection of natural and cultural features, and biologically diverse and important ecosystems can be more easily achieved when a the management of these features is assigned to a single organisation. Alternatively, co-operative planning efforts are required to address the lack of coincidence between ecosystem and municipal boundaries.

Therefore, ecosystem maintenance and stewardship must be established as important values in land use planning. The definition of land and the scope of land use planning should be expanded to encompass the ecosystem; assessment criteria, procedures and techniques used in land use planning must be broadened to include environmental factors and sustainability considerations (GVRD, 1991).

Our urban ecosystems also serve as indicators of ecological health. Especially in urban areas, there is a fine line between ecological health and public health. No one wants their children to play in water that kills fish. Hence there is a need to ensure that development enhances environmental health.

The environmental advantages of urban areas – such as compact development, shorter travel distances, economically viable public transit, and per capita energy conservation – can only be realised if our communities are livable. Perhaps the most important indicator of "liveability" is that livable communities are *communities people want to live in*. Municipal and local governments therefore need to address those issues that cause people to stay in their communities, e.g. employment and educational opportunities, accessible health care services, vibrant arts and culture, and a thriving non-profit sector as well as those that cause people to leave, e.g. crime, dissatisfaction with existing housing choices and lack of opportunity to participate in decisions affecting their lives and well-being (Rosewell, 1992).

It must be recognised and re-emphasised that the ideal urban form for a particular location will very much depend on the climatic, environmental, social and economic conditions. Whatever technologies are adopted, consideration must be given to whether they are 'appropriate' to those conditions; they should not be adopted simply because they are existing or 'western' technologies. Development patterns and technologies suitable for Australian conditions may not be suitable in other countries, and indeed there may be considerably different patterns adopted between the tropical and temperate areas within Australia.

9.4. How Should We Build Our Cities?

Most older inner-urban residential areas across Australia are seen as attractive, pleasant, even beautiful and fashionable places to be. However, the question that must be asked is: how should newer suburbs by designed and the older suburbs revitalised?

Even recent housing areas fail to meet basic performance standards, in terms of accessibility, orientation to the sun, minimum disturbance of the existing environment, or efficiency in the use of energy, building materials and land. Little consideration is given to the degree to which healthy and accessible communities are being nurtured, the daily needs of women, youth and the elderly are met, new demographic realities such as the rise of non-traditional households are served, new immigrants' needs are integrated, or local employment opportunities are provided.

There are many ways in which the average detached dwelling development of subdivision in Australia could be improved. All would result in a decrease of subdivisions that are narrowly focussed on maximum lot yield and minimum up-front infrastructure cost, regardless of the environmental qualities and opportunities of the land (UDTF, 1994). Such improvement opportunities are:

- greater housing choice from alternative forms of residential development (e.g. those based on integrated community design and planned around public transport and service nodes);
- less wasteful use of land (e.g. the avoidance of rigid setbacks that reduce the useable areas of allotments and fail to contribute to the development's public domain);
- better environmental performance through good orientation, avoiding rigid adherence to winding street alignments;
- increased privacy between houses, reduced overshadowing and more site responsive design;
- enriched street life providing safe community space by avoiding, wherever possible, streets that are devoted to cars, garages and blank walls;
- better and more accessible recreation and open space; and
- new housing forms that offer greater choice by responding to demographic changes and a need for greater affordability.

Subdivision and road layouts should be based on the characteristics of their particular environments on good orientation and environmentally respectful site planning, the overall design and functionality of the settlement and the optimal

relation of individual houses to each other. Development, design and building controls must support the optimisation of these choices.

Atkinson (1991) considers that decentralisation is a key to what much of "utopian" urban organisation is all about, which means the construction of living environments at a scale that can be grasped by the majority of people and is controlled by them within manageable organisation systems. It means combining urbanism and nature to create cities that are healthy, safe and enriching places to live.

So the focus of this discussion is on the urban design elements. Making a community that is sustainable, safe and stimulating is the primary objective; engineering design of infrastructure, surveying and lot yield efficiency are secondary objectives. The interest is in the technological, infrastructural and urban form changes that can be made to contribute to the achievement of sustainability, rather than issues of economics, legislative reform and government policy. This is not to say that consideration of issues such as pricing and regulation are not important, since pricing regimes can play a major role in fostering efficient use of resources and in influencing behavioural choices. However, it is the potential for re-construction of cities into more sustainable communities and the pattern of urban development that would contribute to the achievement of sustainability *within the Australian context*, that is of primary interest.

9.4.1. Suburbia: Centralised or Spread?

In 1990, a detailed study was undertaken to identify the most appropriate future development pattern for the Greater Toronto Area. Three (3) urban patterns were considered, namely *spread* which assumed existing development trends would continue; *central,* concentrating most growth in existing central, built up areas; and *nodal,* where the suburban population would live in compact communities, or nodes (IBI Group, 1990). The study found that the *spread* concept is the least compatible with sustainable development in that it would consume the greatest amount of rural land and related agricultural productivity, would use the most energy and produce the most air pollution, and provide less opportunity to enhance stormwater quality and soil management than for the other concepts.

The *central* concept would provide the greatest likelihood of achieving sustainable development by making the most efficient use of resources (e.g. land, energy) and placing the least negative load on the environment. However, it would require the greatest change from the status quo in terms of population densities and housing types, choice of automotive travel and transit, and growth management policies, and would require the greatest amount of government regulation in order to divert population growth from suburban areas to central, built-up areas.

The *nodal* concept would be between the other two in terms of its compatibility with sustainable development and the required level of government regulation. It would appear to provide the greatest range of choice in terms of population densities and housing types, community size and character, suburban and downtown living styles, available range of transportation modes, and integrated

delivery of human services, while reducing per capita resource requirements and pollution levels relative to the *spread* concept.

Because the study found that the capital costs for the three projects would be roughly the same, the choices facing people and government depend not so much on cost as on other factors such as environmental and economic considerations, lifestyle preferences and the quality of community and individual life.

9.4.2. Traffic and Transport

One of the first tasks in moving towards a more sustainable urban form is to reduce car dependency. To do this alternative transit options must be provided, or the need for movement removed. The goal is to reduce the number of automobiles, and particularly single passenger trips; increase opportunities for non-auto transportation including bicycles, walking, rail, buses, and alternative vehicles; and reduce the use of petrol and diesel fuel in conventional buses, cars and trucks.

Cars should not be given the best shore front, mountain gaps, and other such vistas at the expense of the places where people actually live and work. Freeways should be below ground as they are in many urban areas already. Eventually freeways could be reduced in size and eliminated, replaced by smaller roads and streets for shorter connections and replaced by rail for longer distance connections.

Studies have demonstrated that the pattern of growth is more important than the amount of growth in determining the level and efficiency of resource use and traffic congestion (Roseland, 1992). Street design should be as flexible and 'connective' as possible, connectivity providing ease of movement across the system. Sprawling residential suburbs with many cul-de-sacs are generally undesirable, although pedestrian connectivity can be easily achieved in this form.

Well designed road networks provide multi-purpose streets, where there are many alternative routes making it easy for residents to reach shops or transport stops on foot, ensuring comfort and safety for children's play, and for communal, commercial and recreational activity. Pedestrian surveys in Australian cities point clearly to the importance of comfortable movement systems – especially public transport, walking and bicycling – for the making of satisfying places (UDTF, 1994).

The practice of traffic calming has been widely adopted, especially in Europe (White, 1994). Traffic calming includes the transfer of road pavement back to footpaths or cycleways with the addition of new trees, street furniture and lighting.

The road design is altered to force traffic to travel at a lower speed, which changes the psychological feel of a street, telling drivers "beware, this is a space shared with pedestrians". Road space is also transferred to public transport, such as dedicated bus lanes or light rail (Newman, Kenworthy & Robinson, 1992). These measures not only reduce vehicle usage and make road use safer for pedestrians and cyclists, but also improve the public security and amenity, providing opportunities for social interaction within a neighbourhood. Furthermore, where streets are designed more for pedestrians than automobiles, they are typically narrower and more interesting

places. The narrower streets mean that runoff and stormwater pollution is reduced, but also the cost of road construction and maintenance is less.

A special comment should also be made on behalf of protecting railroad corridors and other rights of way: they should never be built upon since they give us the option to rebuild energy-efficient rail transportation – or make great bicycle routes since their grades are gradual and they generally connect concentrations of people, as they emerged before cars (Register, 1987).

Table 9.2
Guidelines for Planning Urban Area for Efficient Transportation Systems

Design Parameter	Planning Guidelines [1] (in Roseland, 1992)	Suggested Designs for Jerrabomberra Valley, ACT[2]	Typical Australian City Conditions[3]
"Village" Population	-	3,500 - 5,000	-
Residential population density			
– central business district	> 50 pers/ha	90-150 pers/ha[4]	35 pers/ha
– inner city areas	> 50 pers/ha	50-75 pers/ha[4]	25-32 pers/ha
– suburbs	> 30 pers/ha	30-50 pers/ha[4]	8-25 pers/ha
Suburban housing density	> 17 dwellings/ha	12-20 dwellings/ha	5-12 dwellings/ha
Employee population density			
– central business district	> 300 pers/ha	-	40 jobs/ha
– inner city areas	> 50 pers/ha	-	11 jobs/ha
– suburbs	> 15 pers/ha	-	2-4 jobs/ha
Business activity centres	4 - 9 km separation	-	-
Proximity to transit station			
– Average, middle aged person	400-800 m (or 15 minute walk or 5 minute cycle)	800 m (or 15 minute walk or 5 minute cycle)	-
– Elderly person	< 250 m	-	-
– 'Bike and Ride'	< 4.5 km	-	-
– 'Park and Ride'	< 16 km	-	
Buses feeding to transit stations	< 10 minute ride		-

(1) After US DOT (1987), and Newman & Kenworthy (1991)
(2) Summarised design recommendations; refer to Foulsham & Munday Pty Ltd, Ecoweb (1994)
(3) Data for Melbourne, from Newman et al (1992)
(4) Assumes an average household occupancy of 2.5 persons.

Indeed, an alternative to bus and conventional rail systems that offers a mass transit capability is light rail. Light rail is a modern electric tram system which runs using multiple carriages, quietly and safely down pedestrian malls, adjacent to houses, or alongside street traffic. It is very flexible and has the advantages of being able to turn at right angles; include street level entry, therefore not requiring platforms; can run on heavy freight rail lines; can be powered by AC or DC electricity; and is generally preferred by commuters over buses. Light rail has proven particularly popular, effective and economically viable in many countries, most notably Canada and Europe.

So instead of thinking of going places, thought can be of being places. Transportation is what you have to do to get to places inconveniently located – the less the better.

The generally accepted view is that transportation systems in new urban developments should be designed for maximum pedestrian and cycle movement, with efficient local bus systems, delivering commuters to central mass transit stations, possibly using light rail. Over recent years, a few rules of thumb have been developed for planning of such transportation systems; refer to Table 9.2. Although there is general agreement on the conceptual layout of the urban centre and transport system, the walking distances and other dimensions can vary considerably.

A maximum walking distance of 400 metres is seen as acceptable to most people according to the UDTF (1994), although with further education and greater awareness amongst the community it would seem conceivable that a greater distance of 800 metres, would be readily accepted as proposed by Newman and Kenworthy (1991). White (1994) proposes that a 10 minute walk from one side of the suburban node or village to the centre is an appropriate scale, which would tend to support a distance of between 600-700 metres.

The Australian AMCORD guidelines for residential development provide further excellent advice on these and other matters of environmentally sensitive design and development (Commonwealth of Australia, 1995b).

9.4.3. Mixed Use Development: Urban "Villages"

Australian cities have a very diverse range of households and inhabitant groups who correspondingly require a diverse range of housing choices. Yet the current stock of housing fails to adequately meet the needs of these people. Even densities in today's newer suburbs are so uniformly low that there is no possibility of creating the fine-grained mixture of land uses which could lead to diverse, sociable community centres.

What is required is community centred, localised economic clusters. Cities need to be divided into smaller, self managed cells where the economic service scale is a few hundred households, and which allow modularity and flexibility in infrastructure provision and renewal over time.

Higher densities must be combined with mixed uses. Instituting mixed use zoning and zoning that concentrates development rather than scattering it is an important part of the solution. Public transportation works best when moving people from one active spot to another; it doesn't work well attempting to connect scattered low density sprawl.

Construction of taller buildings and dense, diverse downtowns, compared to low density, uniform development:

- saves vast areas of land for agriculture and nature;
- promotes energy saving, low-polluting pedestrian and transit access;

- makes commercial, cultural and social diversity easily available; and
- can be built with multi-levelled solar greenhouses, rooftop gardens, fruit trees in the streets, restored creeks, and with other elements of biology extending into and through the city.

Different people have different needs, work and lifestyles. And a family's needs are different from a single person's needs. So an appropriate urban density and form should be determined by simultaneously considering the diversity of the local culture as well as the health of the biosphere. The need for biodiversity can be addressed in part by incorporating terrestrial habitats and wildlife corridors, allowing them to pass through and encircle the urban centre, combined with other open space dedicated to sports fields, nature reserves, stormwater drainage corridors, waste management areas, cropping and grazing land, wildlife sanctuaries, and educational walks.

Figure 9.4 provides some examples of the form and layout of urban villages according to Calthorpe (1993). The designs embody many of the principles espoused by other architects and scholars Arkin, McHarg, Lovins and Register, who have all made some excellent contributions to environmentally responsible urban design (Pezzoli, 1997).

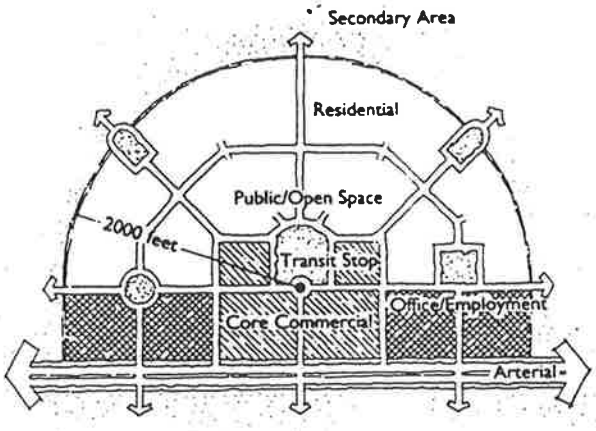
9.4.4. Energy Conservation & Efficiency

Increased urban densities would support and be complemented by efficient building design and construction. Although there has been much research in this field over the last few decades, good examples of the thorough implementation of energy efficient design principles are all too scarce in Australia.

Much greater use of energy efficient design must be made, particularly given that Australia's climate is so well suited. New developments would be designed to include:

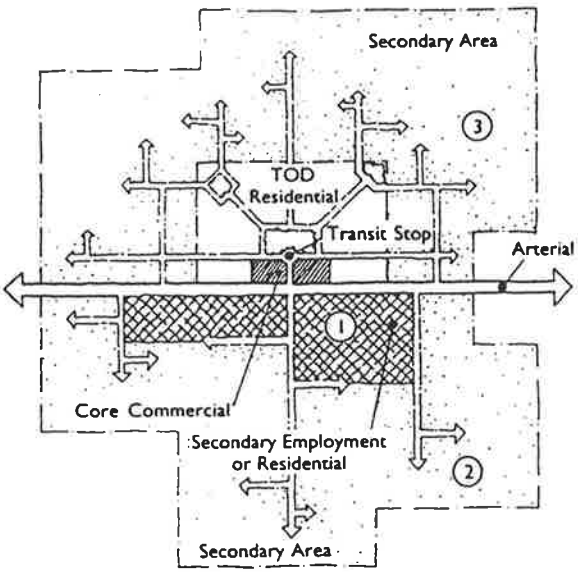
- appropriate building block orientation and siting;
- appropriate building orientation and window layout;
- materials of high thermal mass (e.g. concrete floor slabs) coupled with insulation;
- atriums and sky-lights to maximise natural lighting;
- optimisation of the use of daylight and task specific lighting;
- domestic hot water supply via heat pumps or solar hot water heaters;
- natural ventilation and shading during summer months;
- reclamation and redistribution of heat with buildings; and
- energy production using wind driven and thermal technologies.

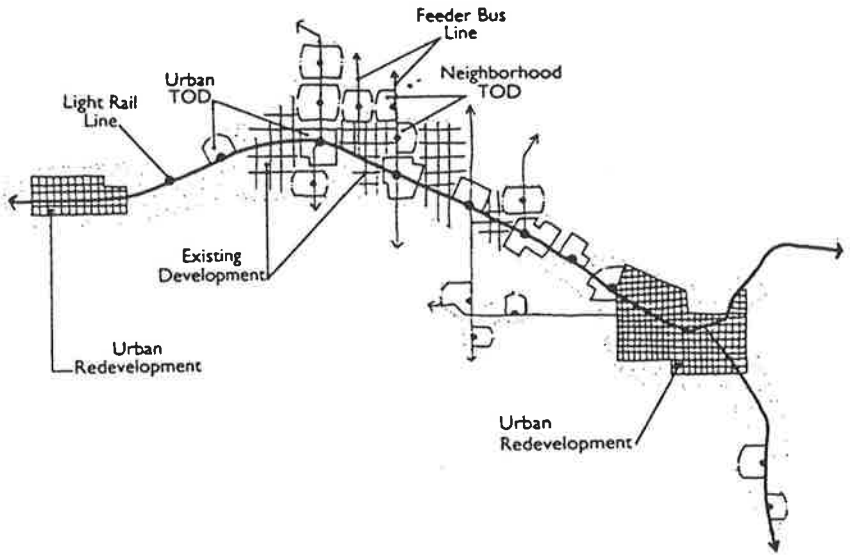
Infill housing and higher densities all contribute to a more efficient use of energy, particularly for heating. Natural building materials (non-synthetic) also contribute to efficiency in energy usage. Timbers should be plantation grown.



A **Transit Oriented Development** (TOD) or urban village is a mixed-use community within an average 2000 ft (600 m) walking distance of a transit stop and core commercial area. TODs mix residential, retail, offices, open space, and public uses in a walkable environment, making it convenient for residents and employees to travel by transit, bicycle, foot or car.

Secondary Areas provide important support to the core commercial areas and transit ridership, as well as low density residential development and large employment areas (too large to fit in the core commercial area). Secondary Areas located across an arterial, but in close proximity to the centre, may be best suited for large-scale employment. Those with direct adjacency should provide low density housing, public schools and community parks. Parks should be distributed within each neighbourhood, and together with small shops can help create sub-centres along with day-care facilities. Arterial streets should allow efficient conveyance of through-traffic and must not pass through TODs - they are a pedestrian barrier.





Transit lines must help define the density, location and quality of growth in a region. They should be located to allow maximum area for new TODs, to access prime redevelopment or infill sites, and to serve existing dense residential and employment centres.

Figure 9.4 Elements of the Development of Urban Villages (after Calthorpe, 1993)

9.4.5. Integrated Water Resource Management

Many of the same land use principles that help urban and suburban areas to save energy – such as clustering development, discouraging automobile-oriented land use, and leaving natural vegetation intact – can help to assure that water resources will survive well into the future.

Much can be done at the household level to significantly reduce the volume of water consumed, using technologies that have existed for many years:

- dual water supply;
- dual flush toilet cisterns or dry toilets;
- aerated shower nozzles;
- front loading washing machines;
- installation of rainwater tanks;
- household fire sprinklers are installed to avoid the need for large diameter mains for fire fighting;
- smaller garden and particularly lawn areas;
- xeriscaping or permaculture based landscaping;
- direction of runoff to gardens and infiltration trenches; and
- automatic meter reading: benefits are rapid reading and billing, leakage and high consumption detection, continuous flow data, meter failure or tamper instantly detected, constant consumer update and projection, variable tariffing to encourage lower use, not labour intensive, low meter maintenance, improved customer service (EWS, 1992).

A number of measures should also be adopted at the local, community and regional level in order to reduce the financial burden of, and stress upon the ageing water infrastructure, which include:

- *Restriction of urban development on floodplains*: floodplains are going to flood, so building development in these areas should be prevented. Instead, good use of the fertile soils should be made through sustainable agricultural pursuits.

- *Adoption of "dry landscaping" techniques*: permaculture or xeriscaping in public open spaces to avoid high summer irrigation demands which, with new fire fighting measures, will eliminated the need for large diameter water supply mains.

- *Use permeable road and footpath pavements*: Narrower roads constructed of permeable pavement materials will enable more water to be recharged to aquifers and reduce road runoff, thereby reducing the pollutant load introduced into watercourses and minor flooding potential. Similar paving techniques should also be adopted where large open car parks are required.

- *Implement wastewater collection and reuse schemes*: industrial wastewaters, sewage effluents and stormwater (with treatment as required) should all be diverted for reuse as close to the generating source as possible. High reuse means little inter-connectivity is required between catchments or urban villages,

saving on infrastructure construction and maintenance costs, as well as providing flexibility and adaptability.

- *Use infiltration areas, retention basins and urban lakes*: More natural urban forms of water purification should be integrated into the urban landscape. This would not only reduce water treatment costs, provide recreation opportunities and improved amenity, but also supply recycled water for irrigation and other applications not requiring potable water.

- *Aquifer storage and recharge (ASR)*: Aquifers can be recharged, either to relieve stress on over-exploited groundwater systems or alternatively for seasonal storage purposes, using leaky wells, gravel filled trenches, trenches with open bores (aquifer recharge by gravity flow), swales and infiltration trenches, permeable pavements, spreading basins and direct injection wells. The recharged water can be recovered at a later time, typically for irrigation or applications requiring a higher quality water (where suitable treatment systems are used).

- *Stormwater pollution control*: Physical devices such as gross pollutant traps, trash racks, artificial wetlands, litter booms, or fine litter screens (e.g. Pollutec devices) can be employed to reduce the pollutant load in stormwater. Adoption of broader catchment management measures and education of the public should complement these options to ensure significant improvements in stormwater quality and associated receiving waters.

- *Modern irrigation management*: Advanced irrigation methods should adopted to ensure only the water required is applied to parks, gardens or crops (e.g. drip irrigation systems, sub-surface irrigation, etc.).

Water management practices should be redirected away from "once through" use and dispose systems, to systems which supply water at different qualities for different uses, incorporate innovative technologies for water reuse, and water treatment and reuse at the local and regional scale (as appropriate). Regulation should be sufficiently light to enable innovation in service provision where private companies are involved.

Advanced technologies and continuous monitoring may be employed to monitor system use and detected system losses, thereby eliminating leaks and illegal connections and reducing losses.

Infrastructure operation should be optimised at the local level. Investigations for water storage in underground caverns or aquifers should be conducted at the local and regional level. The value of engineered ecosystems (such as wetlands) for stormwater and wastewater treatment, and polishing prior to reuse or discharge to receiving waters, is recognised and should be more widely adopted. Development and implementation of 'point of use' technologies to deliver cleansed water may also be desirable, where the final stage of treatment could occur at consumers properties.

The existing trunk water and sewage reticulation system could be used as the general "spine" infrastructure, feeding many operators and service providers, where point-of-use treatments would be used. The suitable combination of all the afore-mentioned options needs to be determined for each particular location.

To maintain the quality of water sources, the ecosystem of the receiving water environment should drive the technologies used in the urban setting. Transferable environmental release permits would also help to address environmental concerns, where the carrying capacity of an ecosystem determines the quality and quantity of wastewater that can be released to a receiving water body.

A policy of tradeable water allocations could be established to enable sale of "excess" water allowance, thereby improving the efficiency of water allocation, where the sale process is maintained under government control to ensure social equity and environmental issues are adequately addressed.

9.4.6. Solid Waste Management

Mixed used development and higher housing densities provide many new opportunities for efficient waste management and recycling. Collection of recyclables is made more efficient through centralised transfer locations within villages, and reduced travelling for collection trucks that would previously have operated under kerb-side collection programs.

The integration of commercial operations and small industry into the villages also provides the means for an integrated waste management strategy. Residuals (formerly called "wastes") from one manufacturing process or from households could be sold or transferred to become an input to another process.

Full cost pricing for the disposal of waste to landfills and waste disposal facilities would mean that prices increase. The result is likely to be greater community dedication to recycling, with improved economic viability and employment in associated 'clean' industries.

The concentration of biowaste (i.e. sewage) enables greater efficiency in treatment and use as a resource. The sludge can then be used largely in fertiliser manufacture or as a compost additive and consumed locally in parks, gardens and farms. In addition, sludge can be directed to brick manufacture and consumed regionally.

9.4.7. Communications

Environmental regeneration requires most of all a major shift in attitudes. The speed with which changes are made will be a function of how much information people are given.

White (1994) quite correctly states that it is the better information and monitoring systems that provide the means for people to take control of their lives, become

aware of the costs of the decisions they take (or postpone), and then prepare to make more intelligent choices:

"If you can see where you draw your resources from and where your residuals end up you are far more likely to realistically address the roots of your physical existence and work out how to make it more sustainable."

For example, there could be more prominent displays of water, electricity and gas consumption in each household.

An intelligent underground circulatory system, similar to the body's nervous system, should be developed in a common, single trench. This would take clean or dual water supplies, sewage, electricity, gas, and communications. Good examples of this technology already exist in Sweden (Commonwealth of Australia, 1995b).

The availability of continuous water quality and flow data would provide information to run successful demand management programs and also to implement variable water pricing strategies (i.e. prices vary during the day, by season, and during drought periods). Cheap and efficient water quality monitoring systems need to be developed, and coupled with electronic metering systems.

Geographical information systems (GIS) will most likely become the spatial databases used for compilation, interpretation and presentation of the information characterising the functioning of the villages. The GIS can be linked to hydrological and land use modelling tools, routinely used for city planning. New GIS technologies that enable a 3-dimensional view of a city could provide the interface and tool for understanding all aspects of the geography, infrastructure and 'health' of an urban centre.

9.4.8. Industry

Sustainable industry means converting the material basis of society. While the shape of sustainable industry is still emerging, several features are likely to be critical (Geiser, 1991):

- technologies appropriate to the desired ends;
- safe and environmentally compatible materials;
- products that meet basic social ends and some individual wants;
- low and no-waste production processes;
- safe and skill enhancing working conditions;
- energy efficiency; and
- resource conservation to meet the needs of future generations.

Closed loop production systems should be developed and continually improved, and a high level of recycling is fundamental. Government policy would require that environmental costs of production are fully internalised, and therefore reflected through the price of the product to consumers.

9.4.9. Social Issues

Sustainable community development implies that we address not only the "hard" urban environmental issues such as transportation, land use, air quality, and energy conservation, but also the "soft" issues such as public health and safety, gender equity, environmental education, and global environmental responsibility.

A sustainable economy must emphasise sustainable employment and economic demand management.

It can be seen that through clustered housing people can gain easy access to important services such as transport, community facilities and shops, while also being in close proximity to a wide range of employment opportunities.

Teenagers are more likely to find others of the same age living within walking distance and may have access to shared facilities places where they can spend time together, out of sight from home, yet not far away.

Education services should be flexible and concentrated regionally to service a number of villages, although child care facilities and kindergartens are likely to remain at the local level. The variety of educational experiences may be improved, through living with a more culturally diverse and variable age community. An understanding of ecosystems and natural processes may also be enhanced.

9.4.10. Summary

To redefine our urban design guidelines with the goal of sustainability in mind, it is useful to reflect upon the principles of community and the village life of the past and tailor them to our future needs – that is, 'go back to the future'.

Consensus is that good urban design requires emphasis upon mixed-use zoning; pedestrian, bicycle oriented and transit-friendly streets; renewable energy sources; water efficient technologies and wastewater reuse; and urban greenery. These design elements are found to effectively complement each other and come together in the form of an urban village.

9.5. Making the Transition

Undertaking the transition to a more sustainable urban form will require a change in social and lifestyle patterns as much as infrastructure and technology. The complexity of social, economic and political systems means that there are a vast number of inter-related issues that need to be addressed. Thoughtfully planning and sensitively implementing change of our urban environments can provide the impetus and forum for these issues to be addressed, while simultaneously providing significant social, environmental and learning opportunities.

All reasons for development of cities must be maintained in the development of ecocities – to provide both a healthy, adventuresome, beautiful environment, as well as that which supports the needs and desires of the individual.

Natural life forms can be established or allowed to coexist with the city by giving them sizeable slices of their natural habitat around the city (greenbelts instead of suburbia) and within it (in parks, along restored creeks and shorelines). The border zones (forest/grassland, water/land) are among the most diverse and ecologically valuable parts of the natural habitat. Public and private funds should be established to gradually buy back and remove badly located buildings, restoring the natural environment, and moving the city toward ecological health.

The vision is clearly for nodal rather than centralised communities – a network of smaller, compact communities surrounded by non-urban land. So as the city grows, and its new "centres" become increasingly compact, the surrounding land can be reclaimed – as open spaces, forests, agricultural land, and wildlife habitat – to simultaneously benefit people and the environment.

9.6. Conclusions

The goal is an ecologically and culturally healthy city – one that can endure and can provide its inhabitants with a meaningful existence without destroying the ecological base on which it stands. Although the practical implications of sustainability in urban design are not fully clear, it should not prevent us from starting with a bottom up approach, beginning in every city, indeed every human settlement.

Good city management requires decentralisation – of funds, political power, technical expertise and personnel – to local "villages" administered by local authorities, which are best placed to appreciate and manage for local needs. This is supportive of good land and water management, particularly where municipal boundaries were aligned with natural (catchment) boundaries.

These urban "villages" would accommodate a variety of land uses. There would be a mix of housing types at variable densities, although predominantly medium density, interspersed with local shops in common squares with open space for playing grounds, urban lakes, grasslands and forests. Commercial, retail and small industry would be interspersed through the village, providing employment close to home and therefore mitigating the need for long car based journeys.

The Urban Design Task Force (1994) has established that there is overwhelming evidence of the beneficial effects on social equity and the national economy of re-orienting urban development toward such environmentally friendly development patterns. Mixed use development can lead to a reduction in transportation demand, reduced parking requirements, more open space, enhanced retail activity, reduced auto traffic, increased safety during evening hours. (Unfortunately, Australia's under-informed and fragmented decision making apparatus impedes progress in this area.)

The changes to urban form previously discussed will inevitably receive criticism and rebuke, most probably from those with a vested interest in maintaining the status quo (such as car manufacturers). Even some proponents of a reorientation of development towards sustainability have dismissed various goals as wholly unachievable, yet it would seem that such positions are often reached because of their ideas are dominated by a world view which deals only with current technologies and methods, but without taking a more holistic view and considering the potential of new technologies and cultural shifts. But those who consider the options objectively and holistically have reached consensus on a direction for future urban development. The direction, rather than the end point, is the most important feature, because achieving sustainability is more about a journey than an outcome.

10

Simulation of Water Resources Management Strategies

10.1. An Overview of Water Resources Modelling

An important component of this research is the modelling of the regional water balance of the Northern Adelaide Plains. Simulation of the availability and use of the various sources of water was necessary to predict the effects of different patterns of urban development, and also to develop a better understanding of the potential benefits of various integrated water management strategies.

Modelling in the field of water resources management has traditionally focussed on the parameters of time and location. Time emerges as an important modelling parameter where the rate of water flow is important, such as in runoff and flood routing, or in the design of drainage, water supply or sewerage systems. Location is an important issue where the transfer of water is required, either from storages or major water sources (such as the River Murray) to consumers, or in taking wastewater away from consumers to discharge points.

A range of generic models have been developed to assist engineers to simulate these temporal and spatial characteristics of water systems for the purpose of design. With the advent of personal computers and their increasing affordability, computer modelling applications flourished. Computer packages commonly used in Australia for runoff routing for the design of dams or drainage facilities include RORB, RAFTS-XP, ILSAX, and the HEC models developed by the US Army Corps of Engineers (Ven Te Chow et al, 1988; Pilgrim, 1987). Yield estimation has often been left to the analysis of historical streamflow records where the data exists (refer to Kottegoda, 1980; Srikanthan, 1989; Helsel & Hirsch, 1992), physically based models such as those developed by Boughton (1966-1993), O'Loughlin (1981, 1986) or Stephenson & Paling (1991), or empirical methods such as the United States Soil Conservation Service (SCS) Method (Wood & Blackburn, 1984) and volumetric runoff coefficients.

Many site specific models have also emerged, most often utilising mathematical optimisation routines where capital and operational costs were typically the target of minimisation. Linear and non-linear programming techniques have been popular in the design and planning, although more frequently the analysis and optimisation of entire water supply systems (refer to Mulvihill & Dracup, 1974; Rogers & Fiering,

1986; Kessler & Shamir, 1989; Dandy & Connarty, 1993). Some researchers have applied goal programming methods to determine the optimum distribution of available water. Noel et al (1980) used linear programming methods to examine the optimal conjunctive distribution of surface waters and groundwater between urban and agricultural settings. In 1981, Ocanas & Mays used optimisation methods in a study examining the potential for conjunctive use of reclaimed and potable waters. Much of the analysis reported in the literature, however, has focussed on improving the operational performance of multiple reservoir systems (Loucks & Dorfman, 1975; Houck & Cohon, 1978; Daniell & Fitzgerald, 1982; Stedinger et al, 1984; Kuczera, 1989; Loganathan & Bhattacharya, 1990; Tao & Lennox, 1991; Crawley & Dandy, 1993; Kuczera & Hill, 1993; Wang & Tamai, 1993).

These general and site specific models have played an important role in the design and operational improvement of water systems, and will continue to be developed and refined. However, many water systems are reaching maturity in the sense of conventional water supply, because existing water sources have become fully utilised and there are diminishing opportunities to develop new sources to meet the increasing demands of growing populations.

At the same time, environmental concerns are growing with the recognition of the degradation caused by humans. Because the planning and management of land use and water services in urban areas have traditionally been considered as independent issues, the impact of land use on water sources and receiving waters has tended to be neglected. This has lead to considerable alteration of the temporal and spatial distribution of water, and affected the cost of infrastructure provision.

Evolution of the criteria that govern the operation of water systems is therefore occurring. Two additional parameters have emerged over the past 10 to 15 years which provide a significant challenge to water resource managers and systems analysts. The design and operation of water systems must now not only address the spatial and temporal issues, but take into consideration the issues of:

- the quality of water as it relates to the carrying capacity of ecosystems to accept the disposal of wastewaters without causing long term harm; as well as
- the suitability of non-potable waters to serve as useful sources of supply; and
- the recognition that the natural environment has a genuine and important need for water.

The introduction of these three issues and their associated objectives and constraints makes the job of the water manager and system analyst considerably more complex. They also act as a catalyst for creative thinking, to explore new ways of managing our water resources to meet the complimentary needs of humans and the natural environment.

Attention is increasingly turning to unconventional sources of water. Demand management, water conservation, stormwater harvesting, and the reclamation and reuse of wastewater are emerging as genuine elements of the urban water system. Water systems modellers are considering how these multiple new sources of water

can meet varying demands in space and time. The environment becomes another 'user' of a water source, although the science of determining the carrying capacity of ecosystems and environmental flows is still relatively young.

Planners and engineers are also questioning the desirability of urban development and infrastructure provision that perpetuates the 'conventional form'. As the existing public infrastructure enters the era of asset replacement, new ideas emerge and old ideas are reworked about the ideal form for future urban development.

The main issue seems to have become that of integration – finding the optimum mix of all sources of water, whether potable or non-potable and surface, waste or groundwater, to meet the vast array of competing water needs.

This is not to suggest that aspects of integrated land and water management have not been addressed in the past. Many studies have examined the benefits to be obtained through the integration of demand management and conservation measures in water supply schemes (such as those by McPherson, 1979; DeCook et al, 1988; Schlette & Kemp, 1991; Macy, 1991 and others). It has often been shown that water conservation and demand management measures can provide significant water savings. However, achieving conservation has often be hampered by the necessary involvement of many consumers (particularly where residential water consumption is a large fraction of total consumption), and such measures are often economically unattractive to a consumer as the return on investment made can take many years.

In contrast, the reclamation of wastewater for reuse has tended to show greater promise, most notably within the USA and Israel where it has been the subject of considerable work (refer to Chapter 8). Indeed, the thinking of Buras & Darr (1979) and Ocanas & Mays (1981) was somewhat ahead of its time, addressing wastewater treatment as a resource management issue to be integrated with water supply, rather than one of disposal.

The feature which distinguishes the emerging concept of integrated land and water management is the *holistic approach*. Only during the last 20 years, and more particularly since the mid 1980s, has there been serious questioning of the once-through, use and dispose approach to water management. 'Closing the cycle' of water management with the integration of water conservation, demand management, wastewater reuse and stormwater harvesting has received increasing attention. Much of the earlier work had tended to focus on water conservation or reuse in isolation from other management alternatives, and often assumed a constantly increasing demand. These studies failed to address the benefits that could be achieved through more holistic water management and integration of the systems for water supply, sewerage and drainage, as well as land use planning and development.

A number of responses to this challenge of modelling and designing new water systems have emerged from a range of disciplines other than just engineering, reflecting the necessary integration of professions in planning for this new age. A view gaining acceptance is that ecosystems and their capacity to support the resource consumption and waste disposal patterns of human populations should

dictate the allowable extent of land and resource development (Pizor & Nieswand, 1984; Glasoe *et al*, 1990; Hollick, 1991). Indeed, it is very much the case that 'we must ensure that development of water resources does not contribute to their destruction' (Tolba, 1988).

Adopting an integrated approach to water management opens up an entirely new range of potential solutions to water resource problems. The integrated approach involves transferring water at variable rates and qualities between supply, sewerage and drainage systems in a range of alternative ways (after Stewardson *et al*, 1995a). Integrated modelling must include relationships within the urban water cycle not included in traditional management modelling. Given that the operation of water systems, both internally and in relation to land use planning, has been segregated, computer models addressing this expanded range of issues have not previously existed. Some of the efforts to redress this are briefly discussed below.

A tool that was developed for the analysis of municipal water systems is also amenable to integrated water system planning. The 'input-output flow chart' is a water system analysis tool that allows simplification of a complex system into its components and the interactions between them. The origins of water (or wastewater) are listed in the horizontal rows, and the flow destinations are listed in the vertical columns. The intersection between a row and column specifies the source and destination of a water flow, the volume of water transferred being the numerical value presented in the cell. The completed matrix provides a great deal of information on the structure of the system and the water transactions that occur within it, presented in an orderly manner with an accounting format. Reading the matrix reveals how water moves through the system from source to final disposal. Bengoechea et al (1981) developed the matrix to plan future capital investment needs, and to ascertain the effects of changes in water transfers within an existing system. This technique was originally employed for the analysis of conventional water supply systems, but Klooz & Hendricks (1982) extended its application to explore the potential benefits of water reuse and alternative transfer arrangements to meet future demand within complex water systems that had reached a 'conventional' state of full development. While the data used can be presented for any particular time step (week, month or year), annual data is most typically used.

The Water Authority of Western Australia (Cargeeg *et al*, 1987a; 1987b; 1987c) are responsible for one of the most comprehensive urban water management and planning exercises in Australia in recent years. A number of models were developed to simulate different components of the urban water system. A detailed hydrogeological model was considered to be important because a significant proportion of all water consumed in Perth is derived from the shallow unconfined aquifers beneath the Swan Coastal Plain. The model that was developed was specific to the region rather than generic, and used a finite element approach. While stormwater and wastewater reclamation for reuse were not considered within a truly integrated management study, demand management and aquifer recharge (with sewage effluent) were included in the alternative management strategies considered. The impacts of various land uses and of urbanisation were also addressed.

A few generic models amenable to exploration of integrated water management approaches have emerged more recently.

The TOPAZ-SUCO model has been developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to operate in the Microsoft Windows environment. This model is an extension of the TOPAZ-URBAN model that is used to evaluate the economic efficiency of urban development. New modelling routines have been incorporated to simulate various integrated water management practices, and evaluates their dependencies and relationships either by 'what if' analysis or by optimisation. The model considers water supply demand and disposal, drainage system loads, hydraulic infrastructure planning, economic costs of water services, and implications of other demands for land use. The main static and dynamic components of land and water use are included, such as industry, commerce, residential, recreation and environment, and spatial zones are established to accommodate these activities. Interactions occur between the activities via network links between these zones (Gibert & Maheepala, 1995).

TOPAZ-SUCO is implemented sequentially via its three modules: land use emulation; infrastructure costing; and simulation of the catchment water balance. One of three alternative water management scenarios can be investigated:

- provision of rainwater collected in tanks for internal contact or outdoor non-contact water needs;
- on-site collection and treatment of wastewater; or
- on-site collection and treatment of stormwater.

Simulation occurs under conditions of average demand, stormwater and wastewater generation. The infrastructure requirements are optimised and costed according to this water flow data. The most suitable 'water dictated' land allocation and urban growth pattern is the determined.

Gibert & Maheepala (1995) applied the TOPAZ-SUCO model to the Northern Adelaide Plains to examine the implications of innovative water management at the MFP development of Mawson Lakes on the entire region. It was assumed that within Mawson Lakes, contact water needs are met by rainwater tanks before mains water supply, and non-contact water needs are met by rainwater tanks, with treated effluent and stormwater used to top-up the local lake. The results of the modelling were:

- under conventional development patterns, significant expenditure was required in the period 1996–2011 to increase the water supply capacity (probably through a new pipeline from the River Murray);
- innovative water management at Mawson Lakes can delay the construction of this $5 billion pipeline by up to 4 years;
- construction of local wastewater treatment plants at Mawson Lakes is more expensive than adding new pipes so long as Bolivar has sufficient capacity; and
- the cheapest locations for new urban development are infill sites because the water related infrastructure is already available at those locations.

The Watercress model has been developed by Cresswell and Clark of the Water Resources Group, SA Department of Environment and Natural Resources (refer Cresswell, 1994). The model has been developed in the operating environment of the ARC/INFO geographical information system and has deliberately been kept simple to provide flexibility. The model has been frequently modified, and in its several forms, can cater for many water service layout options. Watercress is a lumped spatial model, the major explicit performance indicator being the cost of the system and returns which can be made by water sales (Stewardson et al, 1995).

The Krakatoa model was developed for Melbourne Water by Stewardson (1994) at the University of Melbourne to assess integrated urban water management practices in the Plenty Corridor, an area undergoing urban development on Melbourne's northern fringe. Krakatoa is a spatially distributed model allowing representation of different land uses and hydrological inputs or responses within sub-areas. The model has an extensive hydrologic model, a capital and maintenance cost estimation routine and some consideration of environmental and socio-economic impacts (Stewardson et al, 1995).

Both Krakatoa and Watercress are continuous deterministic simulation models, using recorded or estimated data sequences of rainfall, evaporation and water demands, as inputs which are linked to predicted outputs via mathematical expressions. They are less concerned with predictions of remote events and more concerned with prediction of conditions within the range of normal operations.

Stewardson *et al* (1995) note that data availability and the desire for simplicity have placed restrictions on the detail of these models. No attempt was made to develop Krakatoa or Watercress as final design tools or system optimisers. Both are preliminary screening or gaming tools to provide assessment of broad scale management strategies.

A list of issues that should be addressed by a simulation model developed for the exploration of integrated water management strategies is included in Table 10.1.

Of the simulation programmes reviewed, Krakatoa was considered to be the most flexible and potentially the most suitable for the investigation of water resources management strategies at the regional level. The programme and User Manual (Stewardson et al, 1994) was made available for evaluation by Melbourne Water, and was thoroughly reviewed with respect to the desirable model features listed in Table 10.1 and the modelling requirements specific to the region. Ultimately, it was decided that Krakatoa would not be used because of several limitations:

- Flow paths for surface water runoff are determined by the model using land surface elevation data. To incorporate existing stormwater drainage required one of two approaches. Firstly, stormwater drains can be introduced as natural streamlines. Alternatively, elevation data can be modified to force the alignment of flow paths to correspond to the existing drainage network. Stewardson (1995) indicates that this may affect other components of the model, however, such as the sewer costing routine.

Table 10.1
Important Issues to Address in the Development of Simulation Models for Water Resources Management

Issue	Application
Existing Conditions	There are very few circumstances in which entirely major, short-term changes can be made to existing water systems or new systems developed. Change therefore tends to occur over a protracted period of time. It is therefore important to simulate the period of transition and associated impacts, starting by truly reflecting the existing conditions such as any existing flow paths (whether stormwater, sewage drainage, or terrain based, natural stream courses); housing density and population distribution; urban form, land use and land development potential; headworks operation rules (eg. instream releases, storage capacity) and so on.
Consumer Differences	Incorporate the variable consumption patterns that characterise different sectors of society, and which can largely determine the viability of water reclamation and reuse schemes. Sectoral demand patterns are also important in conjunction with water availability patterns to determine storage requirements.
Multiple Water Sources	Identification of all possible potable and non-potable sources of supply, including treater potable water from reservoirs, stormwater, grey water, sewage and treated effluent, groundwater, rainwater, and sea water.
Water Quality	By taking into consideration the suitability of different water sources to meet various demands in terms of water quality, there is the opportunity to match utilise a water source that is 'fit for purpose'. This promotes consideration of multiple use and reuse options, and the priorities of supply. Some modelling of pollutant sources and loads may be valuable.
Spatial Scales	The optimal size or scale of systems for water supply, sewerage, stormwater drainage and reclaimed water reuse should be investigated, as well as the potential for inter-region water transfers. Scale issues are likely to be very site dependent.
Temporal Scales	Natural climatic and systemic variability is an important feature and should not be overlooked. Ideally, a time step of less than a year (month, week or day), and a long, historical times series should be used wherever possible. This will tend to ensure that more 'extreme' conditions are addressed, conditions which often dictate the size and cost of infrastructure.
Costs	Provision should be made for estimation of infrastructure construction, operation, maintenance and replacement costs, calculated using the Net Present Value method to accrue expenditure and revenue over time. The aggregate cost of water to consumers should not be ignored.
Calibration	Wherever possible, a model should be calibrated using historical data to ensure that the simulation routines will reflect actual conditions.
Software	The development of the simulation model as a computer based 'gaming' tool is desirable. The model should be developed for common computing and software platforms, with flexible data input, editing, output and reporting. The capability to interactively transfer data between GIS and spreadsheet packages would be ideal. A menu driven graphical interface would be ideal, with the capability to view simulation results in a graphical format during simulation. An important feature is that it be user-friendly so that planners and decision makers can use it easily.

- Without modification, the package cannot undertake simulations of a region comprising several catchments and outflow points (i.e. Little Para and Gawler Rivers and other minor streams). Furthermore, the flat topography of the

Northern Adelaide Plains may 'confuse' the elevation based runoff module, resulting in erroneous yield and pollutant data.

- There is no capability to consider the effects of inter-catchment or inter-basin transfers, such as the importation of water from the River Murray.

- The model is detailed with many routines and parameters required to simulate different components of the water cycle, such as surface runoff and point source pollution. However, the level of detail provided in the User Manual is limited with regard to model assumptions, limitations and sensitivity to parameter adjustment. A completely documented example of the application of Krakatoa is also not provided.

- The study region is segregated into a grid of regularly sized cells with which spatial information must be associated, such as current and potential land use, soil and geology, infrastructure and elevation. The data is entered using an interactive map of the region. While this style of data input can provide a useful presentation of the data and enable rapid visual confirmation of data integrity, it can also be cumbersome with the potential for over 5,500 cells to be used. Where large and diverse regions are to be investigated according a number of alternative development strategies, the data handling and checking requirements can become a burden. This limitation could be largely overcome by providing the facility for data exchange or integration with a raster based geographical information system.

- Although the simulation time step can vary between 1 and 30 days, the output data for flows, storage and other parameters is aggregated for each year of simulation. (Graphs of data plotted according to the simulation time step, and snap-shots of spatial information can be accessed during simulation however.) Output of the data in this way prevents further detailed analysis of the data following simulation, such as the design of seasonal water storages. It would seem that great benefit could be achieved by modifying the programme to down-load the simulation data for each time step to data files for further analysis.

- Not only are the simulation results aggregated over time but also space. In order to obtain an appreciation of spatial distributions and relationships, a user must establish multiple maps to display snapshots of spatial information, have a strong familiarity with the colour coding used for screen output, and assimilate the data as it is (rapidly) displayed during the simulation process.

It would appear that many of the limitations have arisen because of the context in which the model was developed – for an urbanising, single catchment with a single drainage outlet, with no large plains. Indeed, the development of models for specific projects often introduces limits to their future application to other problems. While there are many other niceties that could have been included in the model (such as the effects of urban consolidation on surface runoff), the strongest inhibiting factor to the application of this model in this research was the lack of more detailed output on the spatial and temporal distribution of demand, consumption, water flows and storage.

Perhaps the greatest promise for computer simulation of fully integrated water management will emerge from the Co-operative Research Centre for Catchment Hydrology in Melbourne, Australia. Mitchell *et al* (1995) are currently developing a computer model using Microsoft Excel as the engine for calculations with a user interface and programme framework developed in Visual Basic. The model accounts for the use and movement of water within the water supply, sewerage and drainage systems, as well as the linkages between them. There are detailed water consumption, wastewater generation and stormwater runoff models, which have a physical basis rather than empirical relationships and 'black boxes'. Clearly, the most important features are:

- the ability to take into account the various qualities of water that are available for use (potable, grey- and black-water) and the demand for them;
- spatial assignment of different water use patterns within a catchment according to land use (e.g. residential, industrial, commercial, open space); and
- water balance evaluation at daily, monthly and yearly time steps.

Initially, the model was been developed to simulate residential areas because this sector accounts for the majority of municipal water consumption. The model has now been extended to accommodate all sectors of the water cycle (*pers comm*, Mitchell,1998).

It therefore seems that a generic modelling package to simulate fully integrated land and water management is still some years away. Those that have emerged are either very elaborate, site specific and expensive, such as the GIS-integrated models discussed by Fedra (1993), or have their applicability limited by their structure.

10.2. Modelling Requirements of the Research

A key research objective is to identify a preferred strategy for urban development and water resources management for the Northern Adelaide Plains. To explore some alternative development paths, three scenarios presenting hypothetical courses for urban development for the period 1996 to 2020 were developed.

The alternative development scenarios provide a comparison of two 'probable' futures (Scenarios A and B) with one 'possible future' (Scenario C). The basic thrust of each course of development is:

- **Scenario A - Business as Usual**: assumes continuation of urban sprawl under conventional development and resource consumption patterns.

- **Scenario B - Virginia Pipeline Scheme**: many of the same features as Scenario A with the addition of tertiary wastewater treatment and a reticulation system for reuse of treated effluent from Bolivar WWTP for irrigation in horticulture.

- **Scenario C - A Rejuvenated Urban Form**: assumes development and renewal of urban areas to produce more condensed, efficient and livable communities. Water conservation and wastewater reuse are widely practiced in the new

urban areas, and there is a gradual return of urban land to open space, new habitat areas and local agriculture.

The objective is to determine which course of action (if any) is the most desirable, and what are the trade-offs.

A model to simulate land use and water management on the Northern Adelaide Plains was therefore developed within the Microsoft Excel spreadsheet environment, making use of the benefit of multiple, linked spreadsheets.

The model was developed to explore how competing demands for water could be met by a range of water sources, incorporating the effects of changes in urban form and alternative management strategies. The objectives of the simulation modelling were:

- to determine the availability of water resources;
- to predict the regional water needs under both normal and extreme climatic conditions (drought and extended periods of heavy rainfall);
- to accurately reflect the consumption patterns of different consumer groups;
- to determine consumer water needs by quality as well as quantity;
- to match water demand with supply according to quality requirements;
- to reflect the existing conditions as they relate to infrastructure and water management;
- to simulate the effects of land use changes (particularly on stormwater generation); and
- to undertake simulation at a time step amenable to investigations of storage requirements, capital and operational costs.

To achieve these goals, a number of investigations were conducted to ensure that model parameters were independently credible and consistent when part of the larger model. The most notable outcomes were an artificial neural network (ANN) model to predict regional water consumption from monthly rainfall data, and the derivation of volumetric runoff coefficients for urban and rural areas. The investigations are discussed below in more detail.

The logical structure of the model is depicted in Figure 10.1, with the computational elements and linkages illustrated in Figure 10.2. Firstly, the availability of water from various sources is calculated on a monthly basis, typically achieved using a polynomial equation determined from historical data which relates water flow or yield to monthly rainfall. In the case of stormwater runoff, a geographical information system (GIS) database provided data on land use and developed areas for use with the volumetric runoff coefficients (discussed further in Section 9.10).

The ANN model provided the estimates of per capita monthly water consumption from which the regional water demand was calculated. From this regional demand, the sectoral demand was calculated using historic data to determine the consumption patterns of each consumer group. Sewage flows are then estimated as a fraction of consumed water on a sector by sector basis, enabling the determination of the total sewage flow.

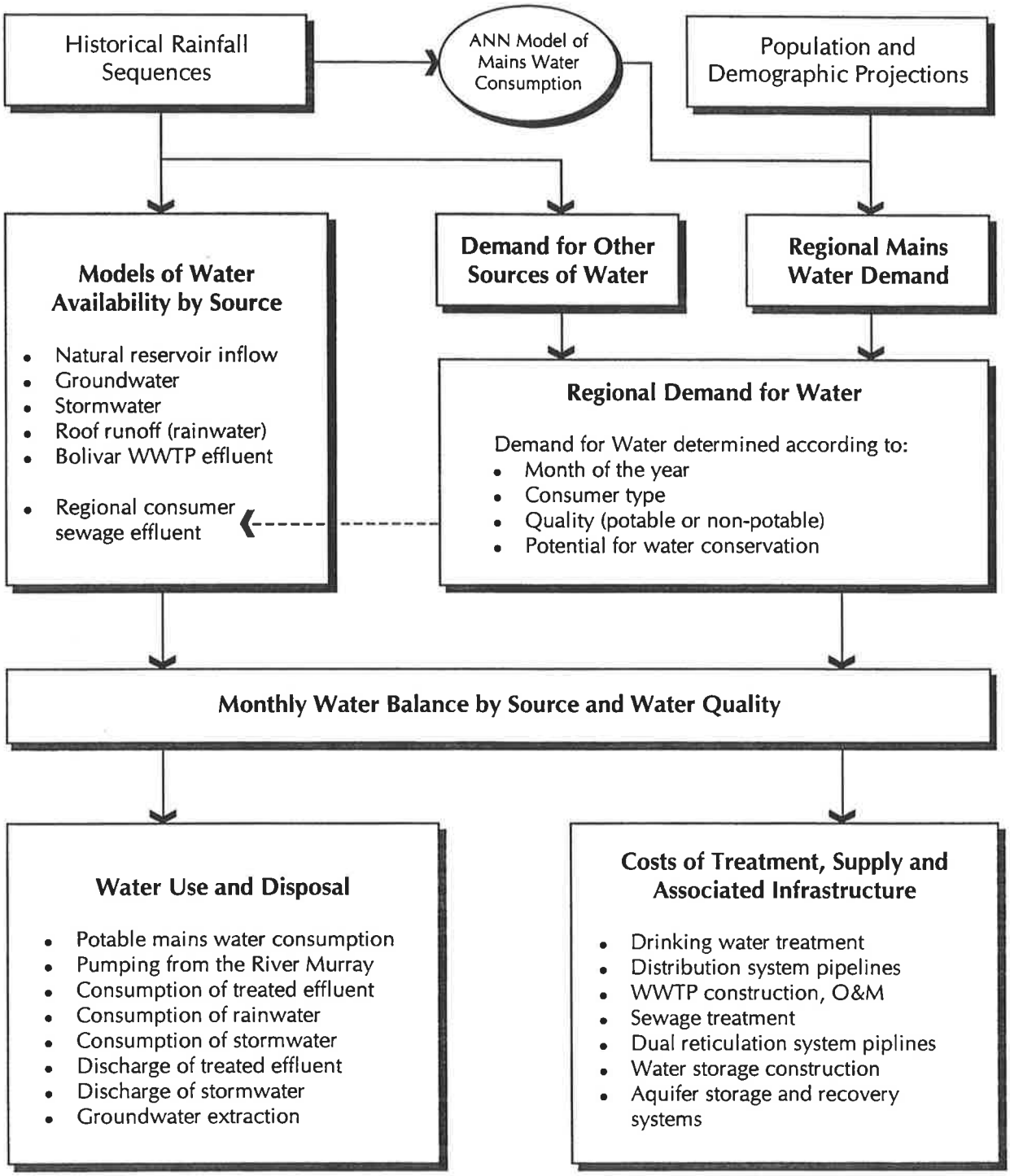


Figure 10.1
Basic Structure of the Water Management Model

Research into the uses of water by consumer group enabled their respective water quality requirements to be predicted, as well as the potential for water conservation or substitution of mains water with an alternative source.

A number of model parameters can be altered to change the simulated operating conditions of the water system, including fractions of water used by each sector, the potable water requirements, the potential for water conservation, and the fraction of consumers using conservation measures.

The data on water demand (quality and quantity) were then combined according to a particular water management scenario to explore the system characteristics such as the volume of effluent discharge to the sea, shortfalls in supply and thus storage requirements, or the need for additional pumping from the River Murray.

Table 10.2
Historical Rainfall Sequences used in Modelling

Climatic Conditions	Period	No. of Months	Highest Monthly Rainfall in Period, mm	Mean Annual Rainfall Over Period, mm
Drought	Jan 1895 - Dec 1899	60	94.2	373
Average	Jan 1940 - Dec 1946	84	146	437
Wet	Jan 1889 - Dec 1893	60	195	579

Modelling was undertaken using three different climatic conditions via historical rainfall sequences selected specifically to represent drought, average and wet climatic conditions. The historic series are summarised in Table 10.2.

The series were selected following an examination of the 5 year moving average of historical annual rainfall using the longest continuous period of rainfall record; this was available for the rainfall gauging station located at Salisbury Post Office (BM023023). An averaging period of 5 years was adopted because it was neither too long to 'flatten out' the peaks and troughs of the annual rainfall history, nor too short to enable a meaningful assessment of system operation under extreme conditions.

The period of record selected for simulation of drought conditions was the lowest 5 year average annual rainfall; the period of wet weather was the highest 5 year rainfall. In the case of average rainfall conditions, a number of 5 year periods were identified that possessed a 5 year average annual rainfall equal to the long term average annual rainfall for station BM023023. This period of record provided the longest period of useful record, spanning 3 consecutive 5 year periods (or 7 years in total). The accumulated rainfall for the adopted periods of record are illustrated in Figure 10.3. There is no consideration of the potential impacts of the Greenhouse Effect on any of these alternative development strategies, given that a substantial natural variability has already been considered.

The resulting model is one that is based extensively upon historical data for the region, and not only simulates water use over time (i.e. monthly time step), but also by sector (e.g. residential, industrial) and application (e.g. garden watering, industrial

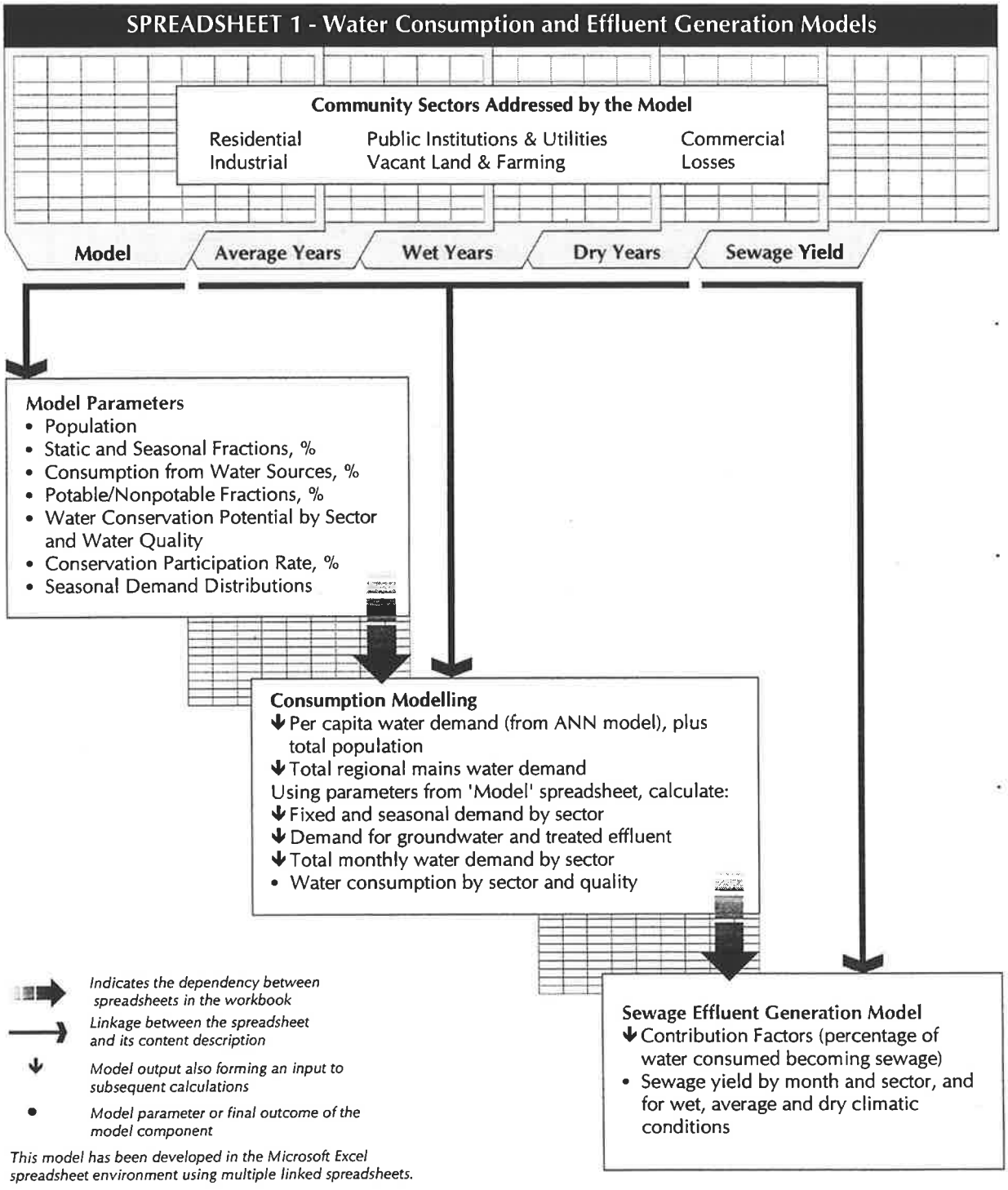


Figure 10.2(a)

Computational Components of the Water Management Model

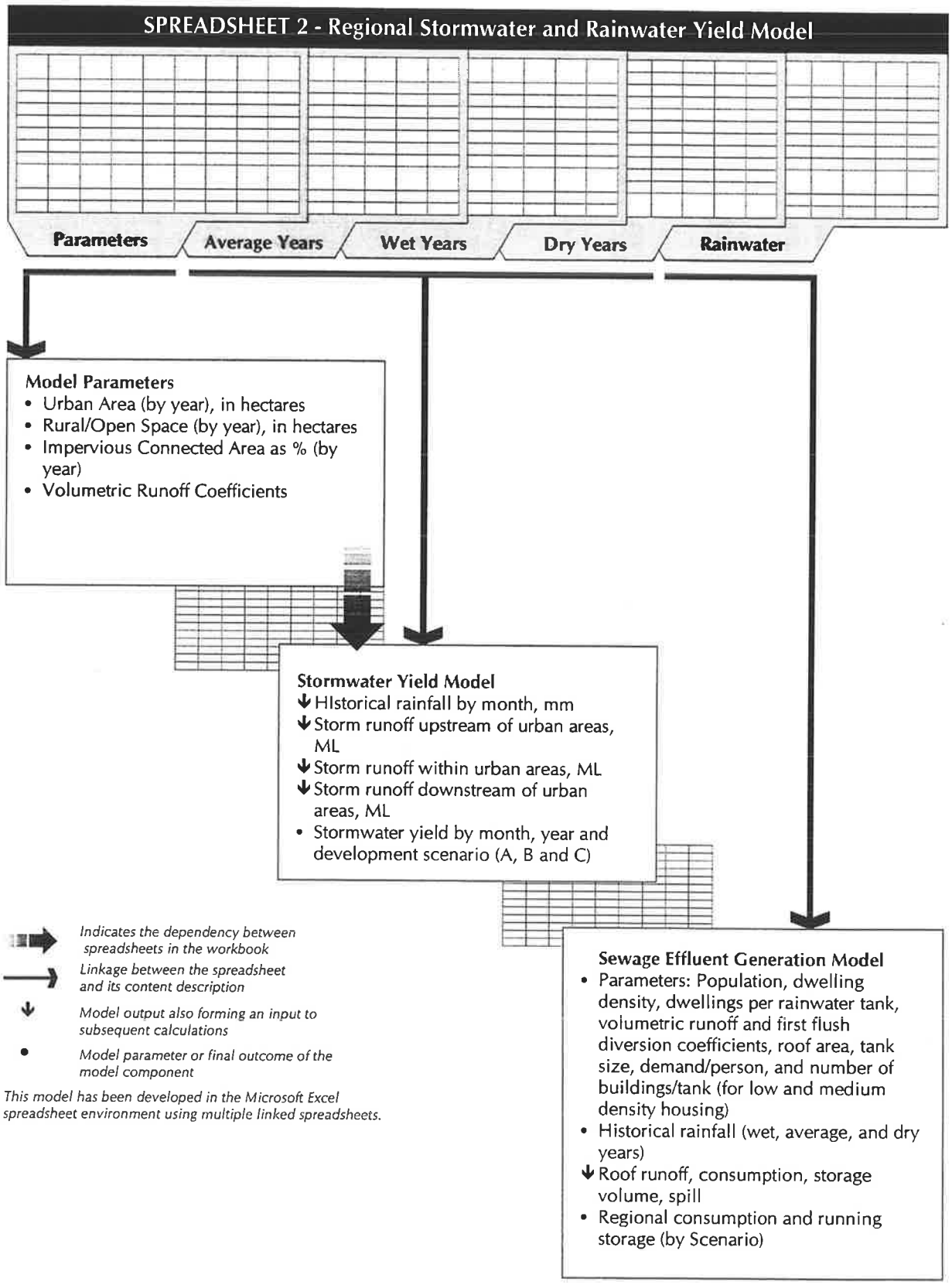


Figure 10.2(b)

Computational Components of the Water Management Model

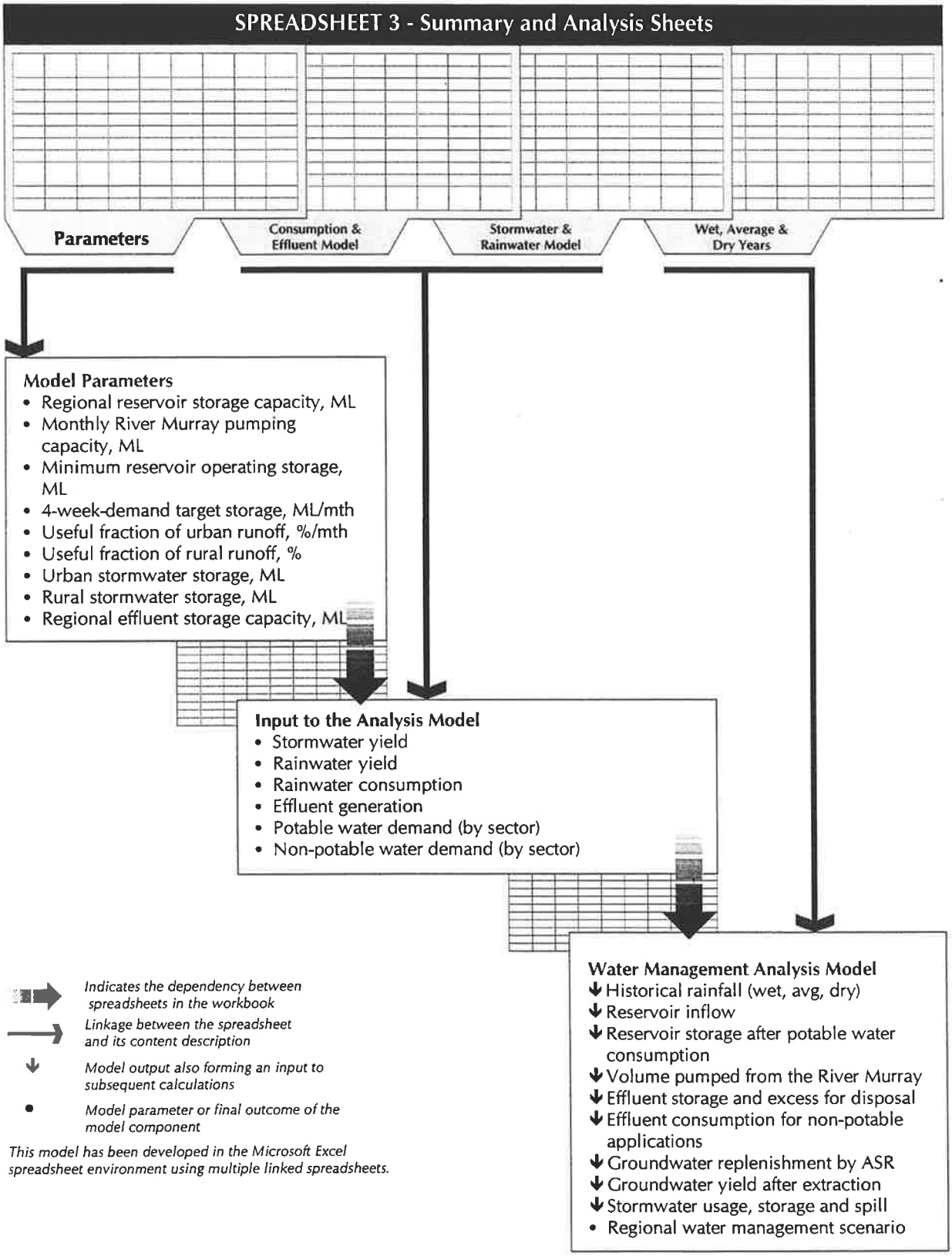
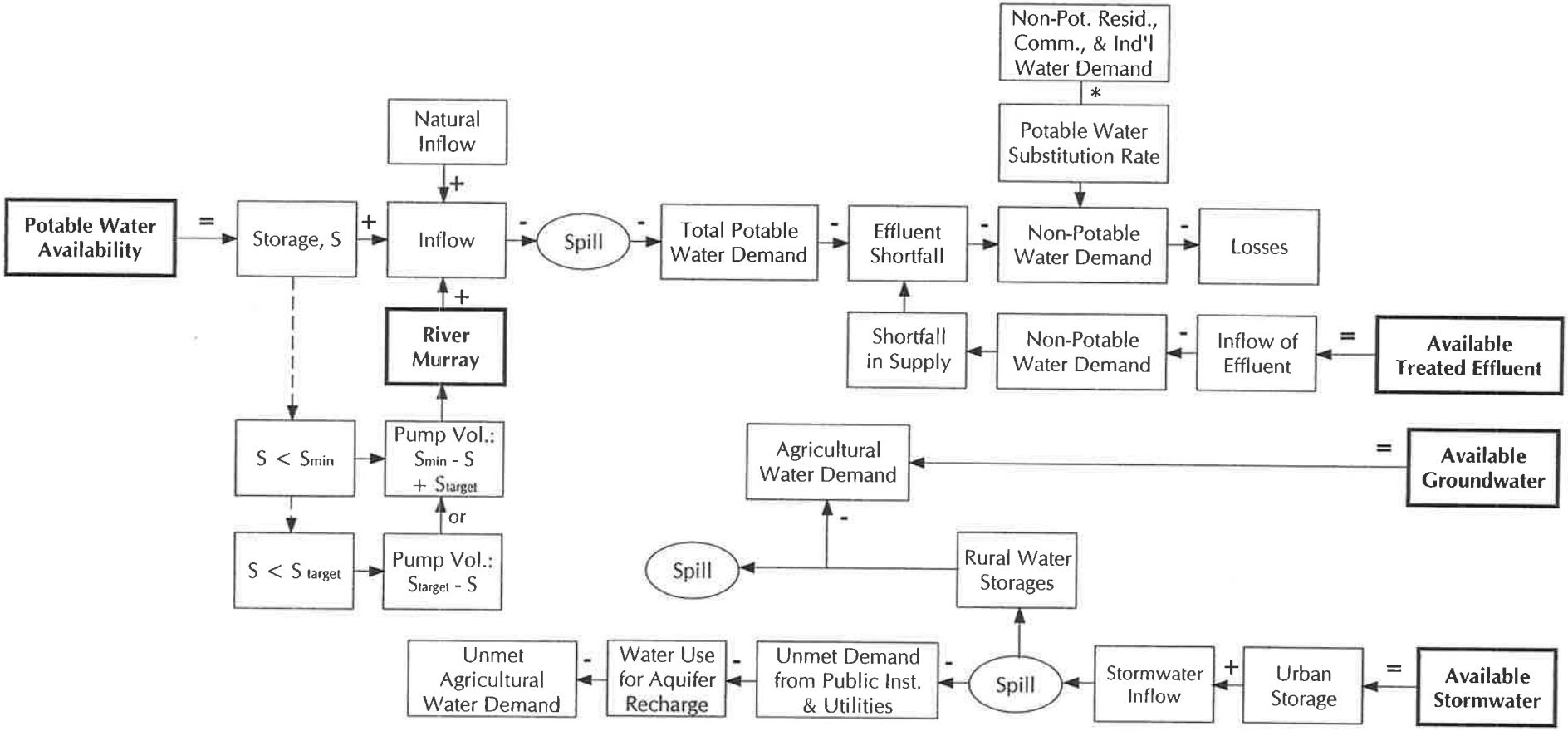


Figure 10.2(c)

Computational Components of the Water Management Model



This figure illustrates the dependencies between sources of water and demand for water that were used in examining the potential benefits of alternative water allocation and management strategies according to Scenario C.

\+ *Indicates the inflow of water*

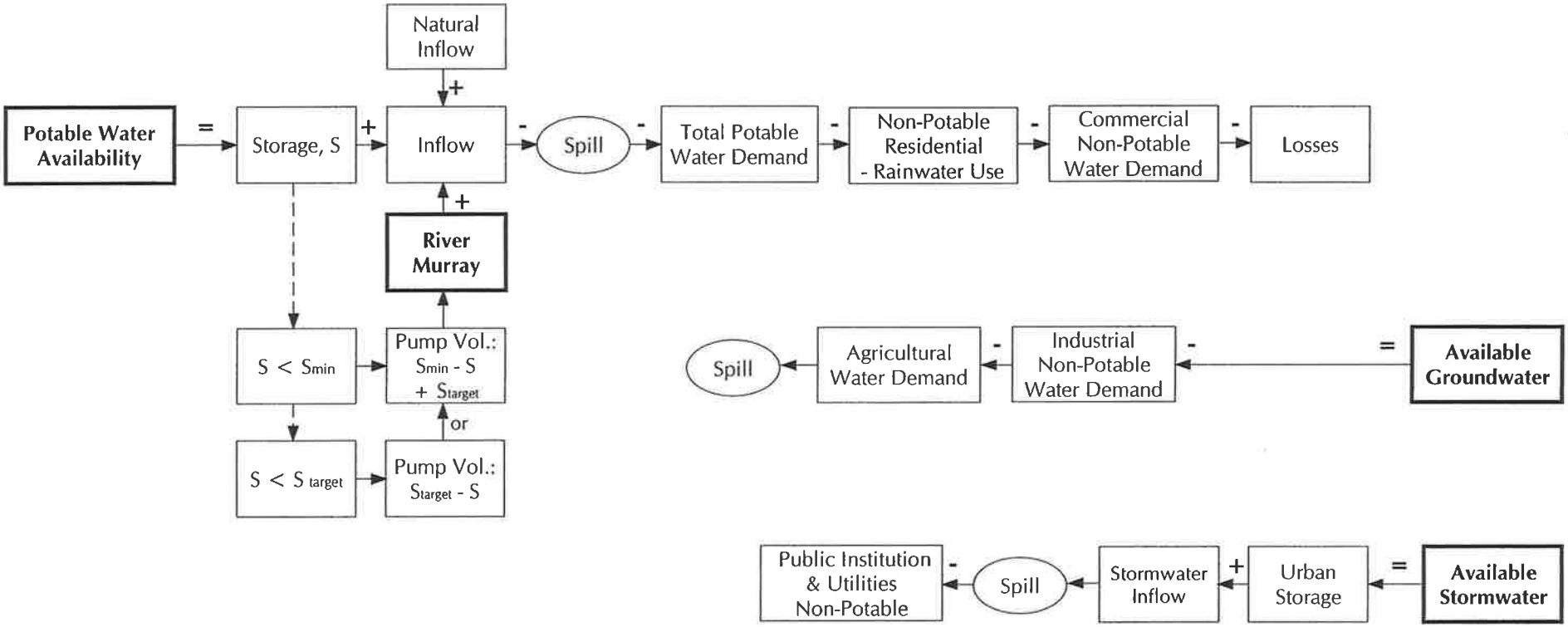
\- *Indicates the extraction of consumption of water*

* *The mathematical product of the defined model components*

→ *Indicates the sequential order of water inflow or outflow to meet demand*

Figure 10.2(d)

Computational Process of the Water Allocation and Management Model - Scenario C



This figure illustrates the dependencies between sources of water and demand for water that were used in examining the allocation and management of water according to Scenarios A and B.

\+ *Indicates the inflow of water*

\- *Indicates the extraction of consumption of water*

* *The mathematical product of the defined model components*

⟶ *Indicates the sequential order of water inflow or outflow to meet demand*

Figure 10.2(e)

Computational Process of the Water Allocation and Management Model - Scenarios A & B

cooling). The demand for water is apportioned by the quality of water suitable for the particular application, from which the total demand for sub-potable sources such as treated effluent and stormwater is determined.

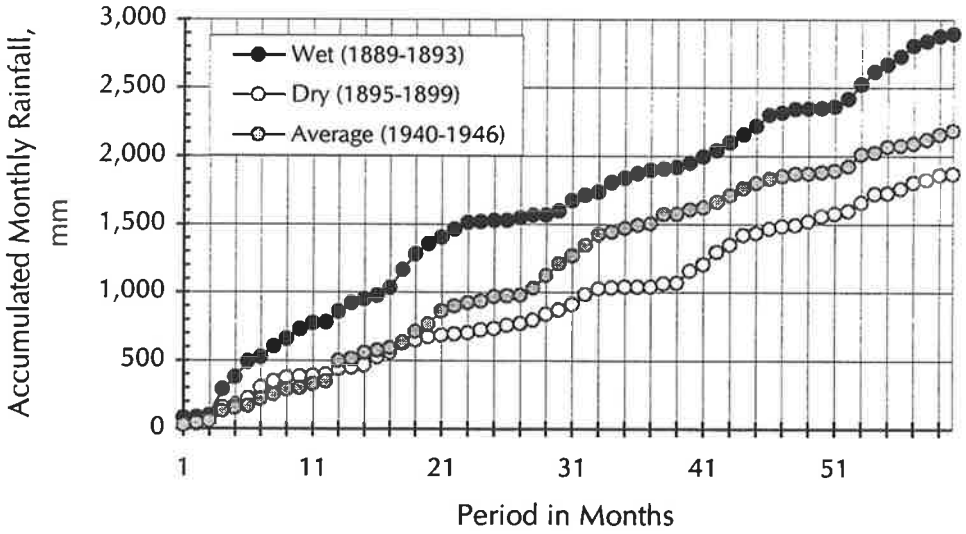


Figure 10.3
Accumulated Monthly Rainfall for Three Historical Rainfall Sequences

10.3. Population Growth and Land Use Change

10.3.1. Population Growth

The estimated current and future populations occupied within the region were derived from publications of the State Government and Australian Bureau of Statistics. Recent projections of population for the metropolitan area and associated local government areas (LGAs) were available for the period 1986 to 2011, along with forecasts relating to the change in household structure and the number of persons per dwelling (DEP, 1989; ABS, 1991; ABS, 1993; and DHUD, 1996).

Population projections for South Australia and Statistical Divisions were available for the period 1991-2026. These projections were used to extend the population data for LGAs beyond 2011. The highly correlated polynomial functions representing the historical and projected movements in the NAP population, both in absolute terms and as a fraction of the metropolitan Adelaide population, were combined to calculate the NAP population during the period 1996 to 2020.

The number of dwellings within the region was calculated from the projected population for each LGA and the number of persons per dwelling. A polynomial function was also derived from historical data to represent the declining rate of household occupancy in the region. The resulting projections are summarised in Table 10.3 and depicted in Figures 10.4 and 10.5.

During the period 1996 to 2020, the population is projected to increase from 230,681 to 317,150 persons, which includes an estimated 11,000 people that will

move into the area in association with the MFP development of Mawson Lakes at Greater Levels (Thomas *et al*, 1994). The greatest population growth will occur within the LGAs of Munno Para and Gawler, but this results in a higher relative increase in dwelling numbers due to a decline in dwelling occupancy from 2.92 to 2.60 persons/dwelling over the same period.

Table 10.3
Population and Dwelling Projections for the NAP, 1986-2020

Year	Elizabeth	Gawler	Munno Para	Salisbury	Light & Mallala	Tea Tree Gully[1]	Enfield[1]
	Estimated Resident Population by LGA						
1986	31,473	12,773	28,359	99,044	2,736	9,207	419
1991	30,233	15,138	35,055	110,783	3,173	10,886	422
1996	28,310	20,174	47,725	118,518	3,625	11,879	450
2000	27,420	24,614	57,872	121,156	3,981	11,879	450
2005	26,706	33,855	66,838	122,018	4,426	11,879	450
2010	26,514	43,009	74,569	121,336	4,871	11,879	450
2015	26,514	48,038	82,501	121,336	5,315	11,879	450
2020	26,514	50,000	90,210	121,336	5,760	11,879	450
Abs. Change	-4,959	37,227	61,851	22,292	3,025	2,672	31
% Change	-15.8	292	218	22.5	111	29.0	7.4
	Estimated Dwelling Numbers by LGA						
1986	10,796	4,504	8,807	31,230	888	2,967	155
1991	10,967	5,552	10,928	35,998	1,046	3,617	165
1996	9,708	6,918	16,367	40,644	1,243	4,074	154
2000	9,603	8,621	20,268	42,432	1,394	4,160	158
2005	9,593	12,161	24,008	43,828	1,590	4,267	162
2010	9,756	15,825	27,438	44,646	1,792	4,371	166
2015	9,980	18,082	31,055	45,673	2,001	4,472	169
2020	10,196	19,227	34,689	46,658	2,215	4,568	173
Abs. Change	-600	14,723	25,882	15,428	1,327	1,601	18
% Change	-5.6	327	294	49.4	150	54.0	11.4

(1) Assumes that the area for residential development within the LGA and Study Area becomes fully developed by 1996 and accommodates no further dwelling expansion except via urban consolidation.

10.3.2. Current and Conventional Land Use

The characteristics of existing and historical land use within the region were determined using the ARC/INFO geographical information system. Spatial data was provided by DENR, DHUD and other government agencies, and was also digitised directly from topographical maps.

The area of currently developed land, according to each primary category of land use zoning, was determined by super-imposing the current urban boundary over land zoning plans. In a similar way, the area of land outside of the urban boundary still available for development was identified. Refer to Table 10.4.

Table 10.4
Land Use in the Study Region (in hectares)

Land Use	Elizabeth		Gawler		Munno Para		Salisbury	
	Developed	Undev.	Developed	Undev.	Developed	Undev.	Developed	Undev.
Commercial	2	0	29	0	13	0	106	30
Community	79	0	0	0	90	427	225	178
Conservation	0	0	0	0	4	6,577	0	25
Industrial	457	1	17	16	24	3,197	642	2,957
Other	0	0	129	84	0	1	71	5,062
Recreation	181	0	0	0	0	0	20	54
Residential	1,318	0	897	297	1,414	1,399	4,703	238
Rural	0	0	16	2,629	1	19,455	87	1,434
Total	2,037	2	1,089	3,025	1,545	31,056	5,854	9,978
Full LGA		**2,039**		**4,114**		**32,604**		**15,832**
Total developed area within the Study Region, ha								10,524
Total undeveloped area within the Study Region, ha								44,061
Other areas outside these LGAs but within the Study Region, ha								10,523
Total area of Study Region, ha								65,109

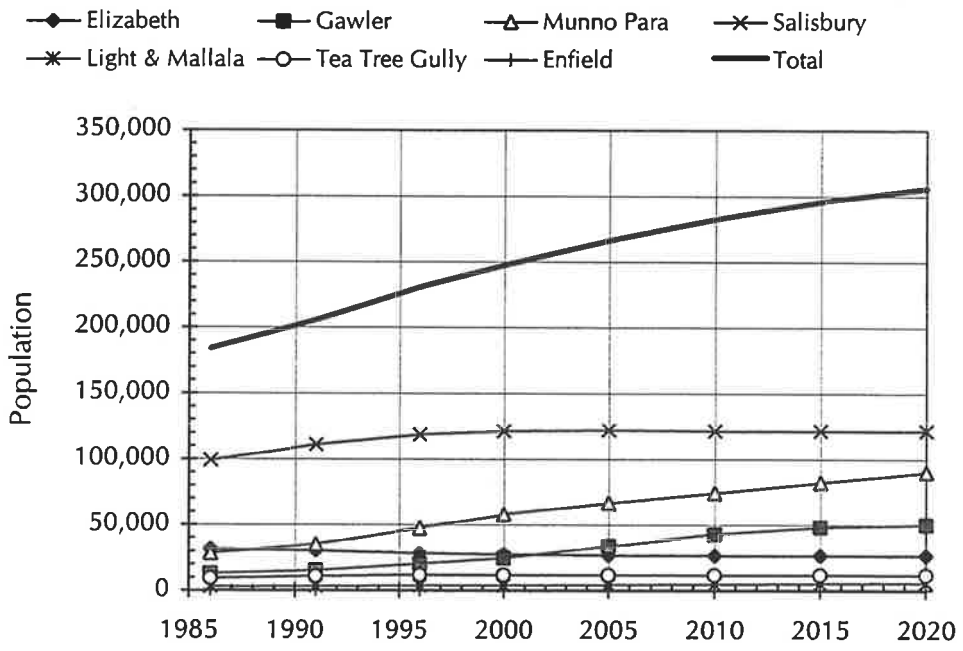


Figure 10.4
Projection of Population Residing Within the NAP

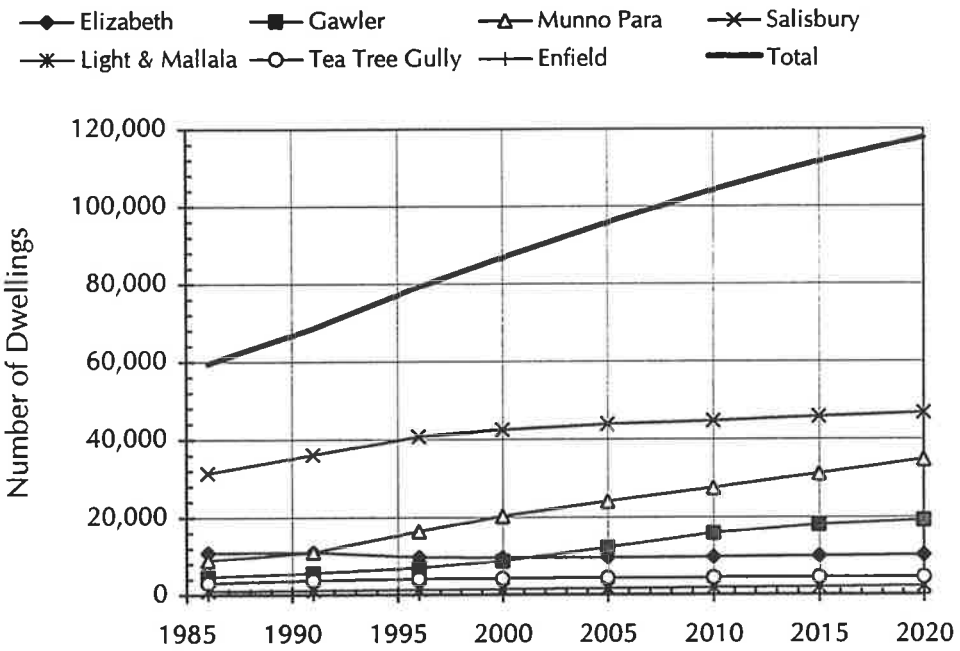


Figure 10.5
Projection of Dwelling Numbers on the NAP

Projections of land consumed by urban growth were based upon the population projections. Two methods were used to predict the rate of land consumption with urban growth. The first method employed published data regarding the typical mix of land use in urban areas. The required residential area was calculated from the projections of dwelling numbers (thus automatically taking into account the changing number of persons per dwelling) and a mean dwelling density of 25 d/ha. Having calculated the required land area for residential development, the total area of new urban development was estimated on the basis that residential areas typically occupy around 44 percent of the entire urban area; refer to Table 10.5.

Table 10.5
Typical Land Use Mix and Surface Types in Australian Cities

Components of the Urban Area at a Regional Scale	Conventional Urban Areas[1]		
	Occupied Land, %	Pervious Area, %	Impervious Area, %
Residential	44	57.5	42.5
Industrial	15	25	75
Commercial (with mixed residential)	3	15	85
Retail (with some mixed residential)	6	5	95
Schools and public institutions	2	70	30
Roadways	20	20	80
Recreation and open space	10	95	5
Estimate for Entire Urban Area	100	44.7	55.3

(1) After KDJV (1991), PAS (1992), Kemp (1993), and Tomlinson et al (1993)

The second approach was based on an estimated per capita urban land take, derived from actual land use data for the region and more recent residential development trends. The data indicated that with 25 dwellings per hectare, typical of recent housing densities (e.g. Golden Grove), the land take on a per capita basis for all land uses is around 420 m². This land area includes not only residential land but also commercial, industrial, public institutions and recreational spaces. Rural and conservation areas are not included. The changes in dwelling occupancy rates were also taken into account. Hence, the progressive development of urban land was calculated as the product of the per capita land take and the incremental population change. Both methods gave very similar outcomes, with approximately 3,200 hectares of currently undeveloped land required for urban development under conventional development patterns over the period 1996 to 2020. The locations of the new urban development are illustrated in Chapter 11, along with the predicted progression of development over time.

These projections of urban land requirements enabled an assessment of the rate of consumption of 'zoned' land. It was found that under conventional development conditions, the presently undeveloped Residential land would be depleted by 2008, requiring re-zoning of some Rural Living land to accommodate any further residential development in the Gawler area. Similar re-zoning would also be required in Salisbury around 2020, if not for the release of land for residential development at the site of DSTO Salisbury.

Urban growth projections were also used to evaluate the change in stormwater yield with time. Of particular importance was the rate of development in open space or rural land to the east of the current urban area. Such development would increase the volume of stormwater passing through existing urban areas and place greater pressure upon the existing drainage infrastructure. In determining the rate of use of currently undeveloped land on the eastern hills face, it is assumed that development occurred incrementally 'at the fringe' in all areas zoned for development.

10.3.3. Land Use Adopting a New Urban Form (Scenario C)

In addition to the effects of changing population and housing occupancy rates, the impact of a changing urban form was also explored. A new urban form was assumed to evolve over time, approaching the style of urban development espoused in Chapter 9. Developing urban areas were assumed to reflect the new ideas on urban form and the benefit of mixed land uses, with older urban areas redeveloped in this vein as the opportunity arose. (Some assumptions have been made regarding the rate of redevelopment of existing urban areas, based upon the age of suburbs, whether they are primarily comprised of public housing, etc. This rate is expressed as a % of the existing urban area that has been redeveloped in the year of interest; refer to Appendix F).

The new urban matrix is assumed to be composed of neighbourhood areas that are clustered together to form urban villages with a population typically not exceeding 4,000 people. Several urban villages surround, and are served by, an urban 'district' that is commercial heart of the area, a centre of employment opportunities as well as recreational, social and cultural activities. The underlying design philosophy is

aimed at achieving a 'healthy' urban area - efficient in terms of infrastructure operation, while being socially and environmentally rewarding as well. The population within each urban node that is formed by the agglomeration of several urban villages around the urban district is limited by design to between 45,000 to 50,000 people. The influx of 11,000 people to the MFP development of Mawson Lakes forms part of a new urban district. Parameters of the urban form model are provided in Appendix F. The locations of the new urban districts are depicted in Chapter 11, where the progression of development is also illustrated.

The average household occupancy within the new urban areas is 2.5 persons per dwelling. The regional average housing density is 37 dwellings per hectare, a 50 percent increase over conventional suburban areas. The increase in density is largely attributed to higher densities in the core of the urban districts. Housing densities do increase in the urban villages and neighbourhoods, but to a lesser degree and the opportunity to own a single detached dwelling remains.

The road network is enhanced, not via more roads but rather an improved interconnection of streets. Streets in residential areas are typically narrower with benefits of reduced vehicle speeds, therefore with reduced land consumption, and a generally more pedestrian orientated environment.

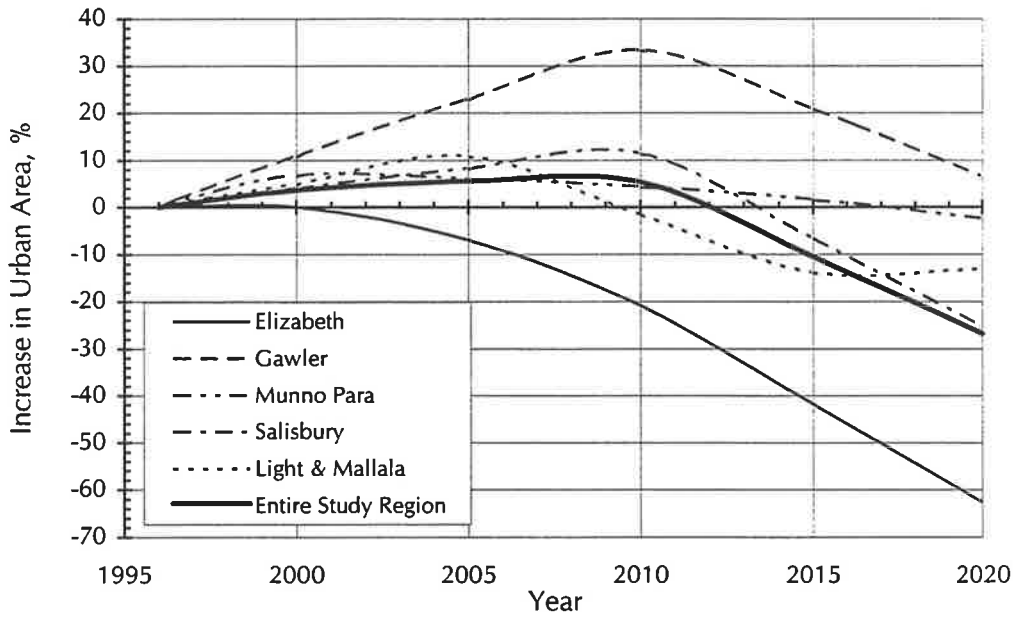


Figure 10.6
Change in the Area of Urban Land with the Adoption of More Compact Urban Forms

Based upon these assumptions and model parameters, it was determined that between 1996 and 2010 the region would experience an increase in the amount of urban land development due to population increase and limited opportunity for redevelopment of existing areas. After 2010, there is greater opportunity for urban renewal. By adopting the new form of urban development, the expanding population can be accommodated within a decreasing land area, reduced to around

73 percent of its original size by 2020 and providing the opportunity to return land to open space, farming land or for restoration of natural habitat. This change is reflected in Figure 10.6.

10.3.4. Impervious Area

An assessment was also made of the impervious and pervious areas within Australian cities, and the potential change in impervious area that could be expected with urban consolidation in established urban areas, or with the adoption of a new urban form. The data upon which the analysis was made is in Appendix F.

The analysis indicated that if urban consolidation was adopted throughout the entire residential area, there would be an increase in impervious surface of approximately 12 percent. This translates to an increase in impervious surface of 4.5 percent for the entire urban area.

Should the existing urban area have been developed according to the guidelines for the 'new urban form', the area of impervious surface would be approximately 15.5 percent greater (Table 10.6) in suburban areas and 8 percent greater on the whole (taking into consideration the difference in land use mix compared with conventional urban areas).

Table 10.6
Potential Impact of New Urban Form Upon Impervious Surface Area(1)

Component of the Urban Area	Conventional Urban Areas			New Urban Form Areas		
	Occupied Land, %	Pervious Area, %	Imperv. Area, %	Occupied Land, %	Pervious Area, %	Imperv. Area, %
Residential	58	57.5	42.5	47	39.8	60.2
Industrial	0	25	75	9	15	85
Commercial (with residential)	2	15	85	3	10	90
Retail (mixed some residential)	6	5	95	3	10	90
Schools and public institutions	4	70	30	10	80	20
Roadways	20	20	80	17	20	80
Recreation and open space	10	95	5	11	95	5
Estimate for Entire Urban Area		50.2	49.8		42.5	57.5
Increase in Impervious Area by Moving to New Urban Form, %						15.5

(1) Occupied land and impervious areas estimated after KDJV (1991), PAS (1992), Kemp (1993), Tomlinson et al (1993), Arnold & Gibbons (1996) and other sources.

This data has been incorporated in the simulation of stormwater yield by accounting for changes in urban form over time, whether due to urban consolidation or the adoption of a more compact style of urban development.

10.4. Modelling Regional Water Consumption using Neural Networks

A reliable tool was required to predict the total consumption of water from the reservoirs of the northern metropolitan water supply system, from which the use of water by different consumer groups could be predicted. As part of this research, a detailed study was undertaken examining time series analysis and forecasting techniques suitable for such consumption modelling.

Three time series analysis and modelling methods were compared – multiple linear regression, time series analysis using the Box-Jenkins methodology, and artificial neural networks. Artificial neural networks were shown to provide the most robust and reliable model of regional water consumption using the fewest parameters.

The following discussion focuses upon data preparation and the outcomes of the study. A detailed discussion of the entire study including the factors that affect water demand, and the development of water consumption models using ANNs, multiple linear regression and the Box-Jenkins methods, is presented in Appendix G.

10.4.1. Preparation of the Model Input Data

The monthly mains water consumption for the NAP was equated to the sum of 'consumption' releases from the South Para, Barossa and Little Para Reservoirs. The SA Water Corporation provided the necessary data in the form of monthly Storage Behaviour Reports for reservoirs in the northern system, for the period 1972/73 to 1991/92. An example storage behaviour report is included in Appendix G.

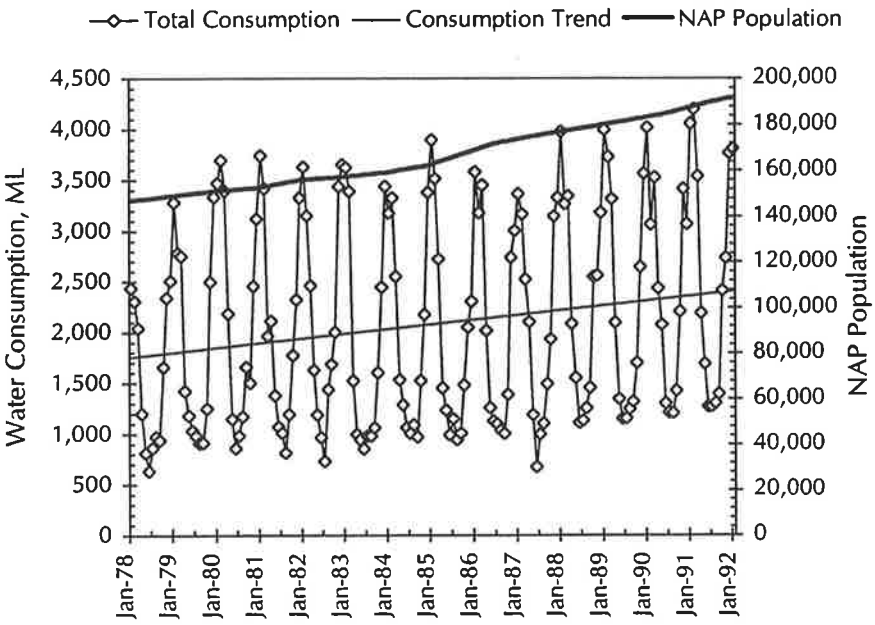


Figure 10.7
Consumption History for the Northern Adelaide Region

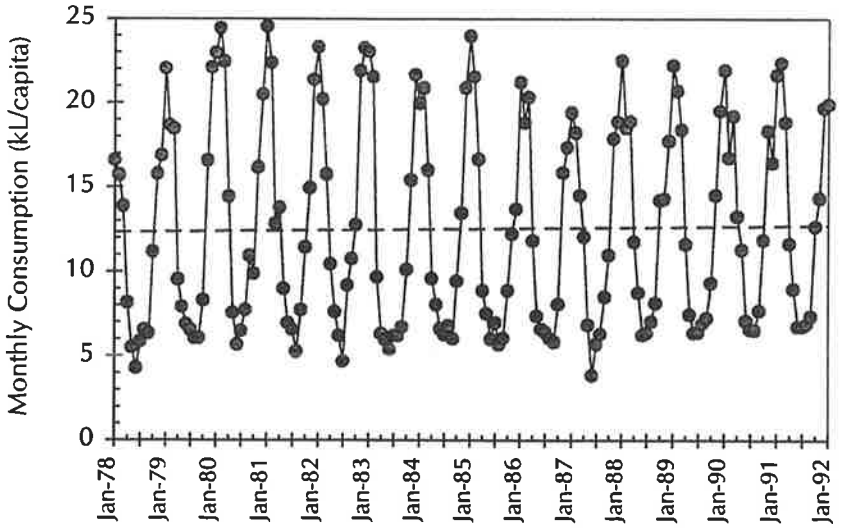


Figure 10.8
Per Capita Water Consumption for the Northern Adelaide Region

The consumption history for the northern region is shown in Figure 10.7, which also includes the water consumption trend and approximate population increase. Population estimates were prepared using historical data for the period 1979-1990 (ABS, 1981...1989), linearly interpolating between known records to determine monthly population data. This procedure was considered satisfactory because the increase in population was gradual and could be adequately represented between periods by straight line approximations.

The population data prior to January 1979 was estimated by linear extrapolation of the trend during 1979 back to January 1978. Population estimates to January 1992 were based upon Department of Environment and Planning projections (DEP, 1989). Figure 10.7 illustrates the near proportional relationship with consumption with population. Figure 10.8 shows that the per capita consumption trend has been nearly constant over the same period.

It is recognised that the consumption calculated as the sum of monthly releases from the storage behaviour reports does not represent water consumed only within the NAP. Approximately 20% of the water released for consumption is diverted to the Barossa Valley; however, this is not considered to be of great importance since:

- the model is of per capita water consumption rather than total water consumption, and there is a good relationship between population and consumption growth; and
- an analysis of water consumption on the NAP by individual consumer records indicates that approximately 90% of total consumption is associated with residential properties; refer to Chapter 7.

Table 10.7
Linear Correlation, r^2, Between Consumption Model Variables

	Month of the year	Monthly rainfall, mm	Total month evap'n, mm	No. of days with rainfall in the month	Per Capita Consumption, kL/mth	Real price of water, ¢/kL
Month of the year	1.00	0.17	-0.18	0.29	-0.27	0.07
Monthly rainfall, mm		1.00	-0.63	0.78	-0.69	-0.03
Total month evap, mm			1.00	-0.76	0.94	-0.09
No. of rain days/mth				1.00	-0.80	-0.02
Cons./Capita, kL/mth					1.00	-0.02
Real price of water, ¢/kL						1.00

In addition to the high residential consumption, there is a strong seasonal component. Therefore, on the basis of the review of significant demand forecasting factors (Appendix G), numerous seasonally related factors were chosen to test their influence in predicting water consumption. Table 10.7 lists the variables chosen, as well as the cross-correlation between the variables. As might be expected, evaporation and rainfall are strongly correlated, with per capita consumption being most highly related to evaporation.

Monthly rainfall and evaporation data were extracted from HYDSYS (a hydrological time series database) for the period January 1978 to January 1992. The rainfall record comes from the gauging station at Salisbury Post Office (BM 023023). This is a reliable station that is representative of the average conditions for the region.

Evaporation data was available for the recording stations at Little Para Reservoir (January 1978 to June 1992) and Bolivar WWTP (January 1972 to March 1989). Both records were incomplete, but the Little Para Reservoir record had far fewer gaps and was therefore adopted. A high correlation existed between the Little Para Reservoir and Bolivar evaporation records (r^2 = 0.992). A linear regression relationship was therefore used to estimate monthly evaporation at Little Para Reservoir in situations where gaps of a few months existed. Where the monthly evaporation total was not presented because a record was missing for only one day during that month, the evaporation was pro-rated on a daily basis:

$$\text{Monthly Evaporation} = \sum_{\text{Days in month } i} (\text{Known Evap. Per Day}) + \text{Number of days of missing data} \times \text{Avg. Daily Evap.}_{\text{Month } i} \quad (10.1)$$

The marginal price of water (cents per kilolitre) charged by SA Water for excess consumption was obtained from Dandy (1987) and Crawley (1992). Consumer Price Index data for Adelaide were obtained from Australian Bureau of Statistics publications. The Consumer Price Index data was modified to a base year of 1978/79, and combined with the marginal price of water to determine the real marginal price of water for the same period. The real price of water was assumed to be constant throughout each financial year.

10.4.2. Findings of the Study

The study clearly demonstrated the superior modelling and prediction capabilities of ANNs over regression and time series methods. While the increased accuracy and reliability may in some cases not be large, such small improvements in forecasting accuracy can often provide considerable savings (Makridakis *et al*, 1982).

Significant variables in the prediction of per capita consumption on the NAP were found to be the month of the year, and rainfall in the 'current' and previous months. Evaporation and the number of days with rain during the month, although strongly correlated with rainfall, did not feature in the best models. The real marginal price of water was not a significant variable, a conclusion similar to that of Dandy (1987).

The availability and quality of input data sets for causal models is a highly significant factor in determining the usefulness of these models and the forecasts they produce. The forecasting ability of the preferred ANN models was therefore tested using average values (based upon historical data) for each input parameter in the month of forecast. For example, the average monthly rainfall for January would be used to forecast the consumption for January, also employing the historical rainfall data for the previous months. The testing confirmed that ANNs were superior to multiple linear regression models using average monthly data for the month of forecast.

The seasonal patterns have been predicted equally well by both simple and statistically sophisticated methods. However, neural networks demonstrated the ability to provide improved forecasts with fewer variables. An ANN was therefore adopted as the consumption forecasting tool.

10.5. Sectoral Consumption Patterns

The prediction of water use by specific consumer groups from the estimated regional water consumption was undertaken on the basis of consumption patterns determined from historical data. Six main categories of consumer were identified from mains water consumer data, within which several sub-classes of consumer were also specified; these are summarised in Table 10.8.

All available historical data was analysed to determine the proportion of water used within each sub-class of consumer type according to the source of supply, whether reticulated mains water, groundwater or treated effluent; refer to Table 10.9. Any existing use of stormwater was ignored as it would constitute only a very small fraction of the total volume of water used within the region.

The 'fraction of total consumption' listed in Table 10.8 indicates how much water is used from all sources by each group of consumers during an average year (remembering that the historical data sets used to determine these fractions only comprise several years of record). A more detailed breakdown is contained in Appendix H.

Table 10.8
Consumer Types Represented in the Simulation Model

Consumer Type	Fraction of Total Consumption	Sub-Classes by Consumer Type
Residential	36.7 %	Single unit Home units and double units Institutional residential accommodation Flats, private hotels, hostels and boarding houses Hotel and motel accommodation Rural living areas
Commercial	1.3 %	Wholesale and retail trade Construction and repair services Professional, personal and business services
Industrial	9.8 %	Food, beverage and tobacco Paper and paper products, printing and publishing Chemicals, petrol, coal, rubber and plastic products Textiles, clothing and leather industries General manufacturing, metal industry, etc.
Public Institutions and Utilities	4.5 %	Educational Places of assembly, cultural activities and exhibitions Government, medical, social, armed services etc Gas, electricity, water, sewage, waste disposal
Vacant Land / Farming	42.6 %	Undeveloped reserve, vacant allotment or car park Agistment or farming land Stock and/or stock and domestic land
Losses	5.0 %	None

Tabulation of water consumption according to consumer type and source provided information on the quantities of water used according to each source. Coupling the information on the typical fraction of water consumed each year by (i) consumer type, and (ii) by source, enabled the reverse calculation to be made, of sectoral water consumption from total regional water consumption. The use by consumer group and source was calculated from the regional consumption of reticulated mains water predicted by the ANN model.

Table 10.9
Typical Water Consumption According to Consumer Type and Source as %

Consumer Type	Reticulated Mains Water	Groundwater	Effluent from Bolivar WWTP	Total Water Use
Residential	65.0	0.0	0.0	36.7
Commercial	2.3	0.0	0.0	1.3
Industrial	12.1	6.9	0.0	9.9
Public Institution & Utilities	7.5	0.7	0.0	4.5
Vacant Land / Farming	4.5	92.1	100.0	42.7
No Classification or Losses	8.6	0.3	0.0	5.0
All Consumers	56.5	43.5	0.0	100.0

The historical data was analysed further to determine the seasonal and non-seasonal fractions of use for each consumer group. Additional data relating water use to the application of consumed water was sourced largely from journal publications (such as Environment Canada, 1986; Ploesner *et al*, 1992; AWWA ,1993).

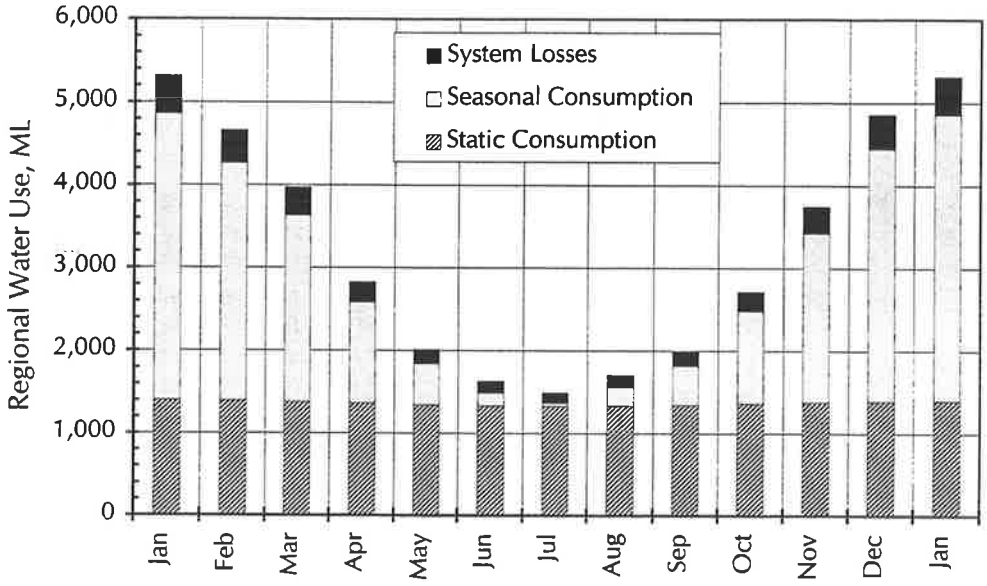


Figure 10.9
Basic Components of Regional Water Use

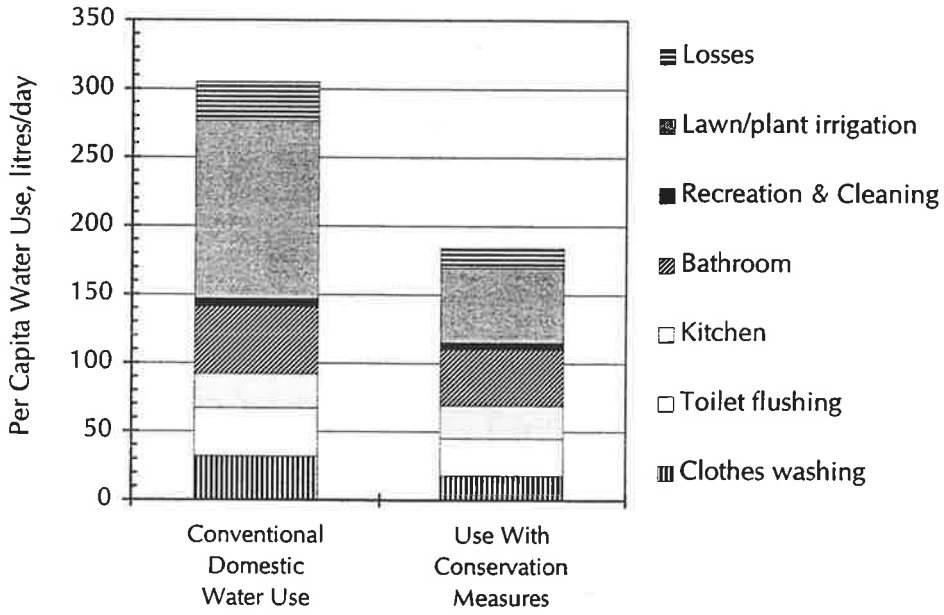


Figure 10.10
Water Use on a Typical Domestic Property in Adelaide, SA

The seasonal distribution of residential water use was inferred directly from the regional water consumption distribution provided by the ANN model. Given that the majority of mains water use is associated with the residential sector, the highly

seasonal distribution of regional water use was considered to be an appropriate and reliable reflection of the seasonality of residential consumption (Figure 10.9).

The static or fixed fraction of water consumed within the residential sector was determined from domestic water use data. This data indicates only 45 percent of water is typically consumed within a dwelling, with the remaining water applied outdoors, mainly for irrigation of lawns and gardens, or lost through system leaks and illegal connections. Refer to Figure 10.10.

The characteristics of industrial water consumption were determined from historical consumption data and records of 'major water users'. It was possible to segregate the consumers within the 'major water user' data set into three broad categories: irrigators, education facilities and industry. It was found that the irrigation and educational use was highly seasonal, peaking during the summer months, while the industrial used was predominantly non-seasonal in nature. These findings are illustrated in Figure 10.11.

Given that more specific local data relating to consumption patterns for the commercial, and public institutions and utilities sectors was largely unavailable, the seasonality of consumption was estimated from the seasonality of the typical components of water use within each sector.

The model parameters that have been adopted to divide the annual water use for a sector into 'static' or non-seasonal, and variable or seasonal components, are listed in Table 10.10. Consolidation of the data in Table 10.10 with that of Table 10.8 indicates that the fixed or non-seasonal portion of regional water use is approximately 48% of total annual consumption by volume. This means that the base consumption during each month would be roughly equivalent to 4% of the total annual consumption. A more complete breakdown of water use by sector and other background data has been compiled in Appendix H.

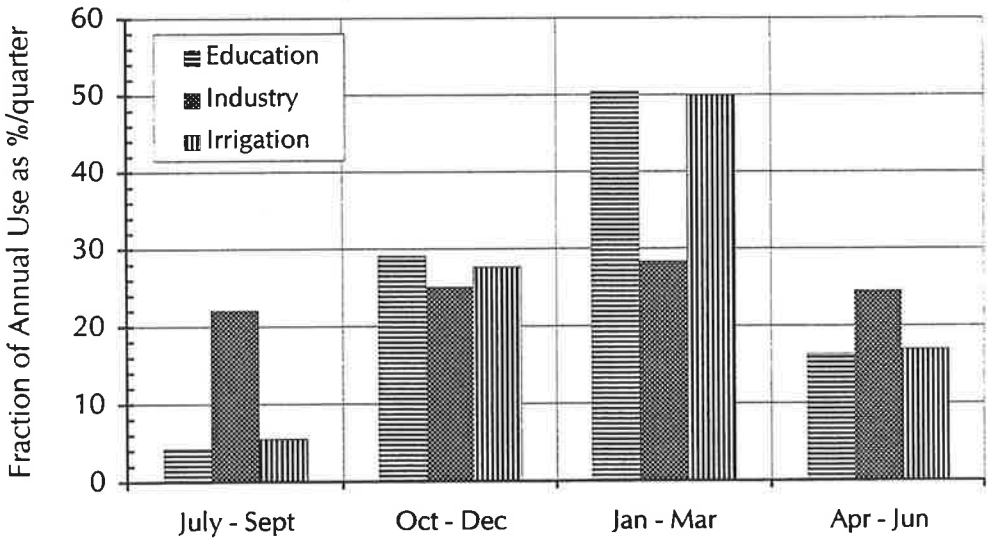


Figure 10.11
Seasonal Water Use Distributions According to NAP Major Water Use Data

Table 10.10
Water Consumption Model Input: Seasonality Parameters

	Residential	Commercial	Industrial	Public I&U	Vacant Land	Losses
Reticulated Water						
Static, %	46[1]	55	84	65	20	45
Seasonal, %	45	45	16	35	80	55
Major Mains Users						
Static, %	0	0	84	16	20	0
Seasonal, %	0	0	16	84	80	0
Groundwater						
Static, %	0	0	84	16	26	0
Seasonal, %	0	0	16	84	74	0
Bolivar Effluent						
Static, %	0	0	0	0	26	0
Seasonal, %	0	0	0	0	74	0

(1) The volume of water consumed within the residential sector (including losses) is determined on the basis of population using the ANN model. The model treats losses separately, and to avoid 'double-counting' of losses, a reduction in the percentage of total use is made. Thus the sum of percentages is not equal to 100%.

The flow chart of Figure 10.12 illustrates the sequence of calculations performed in simulation of regional mains water consumption. The ANN model provides the estimate of per capita water demand under given climatic conditions (represented by historical or synthetic rainfall data), which coupled with regional population data provides the estimate of total mains water use on the NAP in a particular month.

From the derived monthly distribution of regional water use, the sum over the period of January through December in each year provides the annual water use for all consumer groups. The product of annual water use (less system losses) and the non-seasonal use as a fraction of annual consumption (around 4%) gives the total 'static' demand for water in the month of interest.

During the process of constructing and auditing the water consumption model, it was determined that marginal seasonality in the 'fixed' component of water use was required to achieve consistency. This seasonality translated into an effective variation of 2.5% about the mean. No historical or published data was discovered that addressed the issue of seasonality of baseline water consumption that is un-related to seasonal (climatic) influences. This finding may reflect true variability in what is normally considered to be water use of an invariable nature, or more probably, a peculiarity of the model arising from its underlying assumptions and process of establishment.

The seasonal water use was simply determined as the difference between total and baseline water use in each month, less system losses.

The seasonal and non-seasonal consumption patterns of a particular consumer group were then calculated from the regional water use data according to the fraction of use for that particular group relative to all consumer groups. For the industrial

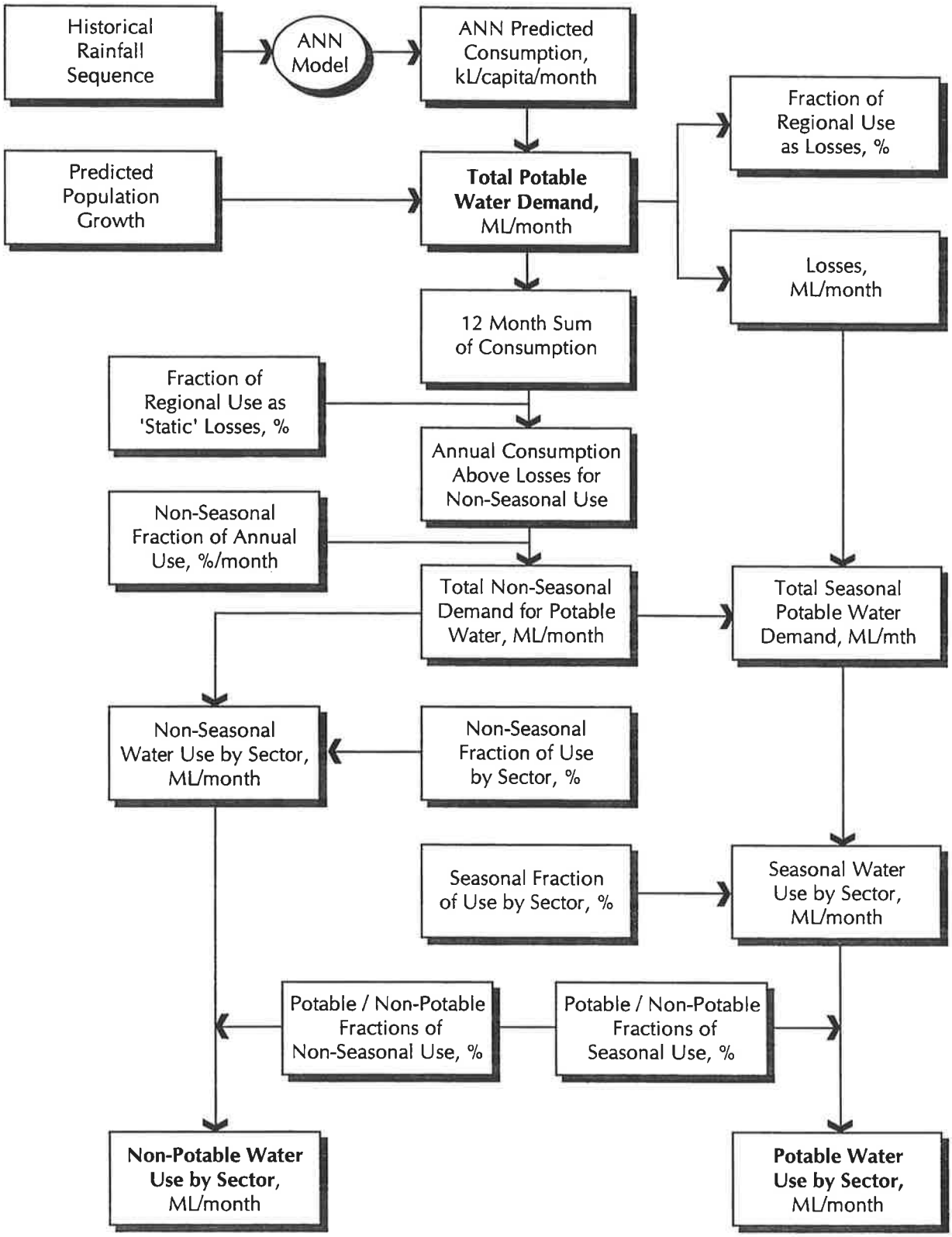


Figure 10.12
Model for Reticulated Potable Water Demand

sector, the volume of water consumed during a particular month under a seasonal distribution would be calculated according to the equation:

$$SU_{Industry} = \frac{SU\%_{Industry}}{\sum_{All\ Consumers} SU\%} \times Regional\ Consumption_{Seasonal} \qquad (10.2)$$

where

$SU_{Industry}$ = water use in the industrial sector within the seasonal distribution and the month of interest, in ML;

SU% = fraction of annual water use within the seasonal distribution, as % (for any particular consumer group);

This achieved the seasonal and sectoral model of consumption of potable water distributed through the Metropolitan Adelaide Water Supply System reticulation network. These consumption estimates were combined with simulated groundwater and sewage effluent consumption data.

An example of the input and output from the water 'consumption' model is contained in Appendix I.

10.6. Groundwater Availability and Extraction

The regional system of Tertiary aquifers provide the supply of groundwater for irrigation and industrial uses. The system of shallow Quaternary aquifers are generally too saline or low yielding to be useful sources of water and are therefore disregarded.

In the debate over groundwater management for the Northern Adelaide Plains Proclaimed Region (NAPPR) it is often forgotten that there is an enormous quantity of water held within the system of the Tertiary aquifers. The volume available for use is almost 800 times greater than the proposed 'sustainable yield' of 6,000 ML per year; refer to Appendix C. It has therefore been assumed that the Tertiary aquifers can be treated as an essentially limitless source of supply with respect to the range of likely and potential demands that could be placed upon the groundwater system within the time frame of consideration.

The adopted 'desirable limit' to groundwater extraction is, however, the rate of natural replenishment. Thus, groundwater yield available on an annual basis has been established at a nominal 6,000 ML/year or 500 ML/month.

10.6.1. Simulating Groundwater Extraction

Most of the groundwater extracted from the Tertiary aquifers of the NAP is used for irrigation of crops. The extraction of groundwater during a year would therefore tend to be seasonal in nature, being greatest during the summer months.

To simulate the rate of groundwater extraction, a relationship was sought between rainfall and extraction on an annual basis. A smaller time-step could not be used,

because the historical extraction data is neither collected or reported on a uniform basis. Just as the consumption of water from the mains reticulation system cannot be measured from all consumer meters at the same time, neither can the extraction from the hundreds of bores on the NAP. A monthly or even quarterly summary of groundwater extraction is therefore difficult to construct, because the meter reading from each bore would correspond to a different period of consumption.

A plot of annual groundwater extraction against annual rainfall shows considerable scatter, and a relationship with strong correlation cannot be developed between these parameters. Examining the historical sequence of annual groundwater extraction over the period 1970 to 1989 (see Figure 7.14 in Chapter 7), it is clear that there is a downward trend, determined to be equivalent to an average annual decrease of 100 ML per year. This trend would most likely be attributable to a combination of factors, including tighter governmental controls on extraction through licensing, increasing costs of fuel and pumping (Desmier, 1987), localised decline in water quality, and improvements in irrigation efficiency.

Removing this trend from the historical series provides a plot that shows less scatter and a relationship that would be more representative of the influence of climate upon extraction; refer to Figure 10.13.

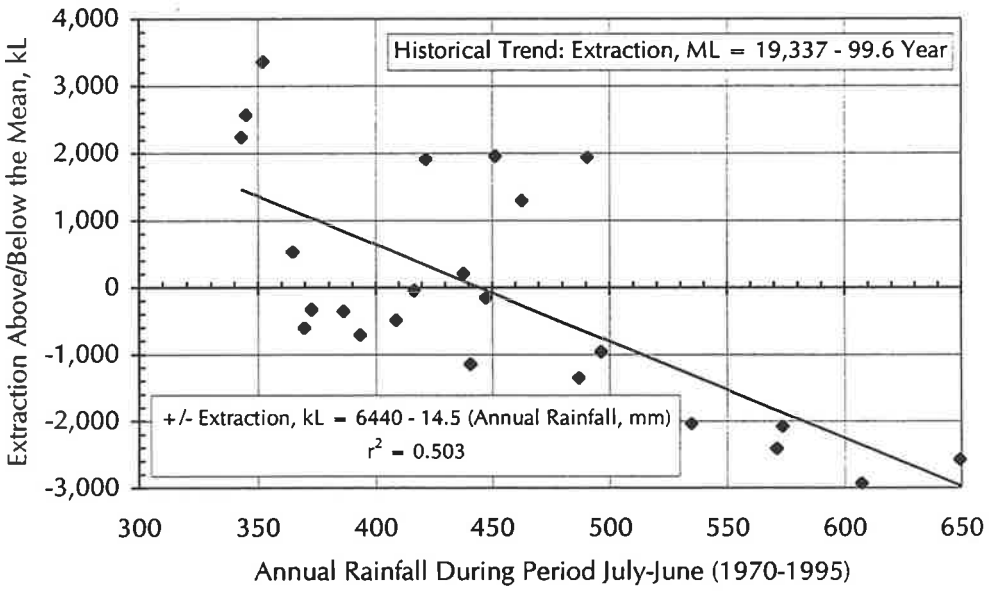


Figure 10.13
Relationship between Annual Rainfall and Groundwater Extraction

The linear relationship depicted in Figure 10.13 was adopted for the estimation of annual extraction based upon the annual rainfall for the year of interest. To reduce the estimated extraction from an annual to monthly time-step, the seasonal pattern of groundwater extraction from Roger Stokes & Associates (1995) has been adopted (refer to Figure 7.19 in Chapter 7). Under this pattern of consumption, around 88 percent of the total annual volume of consumed groundwater is extracted during the months of September through to and including April.

The seasonal extraction distribution was also used to segregate the monthly consumption into 'static' and seasonal components. The minimum fraction of annual extraction in any one month was considered to represent the baseline or static consumption above which the fluctuation in total consumption in any month was the result of the seasonal component of consumption.

The static and seasonal consumption distributions were further classified by consumer groups on the basis of historical data, and using a similar approach to that discussed in Section 10.5 above and Equation 10.2.

10.6.2. Aquifer Storage and Recovery

The opportunity to supplement the rate of natural recharge through artificial recharge or aquifer storage and recovery (ASR) technologies has also be considered. As previously discussed in Chapter 7, Shepherd (1975) first proposed a network of between 40 and 60 injection bores covering an area of around 250 km² at a minimum spacing of 2 km. Recharging for a period of 100 days at 2.5 litres per second, such a scheme would supplement natural recharge by 3,000 to 3,500 ML per year.

Research into the recharge potential of the NAP undertaken by Coffey Partners International (1993) concluded that a similar network of bores could recharge up to 5,000 ML per year, subject to quality and surface storage restrictions. Information from Gerges (1992, 1993) suggests that this figure may be a reasonable estimate. Indeed, ongoing work by Gerges (1996), Sibenaler (1996), Dillon & Pavelic (1996) and others has demonstrated that higher injection rates of between 10 and 20 litres per second is possible to the Tertiary aquifers of the NAP.

Table 10.11
Characteristics Assumed for an ASR Scheme

Feature	Magnitude
Minimum spacing of injection wells	2,000 metres
Effective (circular) area of coverage per injection well	315 hectares
Injection rate per well	15 litres/second
Period of well operation	15 hours/day
Injected water volume per operating month	24.3 ML
Period of injection	4 months per year
Annual recharge volume per well	97.2 ML

For the purpose of estimating the annual ASR potential, the network characteristics listed in Table 10.11 have been adopted. Assuming that the network of injection-and-recovery wells are established over a combined urban and rural area of 200 km², then a total of 64 wells would be required. With injection occurring during the wettest months of the year and for not more than 15 hours per day (allowing for shut-down to prevent noise pollution in developed and residential areas),

approximately 1,550 ML can be injected each month, with an annual volume of recharge of 6,200 ML.

Where ASR is implemented the sustainable yield of the aquifer system is considered to have been increased by the total volume of injected water. Annual extraction of groundwater could therefore be increased from 6,000 ML/a to around 12,200 ML/a without adverse consequences.

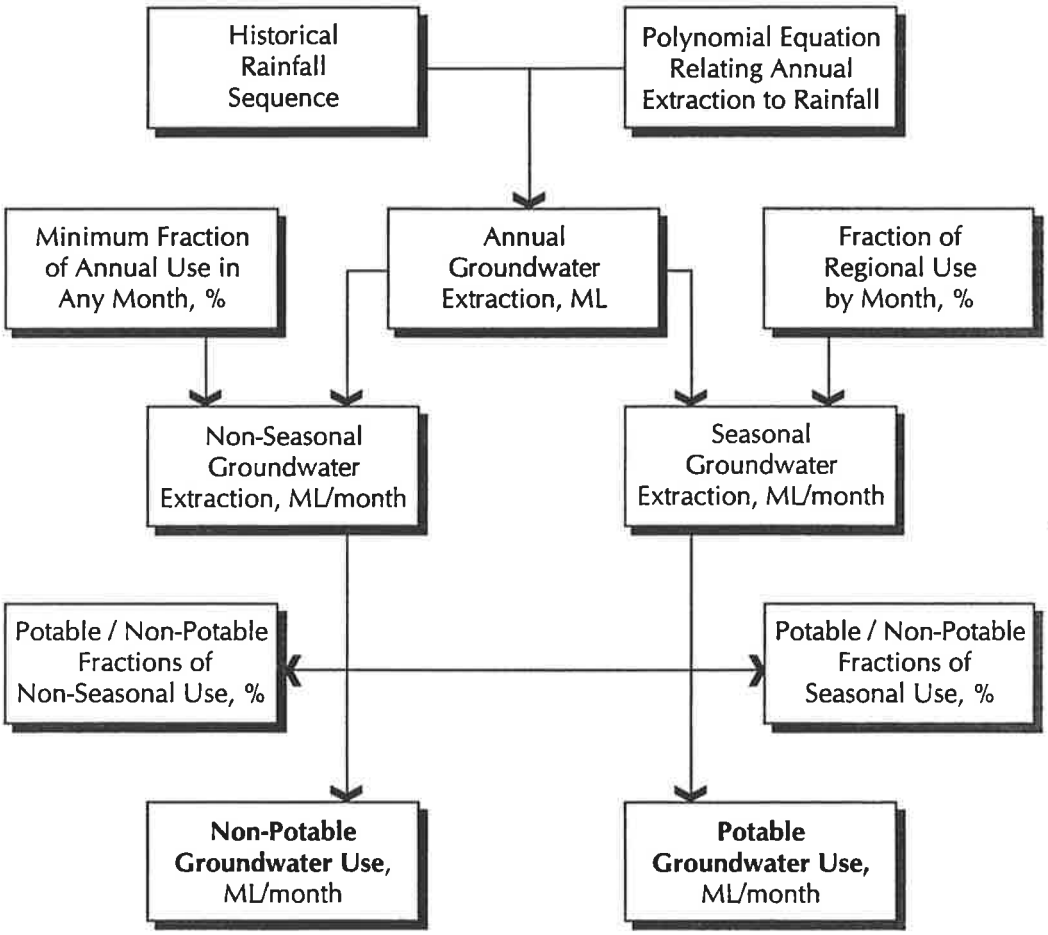


Figure 10.14
Model of the Consumption of Groundwater

10.7. Treated Sewage Effluent Generation

10.7.1. Bolivar Wastewater Treatment Plant

Historical data was available for the period of 1989 to 1993 on the rate of discharge of treated sewage effluent from the Bolivar WWTP. The mean annual rate of discharge for this period is 138 ML per day. This volume of discharged effluent is theoretically available for reuse, although seepage losses and evaporation and mismatches between supply and demand mean that the available volume for use is somewhat less.

While the flow of sewage is often considered to be relatively static in areas with separate stormwater and sewage drainage systems, there is nevertheless seasonality of flow with peak flows of up to 150 ML per day during late winter and early spring. Common causes of such increases in sewage flow are illegal connections of stormwater drains to the sewerage system and increased infiltration of groundwater through cracked sewers. The amount of rainfall therefore has a significant bearing on fluctuations in sewage flows.

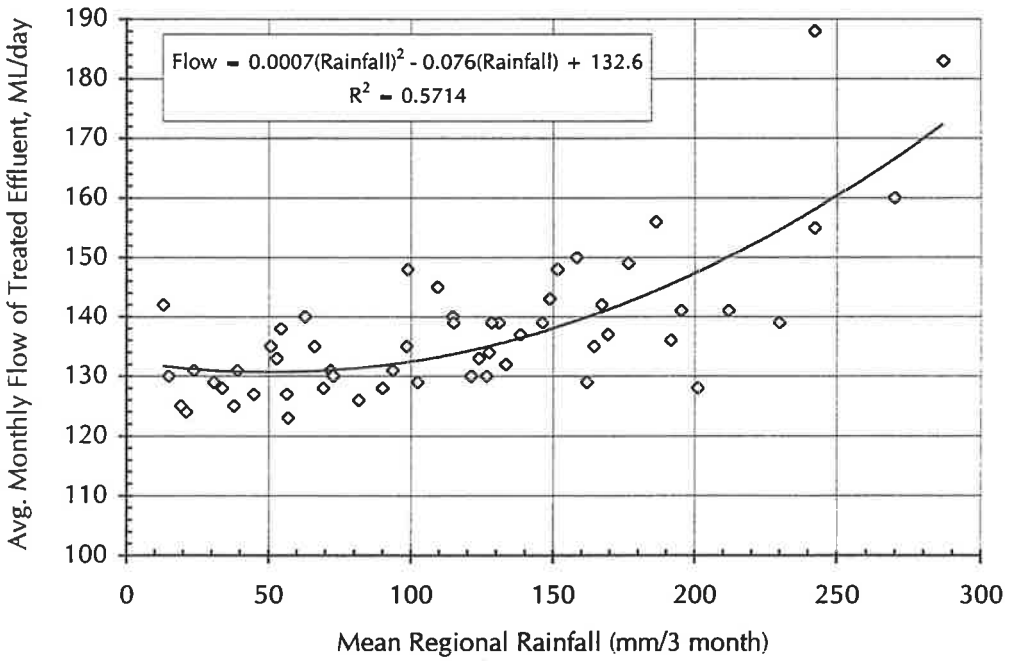


Figure 10.15
Relationship Between Effluent Flows from Bolivar WWTP and Rainfall

Predictions of effluent flows were therefore made through derivation of a simple mathematical relationship with rainfall as the causal variable. Relating the mean monthly effluent flow with a 3 month rainfall sum was found to produce the closest relationship. Taking the sum of rainfall that had occurred during the past 2 months with that in the (current) month of prediction was superior to using the rainfall during the current month only. Given that there is a 2 to 3 month lag between the peak in monthly rainfall and the peak monthly effluent flow, this suggests that there is response to rainfall, although the response is delayed. The infiltration of

groundwater is therefore likely to be a major cause of increased sewer flows during winter and spring.

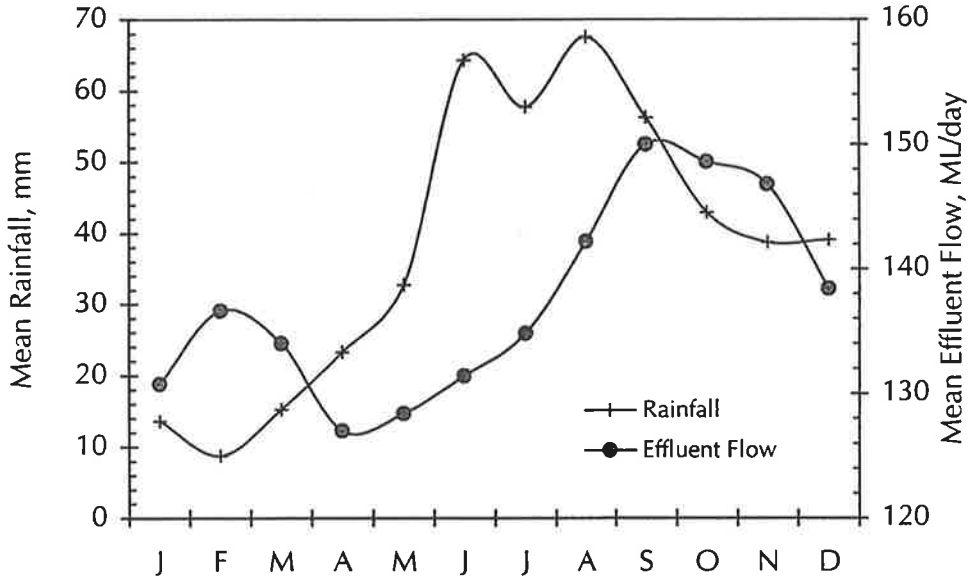


Figure 10.16
Trends in Mean Monthly Rainfall and Effluent Flow (1989-1993)

10.7.2. Current Effluent Consumption

As previously discussed in Chapter 7, there are some growers on the NAP adjacent to the Bolivar outfall channel who are extracting treated effluent from the channel for use in irrigation of crops. A simple model was developed to represent the current demand for use of this effluent. Using annualised data supplied by SA Water for the period 1986/87 through to 1992/93, a relationship was developed between effluent consumption and annual rainfall:

$$\text{Effluent Use, ML} = 3664 - 2.82 \times (\text{Annual Rainfall, mm}) \qquad (10.3)$$

A linear relationship was found to provide the closest fit to the data of any of the standard regression methods (those other than linear including power, logarithmic, exponential or polynomial), with a correlation of $r^2 = 0.70$.

Having approximated the annual demand for treated effluent (under the prevailing conditions), the monthly demand for effluent is calculated from an adopted seasonal consumption pattern. Given that the effluent pumped from the outfall channel is only to be used for irrigation of crops, it is reasonable to assume that the monthly cycle of effluent use would be closely related to the seasonal distribution of groundwater extraction illustrated in Figure 7.14. The seasonal groundwater distribution has therefore been adopted as the pattern of effluent use for calculation of monthly effluent demand, according to the procedure in Figure 10.17.

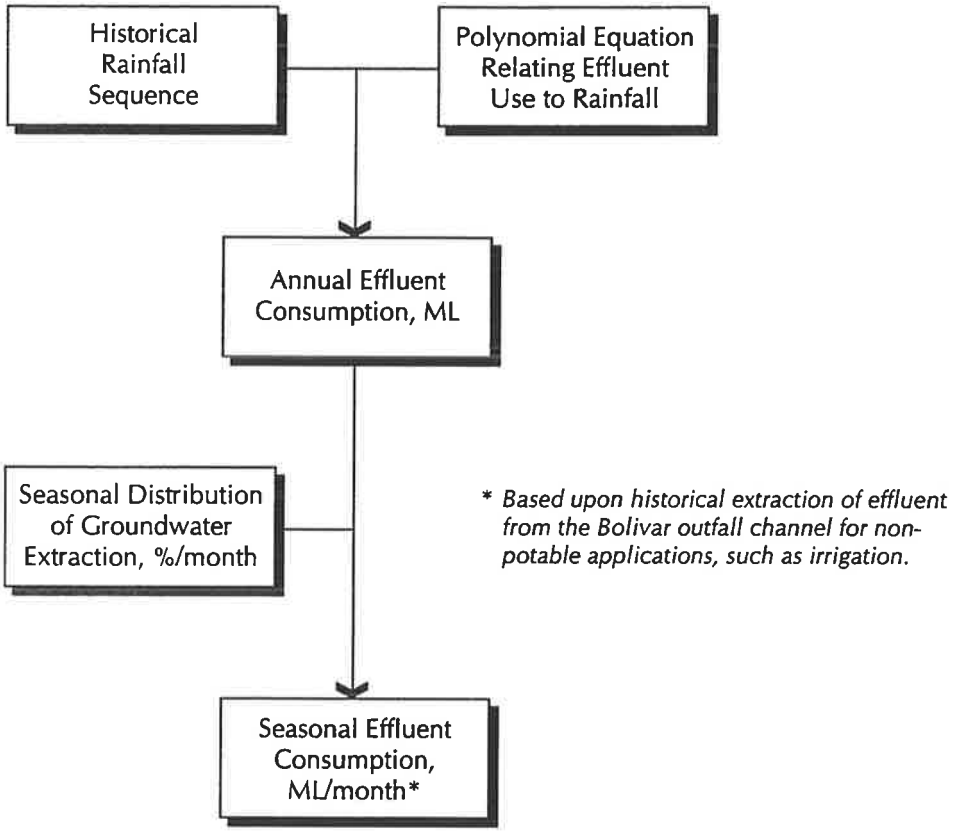


Figure 10.17
Model of Demand for Treated Effluent from Bolivar WWTP

10.7.3. Effluent from NAP Water Consumers

The primary purpose of estimating the rate of effluent flow from Bolivar WWTP was to obtain an understanding of the seasonality and volumes of effluent that would, under normal circumstances, be discharged to the Gulf St Vincent. For the purpose of simulating the potential for community or local scale reuse of sewage effluent, estimates were made of sewage contributed directly from consumers within the study area.

To determine the quantity of sewage generated by each consumer group, estimates were prepared of the quantity of water returned to sewer as a fraction of the water initially consumed. The data presented in Table 10.12 summarises the findings of this approach for the industrial sector, based on extensive research into the application of water in industry, and the proportion that would be returned to sewer. Data has been sourced from numerous journal articles, including those of Blesing (1975), Besselievre & Schwartz (1976), MMBW (1980), Walters & Wint (1981), Environment Canada (1986), Davies (1992), Ploesner *et al* (1992), AWWA (1993).

Table 10.12
Fraction of Consumed Water Discharged to Sewer by Industry

Application	Fraction of Use, %	Possible Savings, %	Percent to Sewer	Water Quality[2]	Flow to Sewer, %	
					Conventional	Conservation
Domestic uses	9.9	28	90	P	8.9	6.4
Landscape	1.9	40	0	NP	0.0	0.0
Cooling and heating	23.4	12	90	NP	21.1	18.5
Process water	36.4	15	90	P	32.8	27.8
Cleaning & sanitation	20.8	12	95	P	19.8	17.4
Laundries & kitchens	0.4	32	95	P	0.4	0.3
Misc. uses and leaks	7.2	47	95	P	6.8	3.6
			Potable		68.7	55.5
			Non-Potable		21.1	18.5
			Total		89.7	74.1

(1) After Ploesner et al (1992) and Environment Canada (1986)
(2) P: potable, NP: non-potable

Table 10.13 summarises the estimated fractions of consumed water returned to sewer. These ratios were directly applied to the estimated monthly water consumption for each consumer group to provide the sewage flow by month. As can been seen from Table 10.12, the fractions of consumed water returned to sewer were also determined in relation to potable and non-potable water requirements.

Table 10.13
Fraction of Water Returned to Sewer by Consumer Group and Form of Urban Development, with Consideration of Water Conservation Effects

Consumer Group	Percent of Total Use	Conventional Development Flow to Sewer, %		With New Urban Form Flow to Sewer, %	
		Conventional Water Use	With Conservation	Conventional Water Use	With Conservation
Residential	65.0	47.2	59.6	47.2	65.9
Commercial	2.3	71.8	55.8	71.8	55.8
Industrial	12.1	89.7	74.1	71.4	54.1
Public Inst. & Utilities	7.5	71.4	54.1	76.2	69.6
Vacant Land	4.5	0	0	0	0
System Losses	8.6	0	0	0	0

10.8. Water Quality and Conservation Considerations

In developing the model to simulate water resource utilisation and to investigate the potential impacts of integrated management strategies, it was important to consider (i) the quality of water required by different consumers, so that the potential for substitution of potable quality water with non-potable water can be evaluated; as well as (ii) the potential for conservation measures to reduce the demand for water and therefore the need for further resource and infrastructure development.

The main applications of water were investigated in terms of the water quality requirements and the potential to reduce water use.

An assumption adopted within the model is that only two qualities of water can be supplied to consumers: potable and non-potable. The only source of potable water is the mains reticulation network serviced by the metropolitan water supply reservoirs and associated water treatment plants.

Roof runoff water (rainwater) is treated as a sub-potable source used mainly for outdoor residential applications where rainwater is collected. Treated sewage effluent, stormwater and groundwater constitute the non-potable water sources.

The water quality requirements of consumers were determined for each general application, specified as either potable or non-potable. The potential for water conservation was also determined for each application, with data sourced from Australian water conservation guides, journal articles, and local specialists and government authorities. From this research it is apparent that the greatest potential savings in water use can be made in the areas of:

- residential water consumption for toilet flushing and garden irrigation;
- recirculation or reuse of process or cooling water in industry; and
- water consumption for toilet flushing and landscape irrigation in both the commercial and public institution and utilities sectors.

Many applications that require large quantities of water, either individually or collectively at a regional level (such as toilet flushing), do not require water of a potable standard. Hence, by coupling water conservation measures with the use of non-potable water for appropriate applications, there is tremendous potential to reduce the demand for potable water. The economic viability of the replacement of potable water and conservation measures is considered.

An example of the data collated for the residential sector is provided in Table 10.14. The potential for water conservation and potable water substitution was determined for fixed and seasonal components of annual water use. This was then factored into the calculations of water demand, thus providing a clear picture of the potential to reduce demand within each consumer group and for the region as a whole, as well as to investigate the potential for reuse of wastewaters to meet non-potable water demand.

The majority of residential consumers remain largely inefficient in their use of water, and so the model must therefore take this potential for water conservation into account. Clearly, it would be an unrealistic to assume that all consumers had implemented water conservation measures, and that the estimated conservation potential could be simultaneously realised over the entire region. A gradually increasing rate of participation in the use of water conservation measures was therefore incorporated into the model. The 'Conservation Participation Rate' was assumed to be influenced by the price of mains water, with an increase in the marginal price for water progressively making the purchase and installation of water conserving appliances more economically attractive. This data is summarised in Appendix J.

Table 10.14
Conventional Residential Water Consumption:
Assumed Water Quality Requirements and Conservation Potential

	Consumption lpcd	Saving %	Quality Required	Consumption, lpcd Fixed	Consumption, lpcd Seasonal	Possible Savings[1], % Fixed	Possible Savings[1], % Seasonal
Indoor Water Use							
Clothes washing	32	20	P	21.8	3.8	3.20	0.56
Toilet flushing	35	23	P	26.9	0.0	4.74	0.0
Dishwashing	18	0	P	18.0	0.0	0.0	0.0
Drinking & cooking	7	0	P	5.6	1.4	0.0	0.0
Bath	7	0	P	6.3	0.7	0.0	0.0
Shower	35	14	P	27.1	3.0	2.59	0.29
Hand basin	7	0	P	6.3	0.7	0.0	0.0
Outdoor Water Use							
Car washing	3	0	P	1.5	1.5	0.0	0.0
Pools & contact rec.	3	0	P	0.0	3.0	0.0	0.0
Lawn irrigation	125	20	NP	10.0	90.0	1.47	13.2
Vegetable irrigation	5	0	P	0.5	4.5	0.0	0.0
Losses (not incl.)	28	10	P				
Conventional Cons.	277	Potable		114	18.7	10.5	0.85
Consumption with Conservation	233	Non- Potable		10	90	1.47	13.2
		Annual average saving, %					**10.6**

(1) Percentages weighted according to the consumption volume.

10.9. Capture of Roof Runoff

At present, it is likely that only a small percentage (perhaps less than 2 percent) of all consumers on the NAP are collecting rainwater to supplement their mains water supply. Though no data has been discovered to indicate the number of rainwater tanks installed in Australian urban areas, it is thought that the vast majority of tanks are installed on residential properties.

Ever since the early days of settlement, rainwater tanks have played an important role in the provision of water supply, however their use in urban environments has never been extensive, largely due to unfavourable economics and alternative sources. A study of the options for water supply for a growing Adelaide conducted in the late 1970s by the then Engineering and Water Supply Department, indicated that although rainwater tanks could reliably provide approximately 4 percent of Adelaide's water needs (7 GL per annum), it was ironic that the closest source of water to the consumer was also one of the most costly (EWS, 1978). A more recent review revised the yield upward to 11 GL/a at 90 percent reliability, but came to the same overall conclusion. The cost of supply from rainwater tanks was estimated at $2.00 per kilolitre compared with current $0.90 per kilolitre. This is only marginally cheaper than sea water desalination or towing icebergs from the Antarctic, but with a much lower yield (EWS, 1989).

Rainwater tanks are often recommended by the members of the general public as partial solutions to water supply and environmental problems. While their adoption within conventional urban environments will continue to be plagued by the problem of high cost, rainwater tanks could have a role within a more integrated water management system, providing benefits such as:

- collection of water to supplement the mains supply;
- reduction in the demand placed upon the metropolitan water supply system;
- reduction in the quantity of stormwater runoff, with some improvement in water quality; and
- attenuation of flood peaks.

Rainwater tanks were therefore incorporated into the study of an integrated water management scenario where alternative urban forms were also considered.

Some assumptions were made about what type and how many dwellings are serviced by a rainwater tank. Where the urban form continues to follow the prevailing and conventional pattern of low density, single detached housing, it has been assumed that:

- only single detached houses are connected to rainwater tanks, and then only a fraction of the total number;
- the fraction of connected houses increases over time (equal to the Conservation Participation Rate discussed in Section 10.8); and
- rainwater is used primarily for the in-house applications of drinking, cooking and dishwashing.

Should the urban form change over time to become more compact (refer to Chapter 9), where medium and higher density housing is more common, then it was assumed that:

- a fraction of newly constructed dwellings within both the low and medium density categories are connected to a rainwater tank;
- a rainwater tank can be connected to and shared between a number of dwellings, such as in the case of two or three townhouse style dwellings within the same building;
- the fraction of connected houses increases over time (equal to the Conservation Participation Rate discussed in Section 10.8), at a faster rate than under conventional circumstances;
- rainwater is used for the in-house applications of drinking, cooking and dishwashing as well as to supplement outdoor irrigation; and
- the amount of water required for outdoor applications is reduced due to smaller lawn and garden areas.

The three historical rainfall sequences were employed to calculate the amount of rainfall that could be captured under different climatic conditions. The demand for rainwater was equated to drinking, cooking and dishwashing requirements for Scenarios A and B. Outdoor irrigation plus indoor cleaning water requirements were considered for Scenario C, where the outdoor irrigation needs were reduced by 88% to take into account the smaller garden area in the condensed urban form.

Tank sizes were initially mathematically optimised to provide a reliability of supply of 95 percent. The size of tank was then increased to that of the next commercially available unit, thus providing reliability equal to or greater than 95 percent.

Having determined the optimal tank size, the amount of water consumed and held in storage was determined, and therefore also the amount of water lost as spill that subsequently entered the stormwater drainage system. The data forming the basis of this model, and the simulation output are contained in Appendix K.

The volume of rainwater consumed and held in storage was then incorporated into the overall regional water balance model. This volume of water is available for supply to the residential sector thereby reducing the demand for potable water. Water was therefore removed from the drainage system and a reduction in storm runoff results.

10.10. Volumetric Runoff Coefficients and Stormwater Yield

As previously mentioned in Chapter 7, there is very little data available to indicate the quantity of stormwater generated within and discharged from any portion of the study region. Another important component of this research has therefore been the development of a simplified method of estimating the quantity of water available as stormwater runoff. The result of extensive research has been the establishment of empirical relationships in the form of volumetric runoff coefficients (VRCs) to estimate stormwater yield. The research is reported in Appendix L.

10.10.1. Volumetric Runoff Coefficients

Hydrologic data relating to rainfall and runoff volumes was obtained from journal articles, texts, governmental publications and in a raw form from government authorities. This data was used to derive VRCs for each month of the year and for urban and rural land uses, where:

$$\text{VRC} = \frac{\text{Equivalent catchment runoff, mm}}{\text{Rainfall, mm}} \qquad (10.4)$$

The 'equivalent catchment runoff' is the yield of a catchment for a particular period of rainfall as an equivalent depth over the entire catchment area.

Data sourced from publications was categorised according to the period with which the rainfall and runoff was associated (e.g. a single storm event, or annual yields), the perceived reliability of the data, and the period of record used to derive a particular conclusion. The segregation of data according to these categories enabled a considered assessment of the likely magnitude of a VRC as well as the degree of confidence placed upon that particular value.

The data consolidated from publications was combined with the analysis of raw hydrological data. That data available for the local catchments of 'The Paddocks'

and Waterfall Gully was incorporated with a large data set from the Australian Capital Territory.

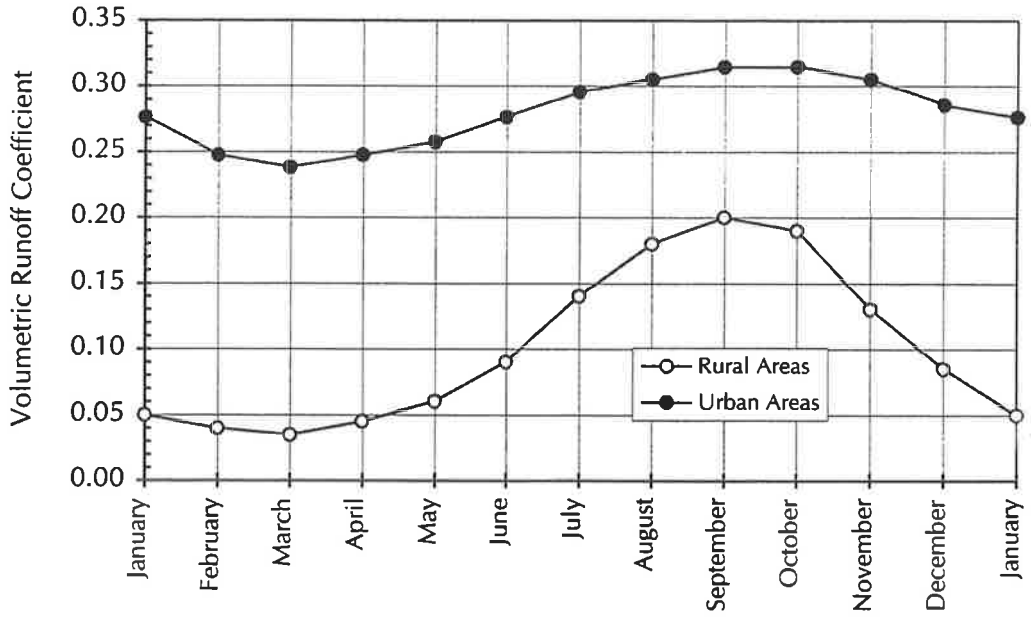


Figure 10.18
Recommended Volumetric Runoff Coefficient Distributions for Modelling and Water Resources Accounting Exercises

While the calculation of VRCs could be made using data compiled over any duration, determining the volumetric runoff coefficient on an event basis would not be of great value in estimating runoff yield on a longer term basis because of the great variability in runoff for events. A more useful calculation can be made using weekly or monthly runoff, which is a similar time scale to that adopted for water resources management, such as in the case of reservoir operation policies.

Therefore, research has been directed toward the establishment of volumetric runoff coefficients, dependent upon general land use categories and month of the year, using all available data. The VRCs can be applied to the urban and rural land use categories, without distinction between industrial and commercial areas in urban centres, or grazing land and crops in rural areas. The results are presented simply in Figure 10.18 and the monthly coefficients are listed in Table 10.15.

Figure 10.18 illustrates that the fraction of runoff arising from urban areas is predicably less variable than from rural areas, a result of the fact that most runoff in urban areas is derived from impervious surfaces. Indeed, with an impervious connected area equal to around 20 percent of suburban areas (and assuming around 90 percent of all incident rainfall on impervious areas becomes runoff), it can be seen that the variability in urban runoff can be largely attributed to pervious area (rural type) runoff.

Indeed, Kemp (1993) found that for an urban catchment at Glenelg in Adelaide, SA, the volumetric runoff coefficient for smaller storms was around 0.24 (compared to a directly connected paved area ratio of 0.243). The runoff coefficient increased to

around 0.30 during larger storms when the other impervious and saturated lawn areas contributed runoff.

Table 10.15
Volumetric Runoff Coefficients for Temperate Climates

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean[1]
Urban	0.28	0.25	0.24	0.25	0.26	0.28	0.30	0.30	0.31	0.31	0.30	0.29	0.28
Rural	0.05	0.04	0.04	0.05	0.06	0.09	0.14	0.18	0.20	0.19	0.13	0.09	0.12

(1) Weighted average based upon monthly rainfall as a mean for the NAP region.

The annual 'flow weighted' runoff coefficients for urban and rural areas are 0.28 and 0.12 respectively, results that are supported by the work of ECA (1991) and BC Tonkin & Associates (c.1992).

The derived VRCs were combined with the historical rainfall data and calculated urban and rural land areas to determine the volume of stormwater runoff under differing climatic conditions and urban development patterns (with increased impervious area from urban consolidation).

10.10.2. Capturable Runoff

Consideration also needed to be given to how much of the storm runoff could actually be captured for use. During the wetter months of the year it would be expected that much of runoff could not be captured and made available for use. This is because storages would often be near capacity and unable to store additional runoff. A spreadsheet model was developed to test this hypothesis and to determine the 'capturable' fraction of stormwater runoff.

The model addressed a 1 hectare area of land possessing 'urban' characteristics. It was assumed that the volume of storm runoff from this area could be determined using VRCs, with the analysis undertaken using daily rainfall data from the NAP for the period from April 1992 to May 1994. A surface water storage, such as a wetland, is assumed to be situated within this catchment, from which water is withdrawn for landscape irrigation as well as aquifer injection for storage and recovery.

The plot under irrigation was considered to cover 10 percent of the catchment, typical of metropolitan suburban areas. Lawns were assumed to be the main vegetation under irrigation, from which the seasonal watering requirements were determined using the efficient irrigation guidelines of WAWRC (1986).

The wetland storage size was determined according to the popular design guidance in Phillips (1991), sized to achieve a residence time that would provide a mean reduction in suspended solids, total phosphorus and E.Coli equal to or greater than 70%. The result was a wetland with a volume of approximately 95 m^3 and mean depth of 0.8 metres. Evaporation losses from the surface of the storage were estimated using historical evaporation data for the region.

The injection of water to underlying aquifers was assumed to occur over a 4 month period from July to October. A single injection well would operate for a duration of 15 hours per day, each day, at an injection rate of 15 l/s or 2.58 kL/day.

The outcome of this modelling is illustrated in Figure 10.19. The spike in the plot of 'calculated spill from pond' during June is due the particular combination of model parameters; smoothing of this curve provides a more generic pattern of spill, which has been adopted for inclusion in the regional water management model. The spill model shows that during summer and autumn, nearly all stormwater could be captured in a the design storage. During winter and spring, the fraction of the total runoff that can be captured can drop to 40 percent.

Another issue associated with the capture of stormwater for use is the feasibility of storage construction. By moving downstream along a drainage course, the area contributing water from storm runoff increases and so does the flow or volume of water that could potentially be captured. However, as often is the case and is the situation with the NAP, the land becomes flatter as the stream approaches the sea and sites for construction of storages become far more limited.

It is also the case that storages for the purpose of water supply should either be situated upstream of the supply zone so that water can be supplied largely by gravity flow, or alternatively, they should be situated near to or within the supply zone. Situating storages on the western side of the NAP and near the coast would therefore fail on both counts, and would require pumping facilities to transfer the water back to consumers.

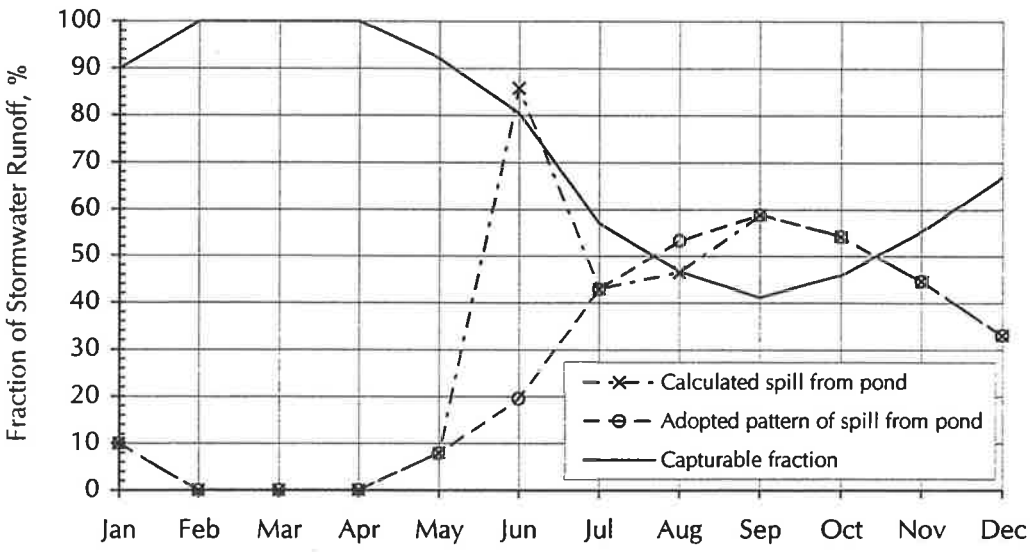
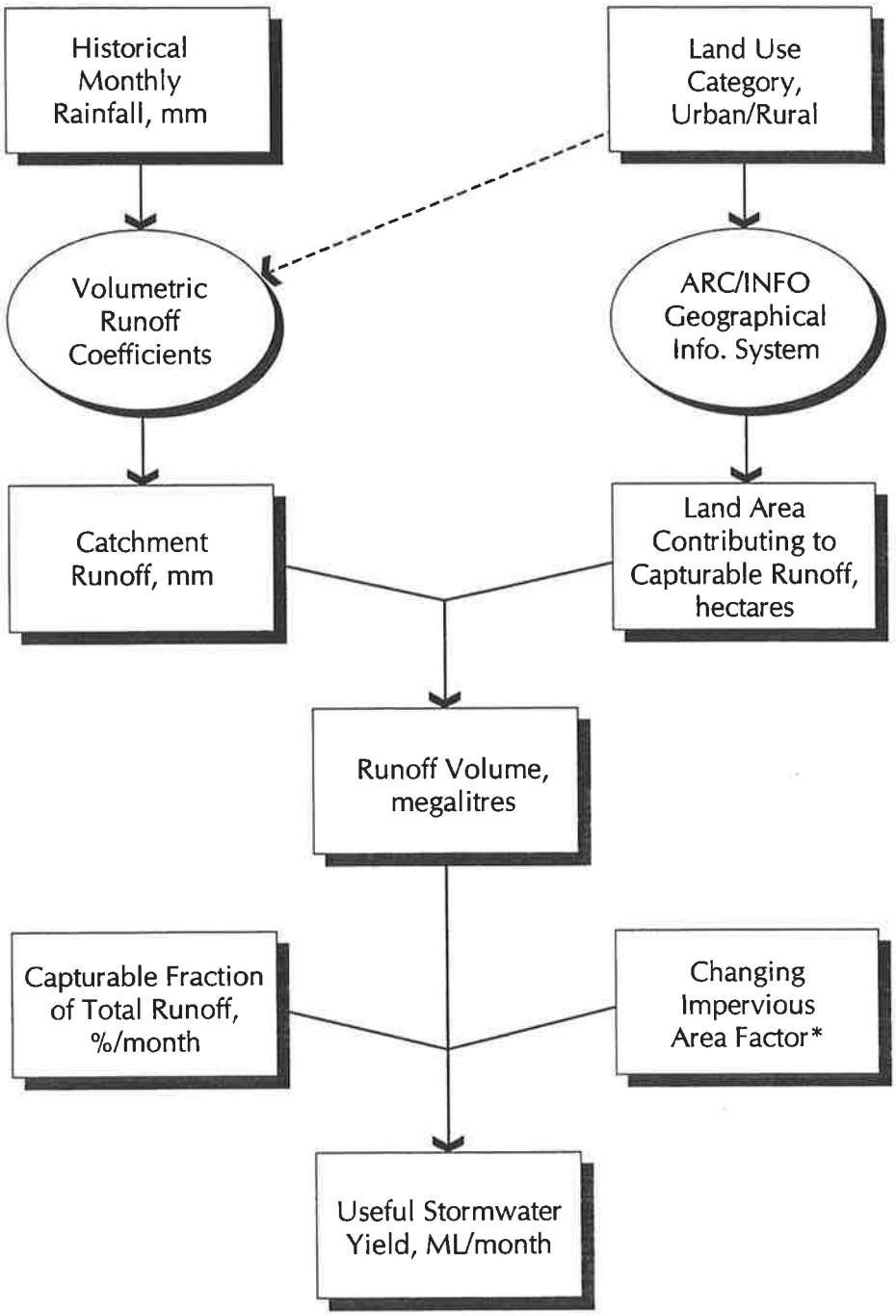


Figure 10.19
Effective Availability of Stormwater Runoff

In terms of the spatial availability of stormwater on the NAP, the assumption has therefore been made that all of the undeveloped land and Hills Face zone upstream of the urban areas contribute runoff, but that only two thirds of the urban area



** Ratio of % Impervious Area in the Current and Previous Time Periods*

Figure 10.20

Model of the Generation of Stormwater

contributes runoff in so far as the location of storage facilities limits the opportunity to capture the available runoff.

Table 10.16
Wetlands and Stormwater Control Ponds on the NAP

Local Govt Area	Storage Description	Year of Construction	Catchment Area, ha	Storage Volume, ML
Munno Para	Heaslip Road Flow Control Park	Proposed	-	900
Salisbury	Kaurna Park	1994	58,700	762
Munno Para	Fradd Road Flow Control Park	c.1995	32,900	396.3
Salisbury	DSTO Salisbury	1994	29,200	380
Salisbury	South Road Connector	1995	306	344
Munno Para	Kudla Creek Flow Control Park	Proposed	-	270
Gawler	Evanston Gardens F.C. Ponds	c.1992	360	170
Munno Para	Stebonheath Flow Control Park	c.1995	31,600	138
Salisbury	Whites Rd / Bolivar	1992	290	127
Salisbury	Greenfields Stages 1 and 2	1990-93	200	110
Salisbury	Walpole Road	1996	114	46
Salisbury	Burton Road Wetlands	1996	270	26.1
Salisbury	Swan Alley Wetlands Stage 1	1996	104	5.67
Salisbury	Lake Windermere	1974	58	5.66
Salisbury	Paddocks Wetland	1975	60	2.54
Total storage capacity of major wetlands or flood control ponds				3,683.27

The majority of detention ponds and wetlands are situated within the urban areas, although the greatest storage capacity exists within rural and open space areas. These assumptions are in part based upon the data relating to existing or proposed storages presented in Table 10.16. With structural adjustments to some retention basins to provide the capacity for detention storage or for development of wetlands, it has been estimated that the regional capacity for storage of stormwater is comprised of 1,000 ML of storage in urban areas and 2,500 ML of storage in rural or open space areas.

The flow chart in Figure 10.20 illustrates the sequence of calculations, combining the data relating to historical rainfall, volumetric runoff coefficients, land use and effectively contributing land areas, and the capturable fraction of runoff to determine the actual availability of stormwater for collection and reuse.

10.11. Reservoir Storage and Water Transfers

The vast majority of water used within developed areas of metropolitan Adelaide is supplied through the Metropolitan Adelaide Water Supply System (MAWSS). Given the highly inter-connected nature of this system, a complex model would be required to simulate all of the operational features and options for water supply and transfer. However, while reliable estimation of the surface water yield of the water

supply catchments of the Mt Lofty Ranges is clearly an important element of the simulation model, some acceptable simplifications can be made.

A core issue of this research is the concept of sustainability. As such, the ability of the region to be somewhat self sufficient in terms of water supply is of interest. It was therefore decided to investigate the potential of the Little Para Reservoir and South Para–Barossa Reservoir system to meet the potable water demands of the Northern Adelaide Plains without importation of water from any source apart from the Mannum–Adelaide Pipeline. The task of headworks simulation was therefore reduced to one of modelling the inflow and outflow patterns of the regional storages (ignoring evaporation losses).

10.11.1. Natural Reservoir Inflow

Inflow to the regional storages was calculated as the sum of the natural inflows to each of the local reservoir systems. Mathematical relationships were established between the historical (mean regional) rainfall and recorded reservoir inflows. The best relationships were found using a polynomial function (as distinct from a power, exponential or logarithmic relationship), where the sum of the 3 months rainfall prior to and including the forecasting month was the determining factor. A period of 3 months rainfall is possibly a better determinant than only 1 month (say), as it would partially account for the antecedent wetness of the catchment.

The regression relationship determined for the South Para and Barossa Reservoir system is:

$$\text{Natural Inflow} = 0.0886 \times \text{Rain}^2 - 11.98 \times \text{Rain} + 276 \qquad (10.5)$$

where the natural inflow is expressed in ML per month, and 'Rain' is sum of the mean regional rainfall over a 3 month period. Inflow is only considered to occur where Rain > 105 mm in the 3 month period. For the Little Para Reservoir:

$$\text{Natural Inflow} = 0.0568 \times \text{Rain}^2 - 1.87 \times \text{Rain} \qquad (10.6)$$

Figure 10.21 illustrates the relationship between rainfall and natural inflow to the South Para and Barossa Reservoirs. There are many months during which the natural inflow would be very low. During the wetter months, the estimated inflow would often be less than the actual inflow, therefore providing a conservative estimate of the potential for water supply, regardless of the prevailing volume in storage. Evaporation losses from the reservoirs were not incorporated into this model of reservoir inflow and storage because of this inherent conservatism and the potential for exaggerating system losses. (Evaporation and other reservoir losses typically constitute around 17 percent of the total withdrawals from the system, where withdrawals are defined to include consumption, groundwater recharge releases, evaporation, seepage and other losses).

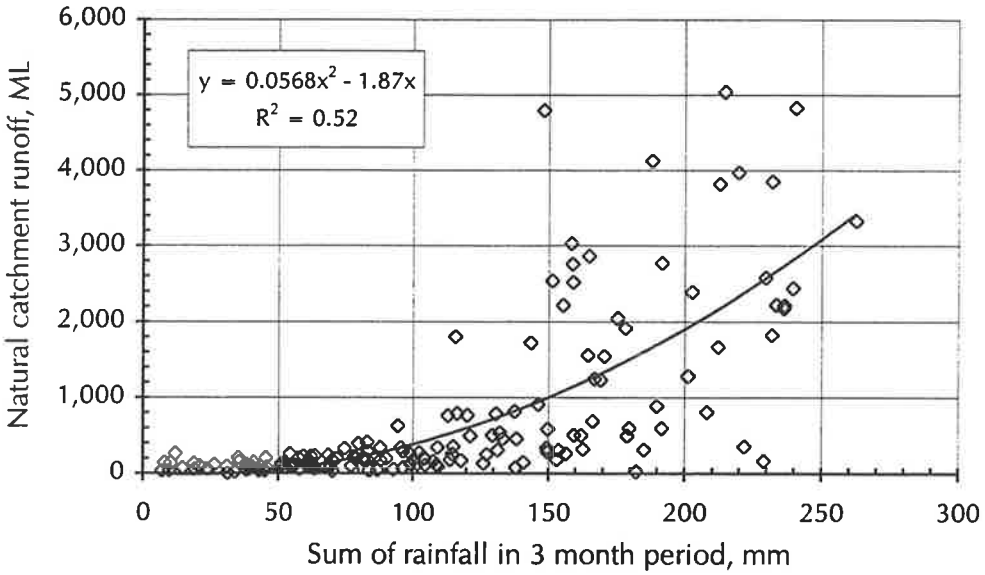


Figure 10.21
Relationship between Rainfall and Natural Inflow per Month to the Little Para Reservoir

10.11.2. Pumping from the River Murray

As mentioned above, the only other major source of inflow to the reservoirs is the River Murray via the Mannum-Adelaide pipeline. It was necessary to incorporate the capacity of the headworks system to divert water from the River Murray to meet metropolitan water demands. The adopted pumping strategy is based largely upon the work of Crawley (1995) who formulated the linear programming models within the Headworks Optimisation Model – Adelaide (HOMA) for optimisation of the operation of the MAWSS headworks in relation to water diversions from the River Murray.

It has been assumed that the River Murray is an effectively unlimited source of water, so that the amount of water that can be diverted from the River during any particular month is only limited by the capacity of the headworks. Indeed, Crawley (1995) notes that the likelihood of sufficient quantity of water being unavailable in the River Murray system to meet metropolitan Adelaide requirements is considered negligible. The volume of water that can be transferred into the northern reservoirs is therefore 5,820 ML per month, the combined capacity of the Mannum-Adelaide trunk main to divert water into the Little Para Reservoir (5,400 ML/month) and the Warren Reservoir (420 ML/month). The maximum capacity of the Mannum–Adelaide Pipeline is 10,800 ML per month. The cost of water diversion is dealt with in Section 10.15.

The requirement for pumping from the Murray is determined by the storage condition of the reservoirs. The target storage levels used in the operation of the northern metropolitan system comprise two components:

- Minimum operating level component; and

- Demand storage component.

The combined storage for the Little Para, South Para and Barossa Reservoirs at their respective nominal minimum operating levels (for all months) is 19,600 ML, as distinct from a combined storage of 7,300 ML at their physical minimum operating levels; refer to Table 10.17 (after Crawley, 1995).

Table 10.17
Northern System Minimum Operating Levels

Reservoir	Physical Minimum Storage, ML	Nominal Minimum Storage, ML
Warren	0	1,000
South Para	1,100	11,100
Barossa	3,100	3,500
Little Para	3,100	5,000
Millbrook	300	3,000
Kangaroo Creek	100	500
Hope Valley	1,200	1,200

The demand storage components corresponding to the '4 weeks demand' for the northern metropolitan system are listed in Table 10.18. Crawley (1995) found that the available pumping capacity and minimum storage levels in the northern system are adequate to accommodate any hydrological shortfalls even when the demand storage component of the target storage values are reduced to 'two weeks demand' above the nominal minimum storage levels, but suggested due to overall reliability and cost considerations that a demand storage component of 'four weeks demand' be adopted for operational planning purposes.

Table 10.18
Four Week Demand Target Storage Component

Month	South Para Reservoir, ML	Barossa Reservoir, ML	Little Para Reservoir, ML	Combined Storage Target, ML
January	800	1,000	1,500	3,300
February	700	1,000	1,500	3,200
March	200	900	900	2,000
April	700	600	300	1,600
May	100	700	100	900
June	900	400	100	1,400
July	600	700	100	1,400
August	800	700	100	1,600
September	800	800	600	2,200
October	600	900	1,300	2,800
November	1,000	800	1,600	3,400
December	1,200	1,000	1,800	4,000

Should the storage fall below the target storage level in any one month, then diversion of water from the River Murray by pumping will occur. If the storage level at the end of the month, S, has fallen below the target storage level, S_{target}, then pumping of a volume V_{pumped} occurs to 'top up' the reservoirs to provide the desired demand storage level for the next particular month ($S_{demand4}$). Presented mathematically:

$$\text{If } (S < S_{target}) \text{ then } \{V_{pumped} = S_{demand4} - (S - S_{min})\} \quad (10.7)$$

If the storage level at the end of the month, S, has fallen below the target storage level, and also below the nominal minimum storage level, S_{min}, then pumping occurs to restore the storage to the nominal minimum level and also provide the additional volume to meet the '4 week demand' for the particular month. Presented mathematically:

$$\text{If } (S < S_{min}) \text{ then } \{V_{pumped} = (S_{min} - S) + S_{demand4}\} \quad (10.8)$$

If, during the month, the storage level rises through natural inflow above the full storage level of the reservoirs, then spill occurs. Given that inflow and consumption occur over the course of the month and not at the beginning or end, it has been assumed for calculation purposes that spill occurs before the reduction in storage due to consumption. (The total capacity of the northern reservoirs at full storage level is 76,610 ML.)

In all cases the volume pumped must be less than the diversion capacity of the Mannum–Adelaide pipeline system, that is:

$$V_{pumped} \leq (V_{cap} = 5{,}820 \text{ ML per month}) \quad (10.9)$$

These routines therefore estimate the total inflow to the northern reservoirs, and when incorporated with the demand for potable water, determine the fluctuation in reservoir storage levels and the requirement for diversion of water from the River Murray.

10.12. Environmental Flows

Environmental flow requirements have not been explicitly included in the simulation model, partly due to the lack of clear guidance on the subject. Both of the major water courses through the region are also regulated, the Little Para due to the construction of the reservoir, and the Gawler River as a result the South Para and Barossa Reservoir system and in excess of 800 farm dams within the Barossa Valley and North Para River catchment (after Cresswell, 1991). There is no suggestion that the operational strategies of the water supply system would alter with affects upon the reservoirs and associated streamflow, and it was therefore unnecessary to directly address environmental flow considerations. Environmental flows are implicitly addressed, however, through the consideration of different land and water management strategies and the incorporation of integrated catchment management principles.

10.13. The Impact of Pricing

Consideration was also given to the potential impact of water pricing upon demand. It was clear that the main factors that could affect the price of water were (i) the commercialisation of the SA water authority in line with the 'Hilmer Inquiry'; and (ii) the COAG water reforms.

The inquiry into National Competition Policy undertaken by Hilmer *et al* (1993) gave recognition to the fact that businesses and the community generally are impatient for much more rapid progress by governments in reforming our infrastructure and regulatory systems. Thus, to facilitate effective competition to promote efficiency and growth in the Australian economy, the Committee of Inquiry offered several recommendations including the following that have particular relevance to the Australian water industry:

- that there be structural reform of existing public monopolies for the separation of regulatory or natural monopoly and commercial or potentially competitive functions;
- that third party access to 'essential facilities' such as public infrastructure be allowed; and
- that governments should cease price fixing or unrepresentative pricing structures, and adopt more realistic pricing on public services and products.

These recommendations for reform were embraced within a larger set of recommendations made by COAG for the water industry.

10.13.1. The COAG Water Reform Framework

COAG – the Council of Australian Governments – consists of the Prime Minister, the State Premiers, the Territory Chief Ministers and the President of the Australian Local Government Association. By agreement among all governments, COAG puts together major policies for the future of Australia, and in 1994 agreed to implement a strategic framework of reform to achieve an efficient and sustainable water industry in Australia.

The issues which concerned COAG included:

- major asset refurbishment needs in rural areas for which, in general, adequate financial provision has not been made;
- impediments to water being transferred from lower value to higher value end uses;
- inefficiencies in the delivery of water services;
- lack of clear definition of water services;
- lack of clear definition of the roles and responsibilities of a number of institutions involved in the water industry; and
- deficiencies in approaches to the management of water and the wider natural resource base requiring the attention of governments (COAG, 1995).

The package of reforms agreed to by COAG involves (COAG, 1995):

- pricing based on principles of full cost recovery and transparency (or removal of) cross subsidies;
- future investment in new schemes, or extensions to existing schemes, to be undertaken only after appraisal indicates it is economically viable and ecologically sustainable;
- comprehensive systems of water allocations or entitlements, backed by separation of water property rights from land title and clear specification of entitlements in terms of ownership, volume, reliability, transferability and, if appropriate, quality;
- formal determination of water allocations or entitlements, including allocations for the environment as a legitimate user of water;
- trading, including cross-border sales, of water allocations or entitlements, within the social, physical and ecological constraints of catchments;
- administration and decision making to provide an integrated catchment management approach to water resource management;
- the separation of resource management, standard setting and regulatory roles of government from the roles of providing water services;
- a greater degree of responsibility for local management of water use;
- public education about water use and consultation in implementing the reforms; and
- appropriate water related research and use of efficient technologies.

Of particular significance in the consideration of water pricing are the reforms aimed at developing water prices which cover not only business or operating costs, but also provide for infrastructure refurbishment or replacement.

10.13.2. Asset Replacement

An investigation by the South Australian Public Accounts Committee (PAC) in 1987 found that the replacement of State owned public assets was due to increase sharply over the decade to 1997 and to continue growing until around 2010. At that time it would fall back a little but remain at an overall level much higher than replacement activity at that time.

Figure 10.22 illustrates the findings of the PAC for all major public assets. The assets associated with highways, electricity supply, water supply and sewerage were found to be the largest cost items. Other items of public infrastructure that were considered included housing, public hospitals, schools and transport. It should be noted that this is not a forecast of replacement that will occur. Rather, it represents the default situation that will occur if decisions and remedial actions are not taken, and assumes that assets are replaced like-for-like.

The peak in total asset replacement expenditure occurs around 2010, corresponding with the ageing of an infrastructure base that was largely constructed after the Second World War to service population increases fuelled by high levels of migration and natural increase.

While there is some downturn in the level of asset replacement expenditure after 2010, the average level to 2035 is still over twice as high as the replacement activity in 1985. The PAC (1987a) used the 50 year projection to show that replacement never again falls to levels as low as experienced during the 1980s. In fact, in the years around 2040, there is likely to be another large increase as the bulk of the post war sewer and water mains falls due for replacement.

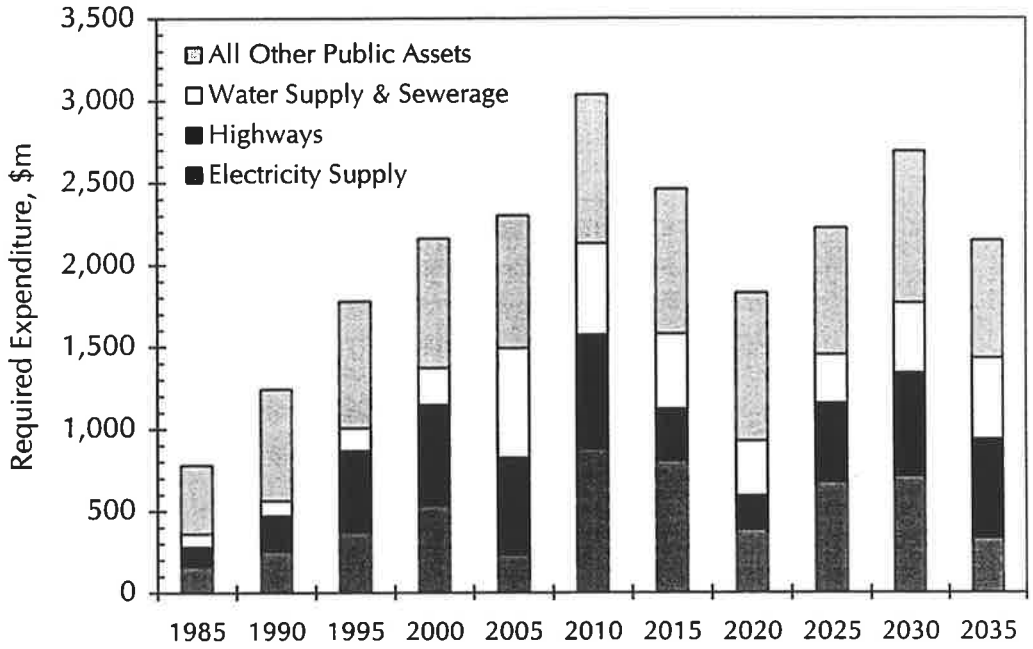


Figure 10.22
Projection of Required Asset Replacement Expenditure
(1984/85 dollar terms; after PAC, 1987a)

In fact, the PAC (1987b) found that SA Water controls the largest stock of replaceable assets in the service of the State Government, which had an average economic life[1] of just over 70 years. The main findings and issues of concern to the PAC (1987b) were:

- Metropolitan sewers will experience a rise in replacement due over the period 2001 to 2015 which reflects the fact that about 44% of the small diameter sewers that make up most of the stock were originally constructed within a 20 year time period of 1921-1940. The large diameter sewers laid in the same period were thought to be in worse condition than their age alone might suggest, and would thus require earlier replacement.

- Sewage treatment was another problem area, even though plants are little more than 60 years old and some upgrading has occurred. Backlogs in electrical

[1] Economic life: the time interval that is expected to elapse between the time of acquisition and the time at which the combined forces of obsolescence and deterioration will justify retirement of the asset (Gordon & Shillinglaw, 1969).

installations and pumps will begin to show and represent a large annual increase over past replacement spending.

- Country mains replacement increases in every period to 2005, with high levels of replacement maintained over the following 15 years.

The PAC (1987b) concluded that by the year 2005, the replacement due would be equivalent to $133 million per annum (in 1984/85 dollar terms), more than double the construction budget of SA Water at that time. After 2005, the amount projected for replacement increases to about 10 times the level of replacement activity at that time of approximately $14 million per annum.

A review of the financial performance of SA Water was undertaken to obtain an indication of the level of current expenditure and potential to cover the projected costs of capital works associated with asset replacement. The data used for this review was sourced from SA Water's Annual Reports for the period 1990 to 1996, and is summarised in Appendix M. It was found that within metropolitan Adelaide and for the category of water supply, the revenue accrued from rates and charges exceeded all operational and associated costs by 15 percent. On a state-wide basis, however, there was a shortfall of revenue over costs of 6 percent. For sewerage services, revenue exceeded the cost of provision at both the metropolitan and state scales by approximately 44 percent and 30 percent respectively. The average annual operating surplus for this period associated solely with the provision of water supply and sewerage services was $18.361 million.

During the period 1990–1996, the average annual expenditure by SA Water on capital works was $76.242 million. This compares favourably with the required rate of expenditure projected for this period by the PAC of $40.2 million (adjusted to 1996 dollar terms). However, according to PAC projections, capital works expenditure must roughly double with on average $151.6 million per annum in expenditure required over the remaining projection period to 2035, peaking at $234.7 million per annum during the period 2005–2009 (in 1996 dollar terms).

Hence, the conclusion is that metropolitan areas subsidise the cost of water services in rural areas. Indeed, in many rural areas of Australia (where water is provided to towns but mostly for irrigation) water prices fall well short of meeting infrastructure maintenance costs, let alone providing for capital investments (COAG, 1995). It is therefore likely that rural systems will also impose the greatest burden in terms of asset replacement.

The asset expenditure projections of the PAC (1987a; 1987b) have been based upon the assumption of like-for-like replacement of infrastructure items. In many cases, however, the original assets can be in part or totally replaced by newer technologies or materials. While it may be expected that the best currently available and proven technology would be employed, it is the case particularly in the water sector that the nature of the surrounding infrastructure limits the options during replacement.

Technological developments in the provision of water and sewer services worldwide have been relatively slow, although some promising rehabilitation techniques and some materials have been developed interstate and overseas (PAC,

1987b). Experience has also shown that technological change can easily give rise to more expensive replacement assets and has aimed at providing superior service rather than cheaper assets (PAC, 1987a).

Increasingly stringent environmental performance requirements require heightened standards of performance and water treatment, incurring additional expense and construction of new infrastructure items. Not only does this require an increase in expenditure on enlarging the asset base but also raises the ongoing costs of asset maintenance and replacement. A like-for-like replacement may therefore remain an appropriate assumption for the examination of asset replacement requirements.

Another factor that affects the bulge in asset replacement expenditure is the economic life of the asset. The economic life of sewers adopted in the PAC reports ranged from 75 to 115 years, while water mains were in the range of 80 to 100 years. Since that time, SA Water have extended their estimates of economic life for water mains from 100 to 120 years, although questions have been raised about the basis for and validity of this shift (*pers comm*, Ritchie, 1997).

Whether or not the PAC calculated figures prove to be pessimistic or optimistic is of little consequence. There is no doubt that the asset replacement task facing the State will be extremely large (SA Govt, 1987). There are opportunities for reducing the size of the asset replacement task, through preventative maintenance, revision of service standards, selective adoption of new technologies, better coordination of asset replacement efforts, modification of pricing policies, and rationalisation of the asset stock. In fact, there may be some revision of the nature of water services provided to non-town country areas and the role of the State in their provision. The question becomes not only one of financial burden but also of appropriate technologies, and how best to provide water services in an era of increasing social and environmental pressures for change, as argued by Clark (1990).

10.13.3. Potential Impacts on Price

A spreadsheet analysis was undertaken to explore the potential impact upon the marginal price for water of the Hilmer and COAG reform processes and the need to finance the asset replacement task. The analysis was based upon the following assumptions:

- that PAC (1987a; 1987b) projections of asset replacement expenditure were and remain representative of the true conditions for water services;
- that any necessary increase in revenue would be raised through the sale of water, and transferred to consumers as an increase in the marginal price;
- the implementation of pricing changes would occur during the period of 2000 to 2010, reflecting the nominated time frames for Hilmer and COAG reforms;
- that the marginal price of water is the same for all consumers;
- the price elasticity of demand for reticulated potable water is -0.40 after Dandy (1987) and Davies & Dandy (1995);
- that the existing metropolitan and rural water infrastructure is maintained;
- there is a 10% reduction in replacement cost due to improved designs and new technologies;

- that 50 percent of both the annual operating surplus and capital expenditure is directed to asset replacement; and
- that sustainability considerations are drivers to achieve full cost recovery to prevent inequitable transfer of financial and asset replacement burdens between generations.

The analysis incorporated historical data relating to the marginal price of potable water and movements in the Consumer Price Index (after ABS 1980-1992; Dandy, 1987; Crawley, 1992). A projection of the CPI was used for calculation of the bill price for water from the estimated real marginal price.

Changes in population, total water consumption, revenue and marginal price of water were simulated over the period 1996 to 2020 using annual time series data. The increase in the price of water over this period was calculated so that sufficient revenue could be raised to cover the projected cost of asset replacement. Based upon the assumptions outlined above and this simple model, it was shown that a significant rise in the billed price for water is required to cover asset replacement costs. While this incurs a similarly significant reduction in total water consumption, there are no adverse impacts on the ability to raise additional revenue. Although consumption is initially impacted by the increase in price, population growth results in an ongoing rise in consumption in the long term. The results of this analysis are depicted in Figure 10.23 with the baseline data in Appendix M.

Since the magnitude of asset replacement expenditure is likely to be reduced or delayed, and due to the political reluctance or inability to implement such a dramatic price shift, the predicted outcome is unlikely to be realised. However this analysis has provided an indication of the potential effect of the projected financial burden of asset replacement.

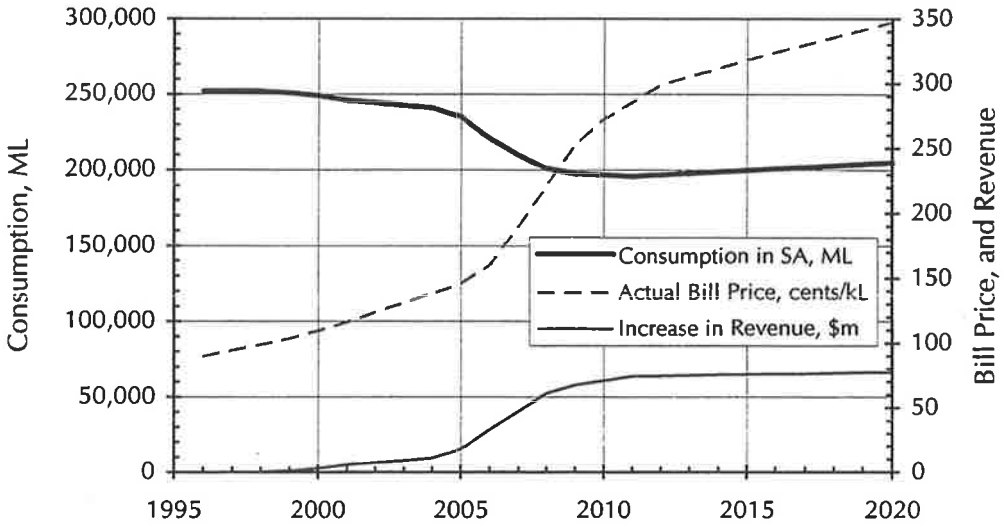


Figure 10.23
Variation in Price of Water, Revenue and Total Mains Water Consumption

The modelled shift in price has, however, been adopted as an indicator of the pressures for change associated with the provision of water services. It has been assumed that consumers will respond to these pressures through the adoption of water conserving measures and appliances. The rate of change in marginal price has therefore been used as a broad indicator to establish the Rate of Conservation Participation used in the water demand model.

10.14. Outcomes of the Regional Water Balance Modelling

The model of regional water availability and consumption has indicated that the potential exists for integrated water management to offer substantial environmental and economic benefits. The outcomes for each development scenario (Table 10.19) are explored in more detail below.

Table 10.19
The Alternative Development Scenarios Under Consideration

Scenario A	**Business as Usual**: assumes continuation of urban sprawl under conventional development and resource consumption patterns.
Scenario B	**Virginia Pipeline Scheme**: many of the same features as Scenario A with the addition of tertiary wastewater treatment and a reticulation system for reuse of treated effluent from Bolivar WWTP for irrigation in horticulture.
Scenario C	**A Rejuvenated Urban Form**: assumes development and renewal of urban areas to produce more condensed, efficient and livable communities. Water conservation and wastewater reuse are widely practiced in the new urban areas, and there is a gradual return of urban land to open space, new habitat areas and local agriculture

Over the period 1996 to 2020 and with sustained population growth, a reduction in the volume of reticulated potable water in the order of 23 percent can be achieved under Scenario C. By comparison, following conventional water consumption patterns the amount of potable water consumed is predicted to rise by 31 percent; refer to Figure 10.24. The reductions in consumption of potable water are the result of the use of water conserving devices, but more particularly the substitution with sub-potable water such as reclaimed effluent where it is appropriate.

Under Scenario C, a flow-on effect is the reduction in the volume of water that must be diverted from the River Murray for supply to metropolitan Adelaide. Under average rainfall conditions, there need be minimal pumping of water from the River Murray. Even during dry periods, the amount of water diverted can be reduced by 63 percent from current levels under similar conditions. The opposite is likely if current consumption trends are to continue, with the volume diverted from the River Murray increasing by nearly 130 percent!

The difference between the volume pumped during average climatic and dry periods is also reduced under Scenario C, due to the less variable nature of potable water consumption. This would enable more accurate forecasting of pumping requirements and greater efficiency and flexibility in pumping schedules.

In the short term there is no decrease in the volume of sewage generated under any development scenario, with ongoing rises in sewage volume in Scenarios A and B proportional to population growth. It is not until the year 2005 that some decline in sewage generation is observed under Scenario C, which is partially the result of potable water substitution with reclaimed effluent but more so the effect of increasing rates of conservation. Between 2010 and 2015, much of the population have implemented conservation measures, and sewage generation begins to grow again with population growth, but now at a level approximately 10 percent lower than under more conventional circumstances.

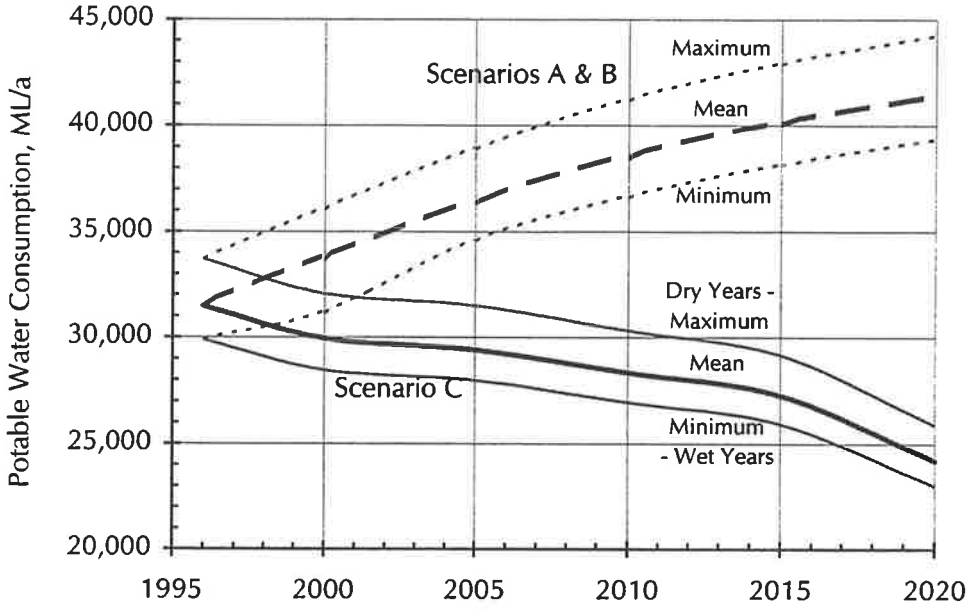


Figure 10.24
Predicted Mains Water Consumption
(Note: Formatting of the maximum, mean and minimum bands remains consistent throughout all figures in this section.)

Scenario B promises the greatest reduction in effluent discharge resulting from the ultimate diversion of 40,000 ML of effluent for irrigation purposes. However, there may be a minor increase in effluent discharge commencing around 2015, if irrigators are unable to continue to utilise the increasing volume of effluent generated by a growing population. Refer to Figure 10.25.

These findings are directly related to the rates of consumption of reclaimed effluent. Approximately 2,500 ML/a is consumed under Scenario A by irrigators extracting directly from the Bolivar outfall channel. Under Scenario B, between 30,000 and 35,000 ML/a is distributed to irrigators via the Virginia Pipeline Scheme, representing around 77 percent of the total volume of effluent generated at Bolivar. Over much of the period, effluent consumption remains around 5,000 ML/a according to Scenario C, but rises to above 10,000 ML/a by 2020 reflecting greater potable water substitution and a greater coverage of the urban area by dual reticulation systems.

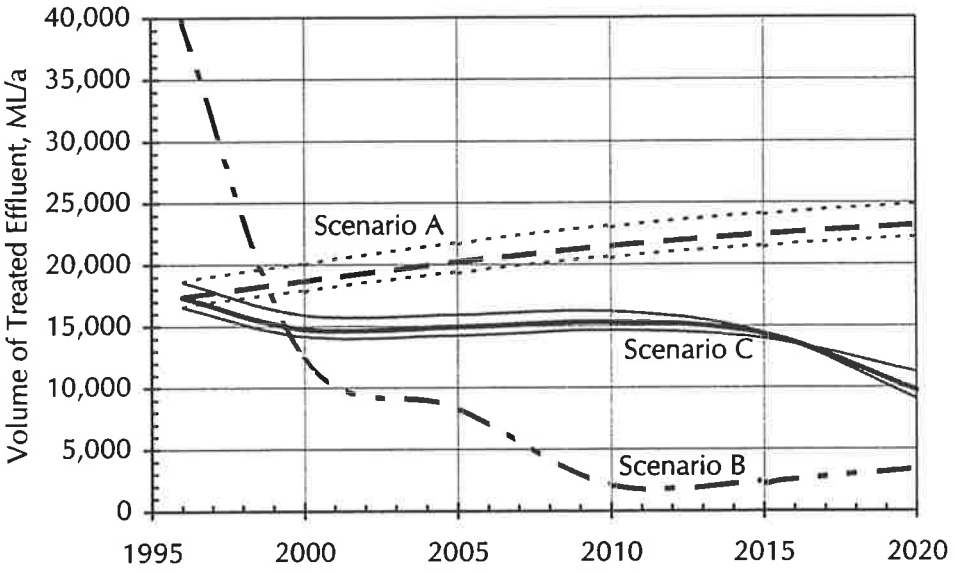


Figure 10.25
Discharge of Treated Effluent to Gulf St Vincent

Under Scenarios A and B, the volume of stormwater runoff continues to increase throughout the period with the growth of the urban area. Under Scenario C, however, a more interesting shift occurs. Between 1996 and 2010, the mean volume of stormwater runoff is greater than that predicted for Scenarios A and B. However, the main increase in stormwater yield occurs prior to the year 2005, when development follows a new urban form that contains a larger area of impervious surface while occupying less land than would otherwise have been the case. With the progressive redevelopment of older urban areas according to this new urban form, less land is required to accommodate the same population and so the area of open space increases. As a consequence, the volume of runoff from these new open areas is much less than in the previously developed form, and so the total stormwater yield progressively declines, as illustrated in Figure 10.26. As would also be expected, during the wettest years when the catchment is saturated, the yield is similar under all development conditions.

There is a similar outcome when considering the volume of stormwater discharged to Gulf St Vincent, except that the benefits of reduced stormwater generation are compounded by the effective use of stormwater collection, storage and use systems proposed under Scenario C. With the modification of existing retention ponds for use as temporary storages, coupled with the implementation of ASR schemes, more widespread stormwater reuse is established relatively quickly. As a result, there is a reduction in the discharge of stormwater to the Gulf in the short-term, with further ongoing but less substantial reductions over time. By the year 2020, there has been a 60 percent reduction in stormwater discharge from that predicted for 1996.

The extraction of groundwater, primarily from the Tertiary aquifers, is assumed to remain constant at 1996 levels according to Scenario A, as there is no regulatory or pricing incentives to alter groundwater consumption patterns. With the implementation of the Virginia Pipeline Scheme (VPS) in Scenario B there is

sufficient reclaimed effluent to meet demand for irrigation water. However, there are areas unserviced by the VPS, however, as well as growers who choose not to connect to the pipeline and those who remain concerned about the water quality who choose to continue to use the groundwater. Under this scenario, the extraction of groundwater is reduced through pricing and regulatory reforms to the level of an assumed sustainable yield of 6,000 ML. As such, there is no 'over-extraction' by the end of the study period.

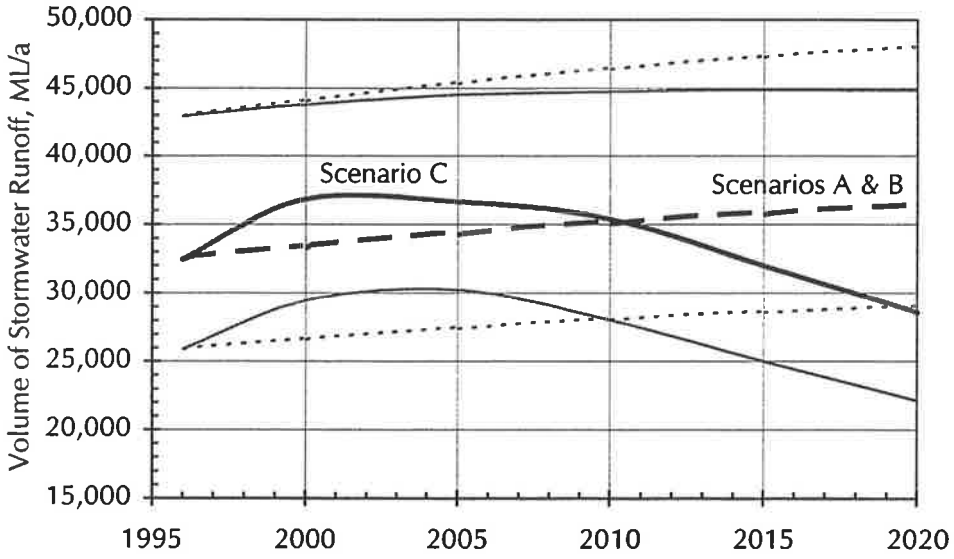


Figure 10.26
Stormwater Yield Under Scenarios A, B and C

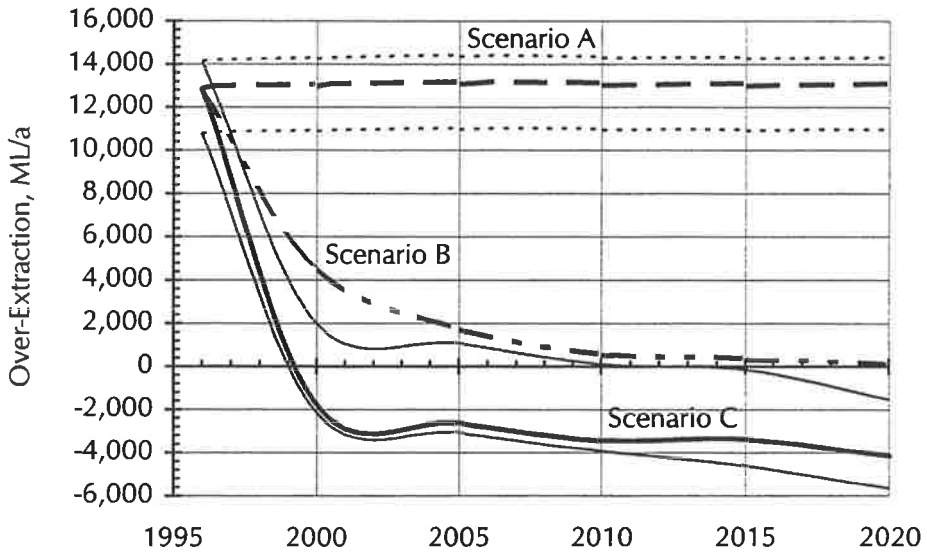


Figure 10.27
Groundwater Extraction in Excess of the Sustainable Yield
(Estimated at 6,000 ML/annum)

Under Scenario C, the establishment of aquifer storage and recovery schemes coupled with improved irrigation efficiency, pricing and regulatory reforms enables the reduction in extraction of groundwater. Indeed, relatively rapid progress can be made toward achieving a surplus over the sustainable yield that can be utilised in the expansion of high value crops or industry.

10.15. Infrastructure and Operational Costs

The cost of implementation of the three alternative water management scenarios has been determined, either from actual costs as they relate to particular projects (e.g. Virginia Pipeline Scheme), official budget estimates (e.g. water main augmentation costs from the SA Water Corporation), or design estimates based on current construction rates and unit costs. The annual series of construction and operational costs have been prepared, from which the Present Value (PV) of each item has been calculated for each scenario. A discount rate of 7.95% has been used, equivalent to the current long term Government bond rate (at March 1997). The results of these analyses are presented in Table 10.20, with the explanation of their derivation provided in the following text.

Every effort has been made to prepare realistic cost estimates and to 'compare apples with apples'. In general, estimates correspond to major infrastructure or cost items. The fundamental difficulty is the comparison of costs of an integrated design with those of traditional services, particularly where cross subsidies exist between operations such as those between metropolitan and country areas, between water supply and sewerage and between the industrial, commercial and residential sectors (Stewardson *et al*, 1995). The primary objective has been to prepare indicative, order-of-magnitude costs for the purpose of comparing the relative economies of alternative schemes. It is believed that this has been achieved.

10.15.1. Water Storage, Treatment and Distribution

The collection and storage of water for treatment and distribution is assumed to continue in the same manner as exists today. Modifications to the water supply infrastructure could result, however, from changes in the patterns and magnitude of demand for potable water. Reduction in the total and peak demand would allow smaller pipes to be used in the reticulation network, with less water being treated and possibly less imported from the River Murray. The cost implications of these potential changes have been explored.

10.15.1.1. Water Pumping and Treatment

The cost of water importation and treatment was sourced from Crawley (1992). The cost of water treatment is approximately $44.50 per megalitre within the northern system (in 1996 dollar terms).

Pumping water from the River Murray through the Mannum–Adelaide Pipeline involves pumps that can be run individually or in parallel. The pumps are electrically powered and SA Water is charged for the power consumed by the Electricity Trust of South Australia (ETSA). ETSA has seasonal electricity tariff schedules comprising off-peak, on-peak and special on-peak periods for the winter, spring/autumn and summer seasons. The combination of the number of pumps and arrangement of the electricity tariff periods, results in a non-linear relationship between volume of water pumped and the associated cost. Crawley (1995) considered all possible combinations of pumps and electricity tariff periods to derive a linear piece-wise pump-cost curve. For the Mannum–Adelaide Pipeline, there appears to be little variation during the year and so an average pump-cost curve was adopted, as illustrated in Figure 10.28. Assuming a straight line relationship, the mean pumping cost was calculated to be $0.088 million/GL (in 1996 dollar terms).

Table 10.20
Summary of Development Costs as Present Value by Scenario

Item of Infrastructure or Operational Expenditure	Scenarios A and B, PV $m			Scenario C, PV $m		
	Dry Years	Average Years	Wet Years	Dry Years	Average Years	Wet Years
Pumping from River Murray	18.45	10.03	1.02	10.12	3.24	0.00
New water supply trunk mains	7.29	7.29	7.29	4.75	4.75	???
New mains in Gawler rural areas	3.10	3.10	3.10	0.00	0.00	0.00
Existing water main replacement	7.40	7.40	7.40	4.81	4.81	4.81
Water treatment	19.59	18.30	17.28	16.18	15.12	14.37
Bolivar WWTP BNR upgrade	89.66	89.66	89.66	80.70	80.70	80.70
Plant upgrade for odour control	20.01	20.01	20.01	0.00	0.00	0.00
Extended ocean outfall & diffuser	36.16	36.16	36.16	0.00	0.00	0.00
Trunk sewer augmentation	12.00	12.00	12.00	0.00	0.00	0.00
Wastewater treatment	24.47	22.84	21.81	23.80	22.22	21.22
New wastewater treatment plants	0.00	0.00	0.00	68.67	68.67	68.67
Dual water supply system	0.00	0.00	0.00	12.39	12.39	12.39
Stormwater drainage	112.79	112.79	112.79	81.21	81.21	81.21
Injection/recovery wells for ASR	0.00	0.00	0.00	10.74	10.74	10.74
Sub-Total (Scenario A)	350.92	339.58	328.52	313.36	303.84	330.10
Virginia Pipeline Scheme(1)	116.87	116.87	116.87	0.00	0.00	0.00
Less Conventional Bolivar Upgrade	-89.66	-89.66	-89.66	0.00	0.00	0.00
Sub-Total (Scenario B)	378.13	366.79	355.73	313.36	303.84	330.10
Residential Infra. Development	309.41	309.41	309.41	980.28	980.28	980.28
Total - Scenario A	**660.33**	**648.99**	**637.93**	-	-	-
Total - Scenario B	**687.54**	**676.20**	**665.14**	-	-	-
Total - Scenario C	-	-	-	**1,293.64**	**1,284.12**	**1,310.38**

(1) Capital cost of $41.6 million and O&M of $1.045 million, plus Bolivar plant upgrades at a capital cost of $45.04 million and O&M cost of $2.86 million.

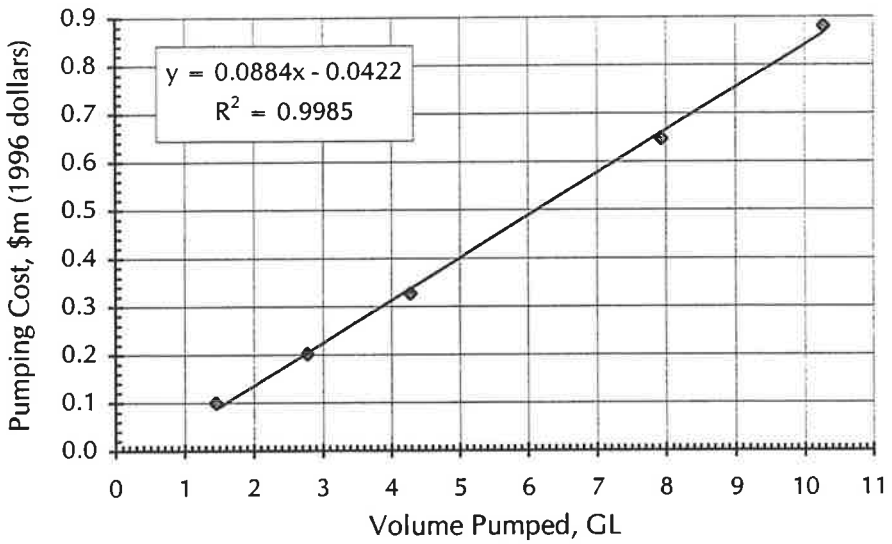


Figure 10.28
Pump-Cost Curve for the Mannum–Adelaide Pipeline (after Crawley, 1995)

10.15.1.2. Augmentation of the Distribution System

An investigation was conducted by SA Water into the water supply augmentation requirements for the northern Adelaide plains over the period 1996 to 2015. According to population and dwelling projections provided by the Department of Housing and Urban Development (DHUD), future urban expansion and increase in demand for potable water would occur primarily in the Munno Para, Angle Vale and Two Wells-Lewiston regions. This would see full development of the remaining areas zoned for residential development, including rezoning of some areas currently zoned Rural Living A and B.

Indeed, there has been significant urban growth in the Angle Vale district over the past 10 years, and this is projected to continue. Around 80-100 allotments in the areas zoned Rural Living are expected to be developed each year in the Two Wells-Lewiston area.

It was considered unlikely for development to be significant in the Gawler and Evanston districts in the immediate future and until the end of the adopted planning period. There is, however, vigorous discussion amongst the Munno Para and Gawler councils at present with regard to the location of the proposed Metropolitan Open Space Scheme areas and how it might affect the development potential of each local government area.

Apart from the dwelling projections provided by DHUD, SA Water gave little consideration to dwelling densities and the potential for demand changes due to urban consolidation. An allowance of a nominal 1-2 percent increase in dwelling density was provided for the existing urban areas.

There is not likely to be a need for any capacity expansion for this area, either in water treatment or pumping from the River Murray prior to 2020-2025. However,

the Swan Reach to Stockwell pipeline is to be complemented by a water filtration and treatment plant at Swan Reach so that potable water can be supplied directly to the Barossa Valley. Although there has been discussion of maintaining the raw water supply through this pipeline, primarily for expansion of supply to vineyards, SA Water rejected this proposal. However, there are plans for utilisation of the excess capacity in the pipeline during winter to supply water expansion of irrigated agriculture. Surface storages and aquifer storage and recovery systems will be used to provide the inter-season storage (Rust PPK, 1996; Kelton, 1998). The construction of another raw water supply from the River Murray to the Barossa Valley (*pers comm*, Damiani, 1987).

The water captured in the Warren Reservoir will then become available for expansion of supply to the northern plains via the South Para and Barossa reservoir system or for conjunctive uses such as aquifer storage and recovery (ASR).

SA Water have planned expenditure of $14 million (1996 dollars) between the period 1996/97 and 2014/15 for the implementation of these augmentation works. These estimates are for major elements of the reticulation network, and do not take into consideration the smaller mains within subdivisions. The timetable for this expenditure is provided in Appendix M.

10.15.1.3. Pipe Design and Replacement

An assessment was made of the potential cost savings that could accrue as a result of reduced demand for potable water (Scenario C). A pipe design and selection process was followed to determine the change in pipe size that could occur and the resulting cost saving.

Most of the water distribution pipes existing on the NAP are asbestos cement (AC), concrete lined cast iron (CICL) or polyvinyl chloride (PVC) plastic in nature. Pipe replacement would now tend to involve concrete lined ductile iron (DICL) or mild steel (MSCL), PVC or high density polyethylene (HDPE) type pipes. The cost for each type of pipe in their available diameters was provided by SA Water.

The flow characteristics of the available pipe types were determined for all pipe diameters, by undertaking a pipe design process according to the standard practices of SA Water (EWS, 1992) and adopting the following design constraints:

- head loss $\leq$ 6.5 metres per 1,000 metres length of pipe; and
- flow velocity $\geq$ 0.45 metres per second.

The distribution system is designed to convey water to consumers at a varying rate throughout the day which fluctuates from a very small flow at night to almost double the average daily flow in the evening (EWS, 1992; CMPS&F, 1996). Gravity supply mains are designed to supply the demand flow, whether it be on a daily, weekly or monthly basis, over a full 24 hour period. Design peaking factors are used to calculate the size of the distribution mains to transfer water from the storages to customers.

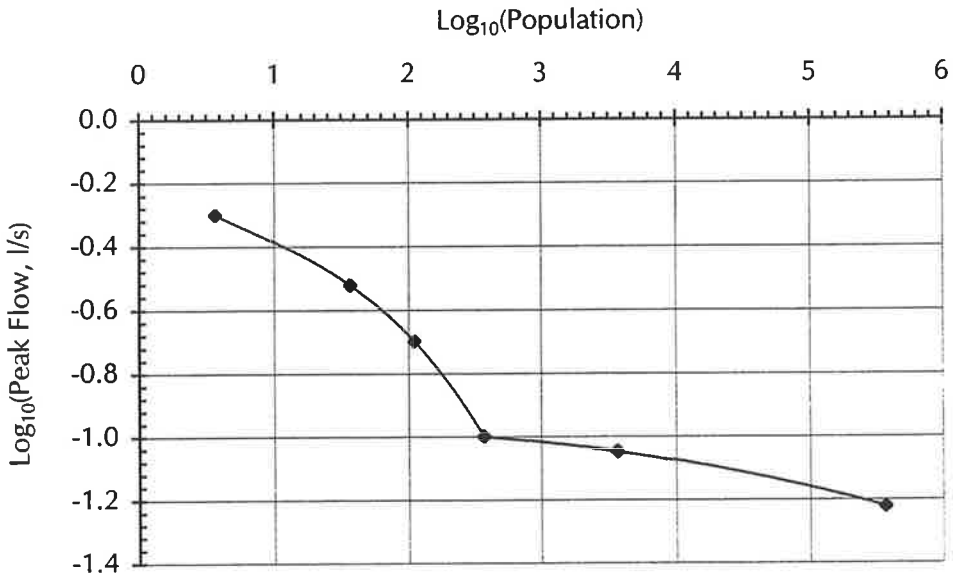


Figure 10.29
Relationship Between Size of the Serviced Population and Design Peak Flow for Water Distribution Pipelines in Conventional Urban Areas

For large areas, the peak flow is calculated to be 5 times the average flow for the total annual quantity of water used for that area. For smaller areas, higher peak flow rates can occur that are up to 10 times the annual average flow. When designing distribution mains for subdivisions where the number of customers can be counted, SA Water recommend the flow rates presented in Table 10.21 (EWS, 1992). This data was used to construct Figure 10.29 from which design flows were calculated for various sizes of serviced population.

Table 10.21
Design Flows for Water Distribution

Customer Base	Design Peak Flow	
1 house	0.5	litres/second
10 houses	0.3	litres/second/house
30 houses	0.2	litres/second/house
100 houses	0.1	litres/second/house
Over 100 houses	0.09	litres/second/house

A similar design curve was derived for the new urban form conditions of Scenario C. Under this scenario, the peak flow would be less because the water applications normally causing the high peak flows (e.g. domestic irrigation) would be serviced by alternative water sources (e.g. reclaimed effluent). With less variability in potable water demand and actual flows, the design peak flow can be reduced. The design curve for Scenario C was thus constructed by modifying the conventional design curve by the ratio of the design peaking factors. That is:

$$DF_{Scenario\ C} = DF_{Conventional} \times \frac{PF_{Scenario\ C}\ (= 3.42)}{PF_{Conventional}\ (= 5.0)} \qquad (10.10)$$

where DF is the design flow, and PF is the large area peaking factor.

The large area peaking factor for Scenario C was calculated from an analysis of historical water consumption rates. It was assumed that water consumption during winter (represented by months with high rainfall when water use for irrigation would be low) was representative of the water demand conditions that would occur under Scenario C. It was found that the peak daily flow was 1.68 times greater than the mean daily flow during winter. Combining this with the 24 hour peaking factor of 1.99 with the low annual variability in winter consumption (around 2 percent), the resulting instantaneous peaking factor was approximately 3.4 compared with 5.0 under existing conditions. That is:

$$\begin{aligned} \text{Instantaneous PF} &= \text{(Annual Variability).(Daily PF).(24 hour PF)} \qquad (10.11) \\ &= 1.02 \times 1.68 \times 1.99 \\ &= 3.42 \end{aligned}$$

The reduced Peaking Factor and lower mean daily consumption of potable water results in a significantly reduced design flow, as indicated in Table 10.22. The lower design flow can be translated into selection of a smaller diameter pipe and hence reduced construction cost. Where the recommended minimum diameter of water main within conventional residential areas is 100 mm, this could be replaced with a 63 mm HDPE pipeline with a saving of $68 per metre; refer to Figure 10.30. The reduced pipe sizes were also compared with the flow requirements for fire fighting (Metcalf & Eddy, 1979) and were found to be sufficient.

Having determined the pipe replacement strategy for Scenario C, the total replacement cost was estimated for the period of 1996 to 2020. Water mains data was obtained from SA Water in an ARC/INFO format which included details such as the length, material type and year of installation of each section of pipe. The sequence of pipe installation was determined, as illustrated in Figure 10.31, from which the timing, total length and cost of pipe replacement was calculated.

Table 10.22
Pipeline Design Parameters

Design Parameter	Conventional Urban Form, Scenario A	New Urban Form, Scenario C
Daily consumption of potable water, litres/capita	350	149
Number of persons/household	2.92	2.50
Daily household water demand, litres	1,022	372.5
Average daily consumption rate, l/s/dw	0.012	0.0043
Large area peaking factor	5.00	3.42
Large area design peak flow, l/s/dw	0.059	0.015

If an economic life of 80 years for water mains (EWS, 1991) is assumed, then all mains prior to 1918 should be replaced. The present value (PV) associated with like-for-like replacement of existing mains was calculated to be $7.40 million, compared with only $4.81 million using the smaller diameter mains.

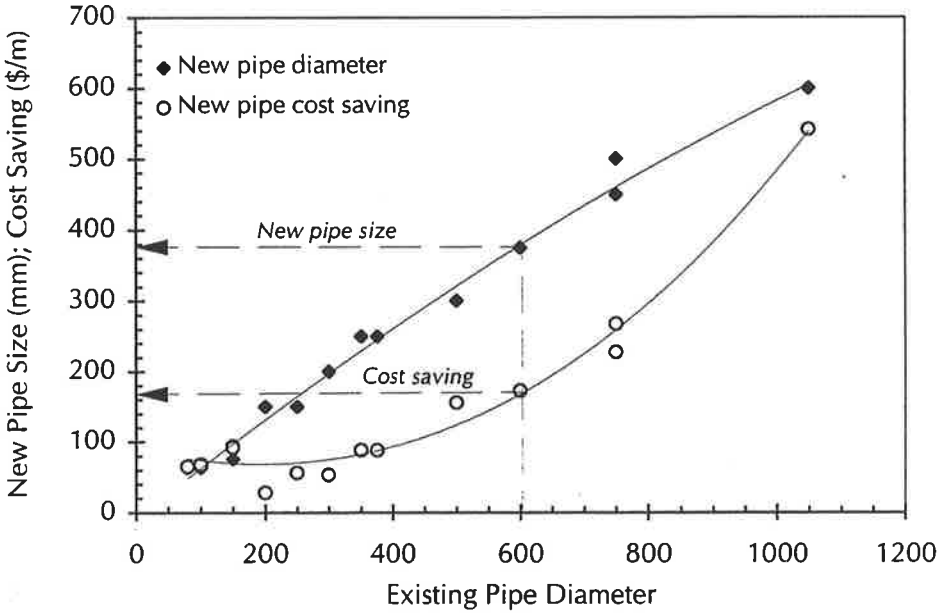


Figure 10.30
Pipe Replacement Benefits of Scenario C

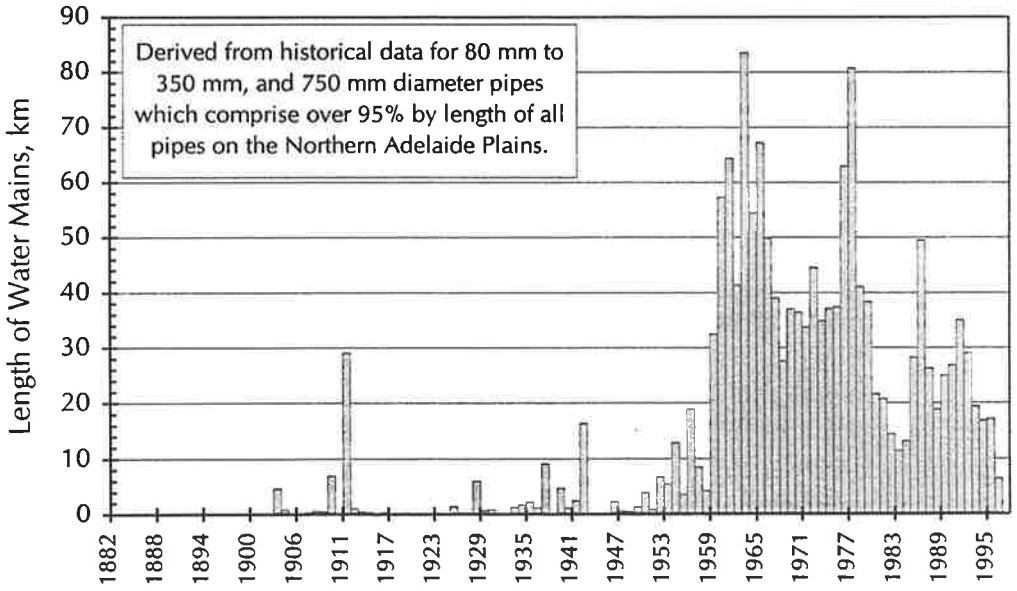


Figure 10.31
Length of Water Supply Mains Constructed by Year

The potential for significant cost savings due to reduced demand for potable water has been recently recognised by SA Water. With the proposal to implement a

system of on-site wastewater treatment and effluent re-use at the new residential development of Northfield, SA Water developed a hydraulic model to measure the potential impacts. It was confirmed that the use of treated effluent for irrigation and toilet flushing could significantly reduce the peak demand flow. As a consequence a smaller diameter supply main could be installed, reducing the construction cost from $470,000 to $280,000 – a 40 percent saving (SA Water, 1996).

10.15.2. Sewage Drainage and Treatment

10.15.2.1. Sewer Design, Augmentation and Replacement Costs

In a similar manner to the analysis of the replacement of water supply mains, the potential for cost savings in the replacement of old sewers was also considered. The capacity of the available pipe sizes was calculated according to the sewer design procedures of SA Water (EWS, 1984) and other authorities (Metcalf & Eddy Inc., 1979; Brady & Eagle, 1984; WAWA, 1986). In Australia, sewers are typically sized to carry a design flow that is calculated by multiplying an annual average 'dry weather flow' by a peaking factor. That is:

$$\text{Design Flow} = \frac{EP \times PF \times DWF}{24 \times 60 \times 60} \qquad (10.12)$$

where the Design Flow is expressed in litres per second, EP is the equivalent population serviced by the sewers, PF is a 24 hour peaking factor, and DWF is the dry weather flow in litres per second. A peaking factor of 2.5 has been adopted during the past, although more recently it has been found necessary to design sewers with variable peaking factors that make allowance for a time of concentration of flows for a given area (EWS, 1984).

The design flow in sewers typically includes the wastewater flow from the design population contributing to the sewer, plus an *allowance* for stormwater and groundwater infiltration and industrial wastes expressed as a flow from an equivalent population (EP).

In South Australia, all sewers are designed to carry the design flow when flowing 60 percent full. This allows air space for ventilation of sewers, provides for the minimum wet weather flow and takes into account the future unknown factors e.g. population habits and trends relating to water usage. It is also essential that wastes are transported to the treatment works in such a way that they are prevented from becoming anaerobic and emitting offensive odours. Sewers are therefore designed to maintain sufficient flow, specified by a 'self cleaning velocity' of 0.6 m/s (EWS, 1984), so that turbulence is created ensuring that solid matter is transported in the flow. The sewers were designed according to these criteria based on the water consumption and contribution to sewer discussed previously in Section 10.7. The design calculations are summarised in Appendix N.

The dry weather flow was estimated to be equivalent to 200 lpcd under conventional circumstances (Scenarios A and B), and 180 lpcd with the adoption of water conservation measures (Scenario C). The design flow is reduced only slightly

because the reduction in potable water demand that can be achieved according to Scenario C is simply a substitution with another lesser quality source of water. Without the use of water conserving measures, the volume of water discharged to the sewer would not change. It was therefore found that only occasional reductions in pipe sizes could be made upon replacement with small cost savings as a consequence.

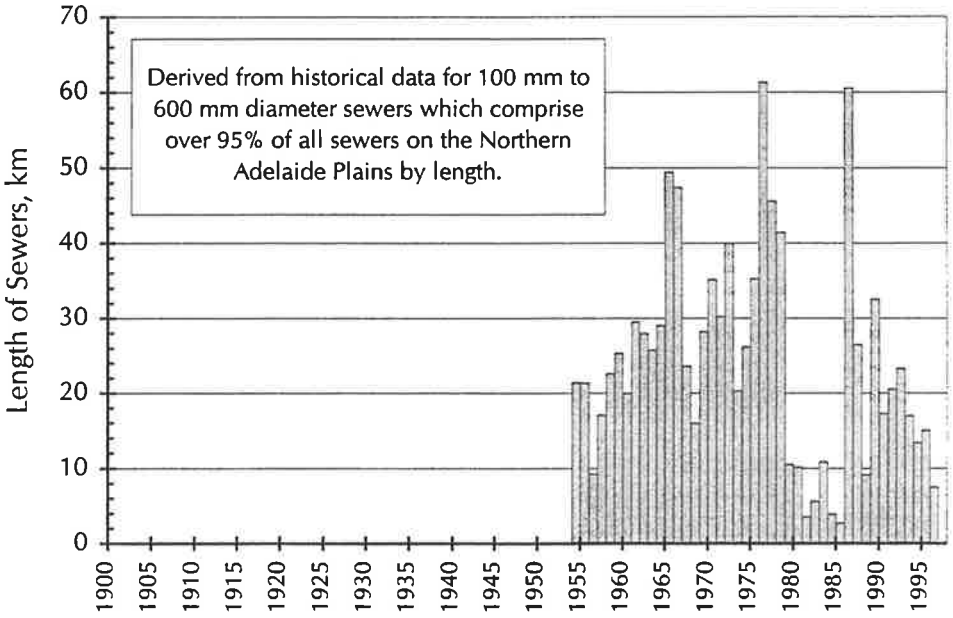


Figure 10.32
History of Sewer Construction on the NAP

Given that the majority of pipes are of an age much less than their economic lives of around 80 years (refer to Figure 10.32), there was similarly little potential for large cumulative cost savings that could accrue from some pipe size reductions.

Discussions with SA Water indicated that some augmentation and maintenance works are required for the existing sewer system in the near future (*pers comm*, Flood, 1997). The trunk sewer servicing the northern Adelaide plains and connecting into the Bolivar sewage treatment works is presently operating at full capacity, and any addition to the sewerage system through areas of new urban development serve only to raise the load on the system further above its design capacity. The construction of an additional main and reconnection of branch sewers is desperately needed to relieve the stress on the system.

Around $8 million in such works is currently proposed, although it is considered to be highly probable to increase to around $12 million. These works are to be implemented before the year 2000.

Indeed, this level of investment is only in new works, and does not cover asset maintenance and replacement which is also needed, particularly in the southern areas of the region. Sewer grouting programmes have been proposed, although grouting is typically only effective for around 5 to 8 years, and are really a stop gap

measure. Infiltration of saline groundwater into the sewers is becoming a problem, to the extent that irrigators currently drawing water from the Bolivar outfall channel have complained in instances that the effluent is too saline for use in horticulture. This may present a potential threat to the Virginia Pipeline Scheme.

Any urban development requiring construction of sewerage facilities north of the Gawler River will also require the construction of a new wastewater treatment plant, probably around the Roseworthy or Lewiston region (see Figure 11.1). Costs for such work are not available, however, as the planning horizon for sewerage works is typically not greater than 10 years. Sewerage requirements are very site specific and require more detailed knowledge of development patterns which can only be obtained at a later stage of development planning.

10.15.2.2. New Wastewater Treatment Plants

Analysis has also been undertaken to provide an indication of the optimum scale of wastewater treatment to service a growing population. Treatment plant capacities have ranged from those of small scale, decentralised plants through to the large, centralised plants such as those presently operating in Adelaide.

Economic efficiency has been used as the measure to determine the most suitable wastewater treatment scale, although other factors would certainly affect any treatment plant design for a particular site (such as terrain, options for disposal or reuse of treated effluent, and the proportion of non-domestic wastewater entering the sewerage system).

A range of cost components have been addressed, including:

- the initial construction cost of the treatment plant;
- annual operation and maintenance (O&M) costs;
- the cost of purchasing land for construction of the plant;
- the cost of constructing holding storages; and
- the cost of purchasing land for any holding storage.

In most instances, data on costs and other factors reflect actual conditions corresponding to existing facilities, or have been sourced from design documents and investigation reports. Much of the data relating to capital and O&M costs has been provided by the Water Resources Group of DENR. A summary of the data sources and analytical calculations is provided in Appendix O.

Data relating to population projections, storage requirements, urban land costs, storage construction costs and land requirements, have typically been derived from actual historical data.

The findings of the analysis, as reflected in Figure 10.33, are:

- Replacement of an existing centralised sewage treatment plant servicing a large population (e.g. in excess of 200,000 people) would be most economically achieved by constructing a similar plant but only if replacement must occur over a relatively short time period in the order of a few years.

- Replacement of an existing centralised sewage treatment plant servicing a large population, or expansion of sewage treatment capacity when an existing system is operating near full capacity, is most economically achieved by the establishment of smaller scale systems (e.g. with the capacity to service 50,000 EP) when that expansion can occur over a longer time period (e.g. 10 years or more).

- The primary cost penalty associated with large sewage treatment facilities is the over-capitalisation that occurs. A large plant is typically designed for the load that it will experience towards the end of the planning period (or when its catchment area becomes fully developed), and therefore the plant's capacity is largely under-utilised for many years. Tailoring treatment capacity to sewage flows (and therefore the rate of population growth and urban development) is far more economical. The construction of a number of additional sub-regional treatment plants may also have other environmental and social benefits, and be supportive of moves toward greater urban densities and transit oriented developments.

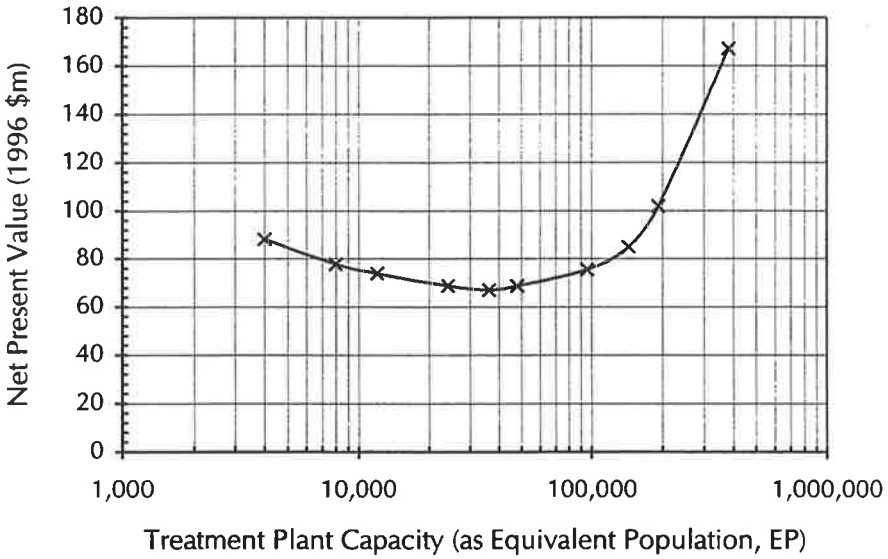


Figure 10.33
Estimated Cost for New Sewage Treatment Facilities for an Expanding Population, 1996-2020

10.15.2.3. Wastewater Treatment

The cost for treating sewage at the Bolivar WWTP was estimated from annual operation and maintenance costs for all major South Australian treatment plants. It was calculated that the average cost of secondary treatment is $100 per ML. This cost compares favourably with that estimated from the sewage treatment works data discussed above.

From the historical cost data, it was determined that the cost of sewage treatment for a sub-regional WWTP serving an equivalent population of 50,000 people is also approximately $100 per ML (Scenario C).

An estimate was also prepared of the cost of treatment following the construction of the tertiary treatment facilities for biological nutrient removal (BNR) at Bolivar WWTP (Scenario B). The additional capital and O&M costs were provided in the Environmental Improvement Programme documentation for Bolivar (SA Water, 1995). These costs were translated into an annual increase in operating cost assuming that cost recovery is required over the conventional 50 year economic life of the treatment plant facilities. Under these circumstances, the effective cost of treatment rises significantly to approximately $356 per ML.

10.15.3. Effluent Reclamation and Reticulation

10.15.3.1. Virginia Pipeline Scheme

The costs associated with construction of the tertiary treatment facilities and reticulation system proposed for the Virginia Pipeline Scheme have been sourced from investigation and design documents provided by the Virginia Irrigation Association and MFP Australia. These costs are presented in detail as part of the discussion of Scenario B in Chapter 11.

10.15.3.2. Dual Reticulation Systems

A conceptual reticulation system was designed on the premise that the majority of demand for non-potable water in the urban environment would be met via a dual water system.

The reticulation system and associated cost was based upon a conceptual layout of an urban village (after Calthorpe, 1993). The pipe system was sized according to the approximate number of people serviced along each road, following the design procedures for water supply mains previously discussed in Section 10.15.1. The dual reticulation system requirements for an entire urban district were simply based upon aggregation of the systems for each urban village.

Over the period 1996 to 2020, the reduction in sewage flows predicted under Scenario C would result in an effective increase in BOD loading from domestic sewage of 36 percent due to concentration of solid wastes in the sewage. In addition, on the basis of volume of water consumed and the proportion returned to sewer, the contribution to sewage flow by the industrial and commercial sectors was calculated to be equivalent to a domestic load from 17,730 persons, or an increase of 37 percent over the urban district population of 48,000 people. (This is based upon the assumption that the BOD loading from industrial effluent is comparable to domestic effluent. Under Scenario C, industrial and commercial premises would be required to internalise some of the 'environmental' costs of production, and as such treat their sewage on site so that the load upon the municipal WWTP is no greater than domestic sewage.) The load upon the sub-regional wastewater treatment plants is therefore equivalent to 84,000 EP, for which 2 WWTPs at 40,000-50,000 EP capacity should be provided per urban district.

It was calculated that the construction cost of the system of pipes for distribution of the reclaimed effluent within an urban centre consisting of an urban district and

surrounding urban villages was approximately $14.9 million. With progressive implementation of dual water supply systems in the region at a rate proportional to that of population growth and urban renewal, the net present value of system construction is $34.72 million.

The combined capital and O&M costs of the dual supply system was determined to be 53.4 ¢/kL, assuming a rate of return upon investment of 8% is required. Comparing the treatment costs for reticulation of reclaimed effluent with effluent disposal, it was found that dual reticulation is more expensive by:

- 430 percent under Scenario A where no additional treatment of the effluent from Bolivar WWTP would be provided (at a cost of 10 ¢/kL); and
- 50 percent under Scenario B where biological nutrient removal and other infrastructure upgrading occurs at Bolivar WWTP (at an equivalent cost of 35.7 ¢/kL).

The reticulated effluent would however remain more than 40 percent cheaper than the cost of potable water which it could replace.

10.15.4. Stormwater Drainage and Collection

There is an existing commitment to flood protection within the South Australian community and in government, as reflected by historical drainage infrastructure expenditure levels of around $16.5 million per annum (SA Local Government Grants Commission), an estimated 80-90 percent of which is incurred within the Adelaide metropolitan area, around $14 million per annum (BC Tonkin, 1993).

Costs of street and collector drainage for the ultimate development of the Adelaide metropolitan area are shown in Table 10.23, which are based on the current land use zoning and the Long Term Development Strategy for Metropolitan Adelaide (DEP, 1987). From these values have been subtracted the estimated value of existing infrastructure to give the required future expenditure to achieve various levels of flood protection as indicated by the average recurrence interval (ARI).

Stormwater management makes a substantial contribution to the infrastructure costs associated with residential development. ECA (1991) provide an example of the costs of stormwater drainage for the residential development at Seaford. At the subdivisional level, around 8-9% of the total cost of infrastructure provision is associated with stormwater drainage. The provision or modification of trunk drainage comprises around 6 percent of all infrastructure costs for major new developments. The resultant cost of drainage can be around $2,400 per block (in 1991 dollars), and this is in an area that has easy access to water courses and a short distance to sea for discharge. The cost could be substantially more in an area without these advantages, and as environmental standards become more stringent, the costs could easily double (ECA, 1991).

With community education and major flow path clearance and redevelopment, it is envisaged that design recurrence intervals of street and collector drainage in existing and newly developed areas should be able to be reduced from 100 years to

between 10 and 20 years with adoption of the major-minor concept of drainage design (ECA, 1991).

Table 10.23
Street and Collector Drainage Infrastructure Costs Estimates to Achieve Ultimate Development (after ECA, 1991)

Catchment Name	Urban Area (km²)	Infrastructure Development Costs, $m[1]		
		10 yr ARI	20 yr ARI	100 yr ARI
Gawler River	6.0	10.8	12.5	15.2
Munno Para	29.6	51.3	60.0	73.4
Helps Road	49.3	85.5	99.8	122.1
Little Para River	34.5	52.7	62.2	78.3
Dry Creek	90.8	143.1	168.8	210.6
Total	210.2	343.4	403.3	499.6
Expenditure to 1987		206.4	206.4	206.4
Additional Expenditure Required		137.0	196.9	293.2

(1) Costs converted from 1987 to 1996 dollars using Consumer Price Index data from Catalogues No. 6410.0 of the Australian Bureau of Statistics.

Trunk drainage costs for ultimate development of metropolitan Adelaide are expected to amount to $420 million (1996 dollars), with expenditure of around $245 million still required.

The range of costs identified for each major component reflect the variation between construction in new broadacre development and within developed areas. It should be noted that the land acquisition estimates were based on the assumption that the land required was vacant.

It can be seen from Table 10.24 that the viability of construction of the swale drain option would be strongly dependent on the required land acquisition costs. That is, if the land required for the swale was obtained as part of a reserve of drainage quota at no cost, this option would be significantly cheaper to construct.

Thus the future trunk drainage infrastructure works cost of $245 million may be able to be reduced by alternative approaches, depending on land cost allocation and site related factors.

There are 119 local government areas within the state which collectively spend around $7.6 million annually on construction of stormwater drainage facilities and $3.7 million (1991/92 dollars) each year on maintenance in the period 1984/85 to 1991/92. Prior to the establishment of the new Catchment Boards, the State Government contributed around $3.5 million annually (30% going to non-metropolitan areas) through the Drainage Subsidy Scheme (DSS) administered by the Department of Transport (DoT). An additional $3 million is spent each year by the DoT as part of its programme of works to improve the principal road network. Thus the total annual expenditure on construction and maintenance of stormwater

drainage infrastructure has been about $17.8 million, the bulk directed toward the metropolitan area (Rolls, 1995).

Of the current expenditure on drainage metropolitan infrastructure of $17.8 million per annum (in 1991/92 dollars), $5.09 million is spent on the construction of trunk drainage and $8.90 million for street and collector drainage, with around $1.9 million in maintenance on each of these.

Table 10.24
Cost Estimates for Trunk Drainage Options(1)

Component	Conventional Drain, $/m	Swale Drain, $/m
Excavation	50 - 90	350 - 600
Culvert / Drain Formation	3,000	120
Landscaping	0	700
Land Acquisition	360 - 600	4,320 - 7,200
Total Capital Cost	3,410 - 3,690	5,490 - 8620
Annual Costs	Negligible	15

(1) These cost estimates (1991 dollars) are based on simple capital and maintenance costs and do not take into account asset replacement or depreciation.

The provision of stormwater drainage infrastructure for flood control for the existing and anticipated development of metropolitan Adelaide will require an increase in current levels of expenditure, depending upon the period of implementation, of either $1.6 million per annum (a 10% increase) for a 50 year programme, $9.4 million per annum (a 65% increase) for a 30 year programme or $19 million per annum (a 135% increase) for a 20 year programme (ECA, 1991).

Consequently, an important objective of any multi-objective approach to stormwater management in metropolitan Adelaide will be to substantially lower water and drainage infrastructure costs in the following ways (after ECA, 1991; BC Tonkin, c.1992; Fleming & Daniell, 1997):

- replacing stormwater pipes and channels in planned residential developments with other, more systems;
- reducing the upgrading of existing stormwater infrastructure costs associated with urban consolidation;
- deferring or eliminating the next major water supply augmentation scheme (that is a new pipeline from the River Murray) and augmentation of the headworks;
- reducing the cost of treating water in reservoirs by minimising the amount of treated water used for garden and parkland irrigation; and
- reducing the cost of pumping water from the River Murray;
- adoption of a more flexible quantity *and* quality orientated arrangement with regard to the provision of open space in residential developments, enabling greater combination with drainage courses;
- make drainage course maintenance more a part of open space maintenance through multi-objective development and use of these areas;
- greater use of small open channel or swale systems within residential subdivisions;

- direction of stormwater runoff to landscape areas rather than into drains;
- contributions by developers who are involved in urban consolidation projects to local or district retention facilities.

The expenditure to achieve full development of the drainage infrastructure over the period 1996–2020 for the study region was calculated from the data presented above. In 1996 dollar terms, the total expenditure required on metropolitan street and collector drainage is $151.8 million, with an additional $90 million on trunk drainage. The current expenditure on drainage is approximately $9.91 million per annum on street and collector construction, $5.65 million on trunk drainage construction, and $4.25 million in maintenance of these systems. In total, an estimated $19.8 per annum is expended. In 1996, the expenditure required to complete construction of the drainage system amounts to $125.4 million on street and collector drainage construction, $74.9 million on trunk drainage construction, with $1.414 million per annum for maintenance of both systems. At a discount rate of 7.95 percent, and for the provision of conventional drainage, this represents a PV cost of $112.79 million.

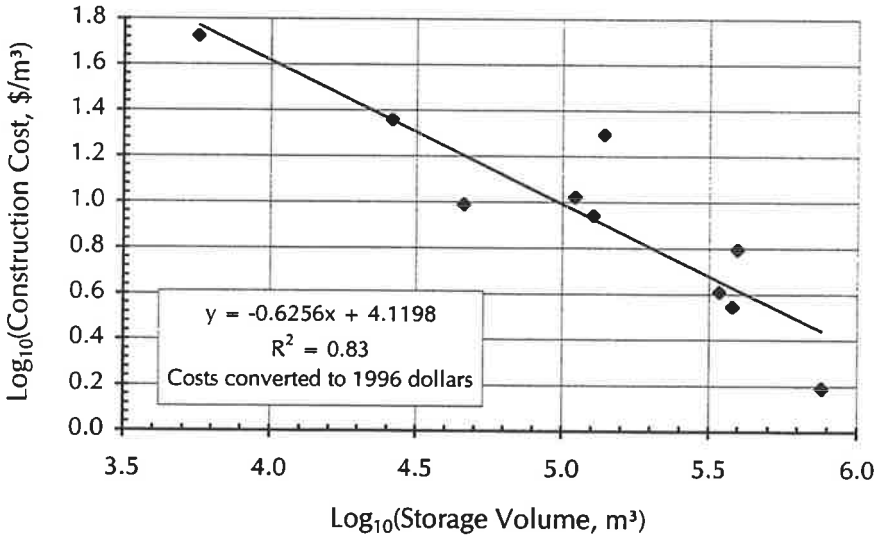


Figure 10.34
Construction Costs of Artificial Wetlands Existing in Adelaide

An estimated 54% saving could be achieved in the construction of trunk drainage by the adoption of open channel, multi-purpose drainage courses. Assuming that all other costs remain the same, the overall PV cost for drainage reduces to $81.21 million. This cost estimate also included an allowance for construction of wetlands for stormwater capture, water quality improvement and reuse. The wetlands were sized following recognised design guidelines and the findings discussed in Section 10.10.2. The cost of wetland construction was estimated from historical data relating to artificial wetlands existing in metropolitan Adelaide; refer to Figure 10.34. It was determined that 1 wetland with a storage capacity of around 25 ML should serve each urban district, with a construction cost of $580,000. Six such wetlands would be constructed during the study period.

10.15.5. Aquifer Storage and Recovery

BC Tonkin (1993) consider that the most feasible opportunities for the use of stormwater involve local or district reuse, most probably involving aquifer recharge. Reuse at the regional level is discounted as the supply of treated effluent from Bolivar WWTP represents a more reliable source of supply in terms of quantity, seasonality and quality. Indeed, this appears to be a most reasonable and practical approach, as the cost of construction of storages sufficient to enable stormwater to become a viable major water source is prohibitive.

The costs for the installation and operation of dual injection and recovery wells for aquifer storage and recovery have been determined from recent publications, many of which address ASR for northern Adelaide, including those of Gerges (1995), Stevens *et al* (1995), KME (1996) and Dillon (1996). A well construction and commissioning cost of $85,000 was adopted, with an annual operation and maintenance cost of $5,600 per well.

The system design was based upon the parameters and previous experience discussed in Section 10.6.2. An examination of the location and capacity of existing stormwater retention ponds and wetlands indicated that there are 5 notionally suitable locations for implementation of ASR systems. Adopting a simple system of 7 wells around each injection water source (pond), and ensuring a minimum of 2 km spacing between injection wells, then around 12 km of water supply pipeline would be required. Based upon a flow rate of 15 litres per second, a 160 mm HDPE pipeline would be suitable, for which the estimated construction cost is $468,000 per system. These costs do not include ~~the~~ those for water storage construction and maintenance which have been addressed via stormwater drainage and collection.

With 7 systems operating early during the study period, 35 injection and recovery wells would be installed, with the projected increase to the full regional system of 64 wells achieved by the year 2005. The net present value of all construction and operational costs associated with implementation of this regional ASR scheme was calculated to be $10.74 million.

10.15.6. Cost of Water by Source

The real marginal price of water for each source of supply has also been calculated. The cost of water supply from new sources has been estimated on the basis of providing an acceptable rate of return on the investment. For example, the cost of treated wastewater from community scale wastewater treatment plants must be sufficient to cover the capital, operation and maintenance costs over the economic life of the asset (e.g. 50 years) and make a return on the investment of 8 percent. The Annual Equivalent Worth (AEW) is calculated on this basis, and dividing through by the mean annual consumption rate provides an estimate of the cost of water (as ¢/kL in 1996 dollars). These costs are summarised in Table 10.25.

Table 10.25
Real Marginal Price of Water over the Period 1996–2020, ¢/kL in 1996 dollar terms

Water Resource	Scenario A	Scenario B	Scenario C
Mains potable water	90 - 219	90 - 219	90 - 262
Treated sewage effluent	0.59[1]	10 - 23[2]	50
Groundwater	6	9	12[3]
Stormwater with ASR[4]	25	25	25

(1) From EWS (1993) Reclaimed Water Use in South Australia
(2) Distribution of additional infrastructure costs over users of metropolitan Adelaide sewerage system.
(3) Costs of ASR scheme construction and operation distributed over all groundwater users.
(4) Covers all construction and O&M costs of ASR; storage costs not included as these are an integral part of stormwater drainage measures.

In order to determine the total expenditure on water during the study period, the unit cost for each source was combined with the consumption of water resources according to the simulated movements in water use by source and magnitude. The aggregate cost to consumers of water supply from all sources for the entire period 1996 to 2020 is presented in Table 10.26. This data demonstrates that during the study period, consumers on the whole would incur the least cost by adopting multiple water sources available under Scenario C when compared with the more conventional development course of Scenario A.

Table 10.26
Summary of Accumulated Water Purchase Costs to Consumers

Present Values[1], $m	Scenario A	Scenario B		Scenario C
		VPS Costs Only	Inc. Bolivar[2]	
Mains Water Consumption	555.6	555.6	555.6	499.5
Sewage Effluent Consumption	0.17	27.6	91.0	23.6
Groundwater Consumption	13.2	10.8	10.8	9.0
Stormwater Consumption	14.8	14.8	14.8	37.9
Total	**583.7**	**608.8**	**672.2**	**570.0**
Increase over Scenario A, %		4.3	15.1	-2.4

(1) Assuming a discount rate of 7.95% over the study period of 1996–2020 (25 years).
(2) Includes the full cost of wastewater treatment at Bolivar prior to supply to the Virginia Pipeline Scheme, rather than only the costs of additional treatment and distribution of the reclaimed water.

10.15.7. Residential Developments

The costs associated with the provision of suburban infrastructure for residential development were sourced from numerous recent publications, many of which were devoted to a comparison of the residential and public infrastructure costs of urban consolidation with newer urban forms. The South Australian Housing Trust (SAHT) provided supplementary data on allotment development costs and the associated schedules of rates, for newer developments such as 'The Parks' at Ferryden Park, New Haven Village at Osborne, and Mitchell Park. Data was also

sourced from the SA Department for Environment and Natural Resources (DENR) for similar residential developments at Northfield and Montague Farm. From this data the main elements of cost associated with residential land development were determined; refer to Figure 10.35.

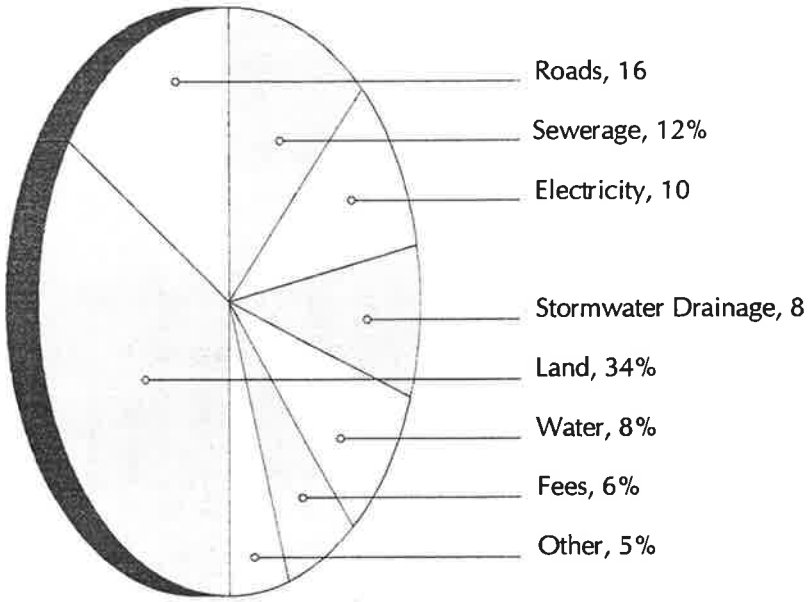


Figure 10.35
Main Cost Components of Residential Land Development
(after Collie Planning and Development Services, 1989; SAHT and DENR)

The objective was to determine an indicative cost for the provision of minor infrastructure to service residential areas under 'greenfield' development, infill housing or urban consolidation, as well as the proposed new urban form of development. The adopted costs are summarised in Table 10.27, which have been modified from the baseline data to avoid double-counting of cost items previously addressed, such as the provision of water distribution pipes, and also to take into consideration the dwelling densities of each urban form.

For the purposes of calculating the net present value of residential infrastructure development over the period 1996–2020, it was assumed that under conventional development patterns residential areas would occupy around 44 percent of the developed urban area, and that 95 percent of new housing would be situated in fringe developments with the remaining 5% derived through urban consolidation. Under these circumstances, the PV cost was $309.41 million.

Where a new form of urban development was assumed to prevail, then residential areas were assumed to occupy around 45 percent of the total urban area, with 90 percent of new housing in fringe developments and partially redeveloped urban areas, the remaining 10 percent through wholesale urban redevelopment. Under these circumstances, the PV cost was $980 million.

It is clear that in the provision of residential infrastructure a considerable cost differential arises with the adoption of the new urban form model over conventional

development patterns. Much of this cost increase is the result of partial and complete urban redevelopment, which is based upon historical development costs. The SAHT has indicated, however, that it is the State Government's intention to develop all future public housing within a more decentralised, nodal arrangement on smaller allotments at higher dwelling densities (Mitchell, pers. comm., 1997). The SAHT concur with the opinion emerging from the planning profession, that a more condensed urban form offers many social and environmental benefits that may outweigh some higher costs.

Table 10.27
Indicative Residential Infrastructure Costs (1996 Dollar Terms)

Development Type	Comparable Example	Avg. Lot Size	Cost / Allotment
Conventional Development			
Greenfields / Broadacre	Northfield, Montague F.(1)	450 m²	$ 20,000
Urban Consolidation	Inner City Infill(1)	200 m²	$ 1,000
Adopting New Urban Form			
Greenfields / Broadacre	New Haven	300 m²	$ 11,530
Partial Urban Renewal(2)	The Parks, Mitchell Park	300 m²	$ 13,000
Complete Urban Renewal(3)	Typical Med. Density(1)	300 m²	$ 25,000

(1) Also from Development Now, *December 1992 and June 1993, modified to 1996 dollar terms.*
(2) Redevelopment within the existing street pattern.
(2) Complete redevelopment of all infrastructure within an existing urban area.

Indeed, Jensen (1994) considers that the affordability of such higher density developments like New Brompton Estate can be expected to improve as they become more commonplace, and builders introduce a greater range of standard products suitable for compact allotments. The magnitude of the predicted cost differential may therefore be excessively conservative, and not realised in practice.

10.16. Conclusions

A continual improvement in computer technology is enabling more frequent and extensive use of computer simulation for modelling of environmental systems and processes. However, the problems that must be addressed are often more complex as well. No longer can the water resource manager focus upon the traditional issues of flooding, water supply and sewage drainage. The study must go beyond the analysis of the basic parameters of space and time, to incorporate *in an integrated way* the issues of water quality and the environment as a genuine user of water. The issue has become one of integration – finding the optimum mix of all sources of water, whether potable or non-potable and surface, wastewater or groundwater, to meet the vast array of competing water needs.

As yet, there are very few computer modelling suites available to the water manager to explore the impacts of alternative water management strategies on the desktop PC. Those software packages that do exist tend to be limited in their application, either because they have been developed to work with a particular piece of software (such as a GIS) and for a constrained set of operating conditions; or for particular

catchment conditions; or to simulate 'normal' or 'average' operating conditions and do not allow consideration of extreme conditions.

A flexible, generic computer model is required that can be tailored to simulate any potential system of water transfers, supply, treatment, reuse and disposal. The model should enable consideration of multiple sources and qualities of water, various patterns of water use and disposal both in time and space, the costs of adopting alternative strategies, and should be capable of calibration. Furthermore, the software must be available to run on a variety of platforms, including DOS, Microsoft Windows, and Unix. Perhaps the computer model that most closely meets these criteria is presently under development at the Cooperative Research Centre for Catchment Hydrology in Melbourne, by Mitchell *et al* (1996).

For the purpose of this research, a region specific model was therefore developed within the Microsoft Excel spreadsheet environment, making use of the benefit of multiple, linked spreadsheets. The model was developed to explore how competing demands for water could be met by a range of water sources, incorporating the effects of changes in urban form and alternative management strategies. These alternative strategies were represented by three different development Scenarios A, B and C; refer to Chapter 11 for a detailed discussion of these scenarios.

Extensive research using historical and published data was undertaken to establish the model parameters, employing a GIS to consolidate, analyse and interrogate spatial data. Simulation was undertaken at a monthly time-step, for which rainfall was often used as the causal variable for modelling of the response in components such as water availability. Importantly, historical time series rainfall data was used to simulate the operation of the water system under normal as well as extreme climatic conditions.

Notable components of the modelling exercise were the development of volumetric runoff coefficients (VRCs) for the estimation of catchment yield from rainfall, and the use of artificial neural networks (ANNs) for the prediction of regional potable water demand from historical rainfall data.

Beyond the purely technical issues of water treatment and distribution, other impacting issues were addressed such as the form of urban areas, infrastructure ageing and replacement, and government policy and pricing issues. It was found that in response to new government policies on competition and institutional reform, the price of reticulated potable water is likely to rise. Coupled with the need to replace ageing infrastructure and to raise sufficient revenue to do so, there is the potential for potable water prices to rise substantially in real terms over the coming decades with significant reductions in water consumption.

The modelling exercise served to demonstrate that an integrated approach to land and water management (Scenario C) can offer numerous environmental and social benefits, and some economic benefits over the more conventional approach (Scenario A). The potential benefits can be broadly summarised as:

- almost a 25% reduction in the volume of potable water consumed by 2020 compared to 1996 levels, with approximately half the potable water consumed when compared to the predicted growth under conventional water use;
- essentially no pumping of water from the River Murray to service the northern plains under 'normal' conditions, with up to a 63 percent reduction in drought conditions compared to 1996 levels;
- little more than a 10 percent reduction in the volume of sewage effluent over the period to 2020;
- a 400% increase in the volume of treated effluent used for irrigation and in industry to 10,000 ML/a, which is only modest compared to the 35,000 ML/a or more that could be used under the Virginia Pipeline Scheme (Scenario B);
- more than a 40 percent reduction in the volume of effluent discharged to Gulf St Vincent, which is less than the 80 percent reduction achievable under the Virginia Pipeline Scheme;
- an ultimate reduction in stormwater generation in the order of 10%, with a 60% reduction in the volume discharged to the Gulf because of greater capture and productive use of stormwater;
- reduction in groundwater extraction from the Tertiary aquifer to a volume equivalent to or less than that required to maintain the semi-confined nature of the aquifer; and
- cost savings in the areas of water main replacement, provision of new wastewater treatment facilities, stormwater drainage, and the cost of water purchase by consumers.

Although stormwater is often regarded as a valuable resource, it should perhaps be seen more so as a reserve, in an analogous way to mineral deposits that are uneconomic to retrieve and are therefore not regarded as a resource. Stormwater may initially appear to be a more suitable resource for urban use. However, due to the intermittent nature of rainfall and the variable quality of stormwater, there are substantial difficulties associated with full utilisation of this resource. Some of the options for stormwater use include: on-site rainwater tanks; and community collection and storage for irrigation, groundwater recharge, and/or habitat restoration such as a wetland or stream (Mitchell *et al*, 1995).

By comparison, sewage effluent is a far more reliable and consistent source of water, both in quantity and quality and over time. As a result, it is often easier to match supply with demand and without needing to construct large storages. An issue with the reuse of effluent is, however, the means by which the effluent is provided to the consumers. Hard-piped distribution systems are often required which must be constructed at considerable expense, either as large-scale specific-use systems as in the case of the Virginia Pipeline Scheme for horticultural irrigation, or extensive systems for dual supply. With the increasingly stringent treatment standards for reuse or discharge of effluent to the marine environment, it is questionable whether

some additional tertiary treatment for full potable reuse is the most appropriate course to follow. While it would appear that such a course of action will not be pursued at anything but a small scale for some decades, there are a number of water practitioners in Australia beginning to promote this alternative (refer to Chapter 8).

Environmental and social benefits are available by adopting a total or integrated water management approach, but still with some additional economic cost.

At the present time, much of the progress that is being made for sustainability is attributable to the efforts of local government, private enterprise and the public, who are demonstrating that they are willing to absorb some additional expense in order to improve their environmental and social conditions. State and Federal governments have failed to act in a comprehensive and focussed manner, beyond the preparation of strategy documents. Without strong and visionary leadership from the higher levels of government, there will be duplication of effort, waste of resources, conflicting economic and development policies, and ongoing environmental deterioration (Fleming, 1996).

The success or viability of such an approach will therefore ultimately be determined by the willingness of consumers to pay and the existence of the political courage to depart from conventional methods.

11

Alternative Water Management Strategies for the Northern Adelaide Plains

In the 1970s, the Club of Rome published *The Limits to Growth* (Meadows, 1972), which was a report on a modelling exercise to investigate alternative global resource strategies. This modelling was judged literally rather than indicatively and was widely denounced for its inaccuracies. However, *The Limits to Growth* provided a thought provoking illustration of human development, warning of adverse impacts which extended to the global scale. These impacts had potential to leave future generations with depleted stocks of natural resources and a degraded environment (Sadler *et al*, 1991). In many senses, those early indications of alarming trends have been fulfilled.

The modelling reported in this thesis emerges from a similar background of concern for the environment, but with a more positive objective: to look for desirable and beneficial courses of development for a sustainable future.

The modelling addresses a set of alternative development scenarios, which look forward (or foresight) from a description of the existing circumstances, to a future that could be created through the actions that can be taken today (ASTEC, 1995). The description of baseline conditions is a simplication of reality, achieved by grouping objects into classes, and by aggregating properties and processes. This aggregation tends to smooth out much of the natural spatial diversity and short term variability. To reintroduce some of the richness of real system behaviour, historical data has been used wherever possible (such as natural climatic variability). Limitations inevitably remain, however, because the scenarios are rooted in current paradigms and, as Hollick (1991) points out, none of them may capture some aspect of the system which may be important in the future.

Three alternative water management scenarios are presented for the Northern Adelaide Plains study region (refer to Figure 11.1). These scenarios have been specifically developed for comparison using the MESA methodology, to determine which development strategy offers a more sustainable future.

To attempt to truly assess the sustainability of each alternative scenario, the evaluation cannot be isolated to water related issues and must necessarily address other social, environmental and economic matters. A substantial effort has been made to organise and 'tie together' the various themes of each scenario in a logical

and consistent manner. Thus, while the scenarios presented do have a focus upon water resource management issues, there is also discussion of other issues with quantification of effects where possible. (It is important to note that, as with *The Limits to Growth*, the significant outcomes of this research are in the trends, rather than specific details.)

The three scenarios are:

- **Scenario A - Business as Usual**: assumes continuation of urban sprawl under conventional development and resource consumption patterns.

- **Scenario B - Virginia Pipeline Scheme**: many of the same features as Scenario A with the addition of tertiary wastewater treatment and a reticulation system for reuse of treated effluent from Bolivar WWTP for irrigation in horticulture.

- **Scenario C - A Rejuvenated Urban Form**: assumes development and renewal of urban areas to produce more condensed, efficient and livable communities. Water conservation and wastewater reuse are widely practiced in the new urban areas, and there is a gradual return of urban land to open space, new habitat areas and local agriculture.

The scenarios present hypothetical courses for urban development over the 25 year period of 1996 to 2020. Every attempt has been made to ensure the alternative development strategies are plausible, often being a simple projection of current development patterns and social conditions. The scenarios have been developed from existing planning strategies and forecasts of population, housing and associated urban infrastructure requirements. Actual data and cost estimates have been used where the data was available, with costs in 1996 dollars unless otherwise indicated.

The sustainability of the provision of water services and urban infrastructure is the primary consideration, with costs typically reflecting necessary expenditure of public (government) rather than private money. All calculations of present value (PV) employ a discount rate of 7.95 percent, equivalent to the long term Government bond rate.

The key issues and financial aspects of each scenario are presented in Section 11.7.

There is no consideration of the potential impacts of the Greenhouse Effect on any of these alternative development strategies.

11.1. Scenario A: 'Business As Usual'

This scenario assumes the perpetuation of conventional patterns of residential and urban development over the coming decades, to accommodate the major share of the expanding metropolitan population.

Incremental urban growth will continue essentially along a north-south axis between the area of the Virginia Vegetable Triangle (VVT) and the hills face; refer to Figure 11.2. There will be:

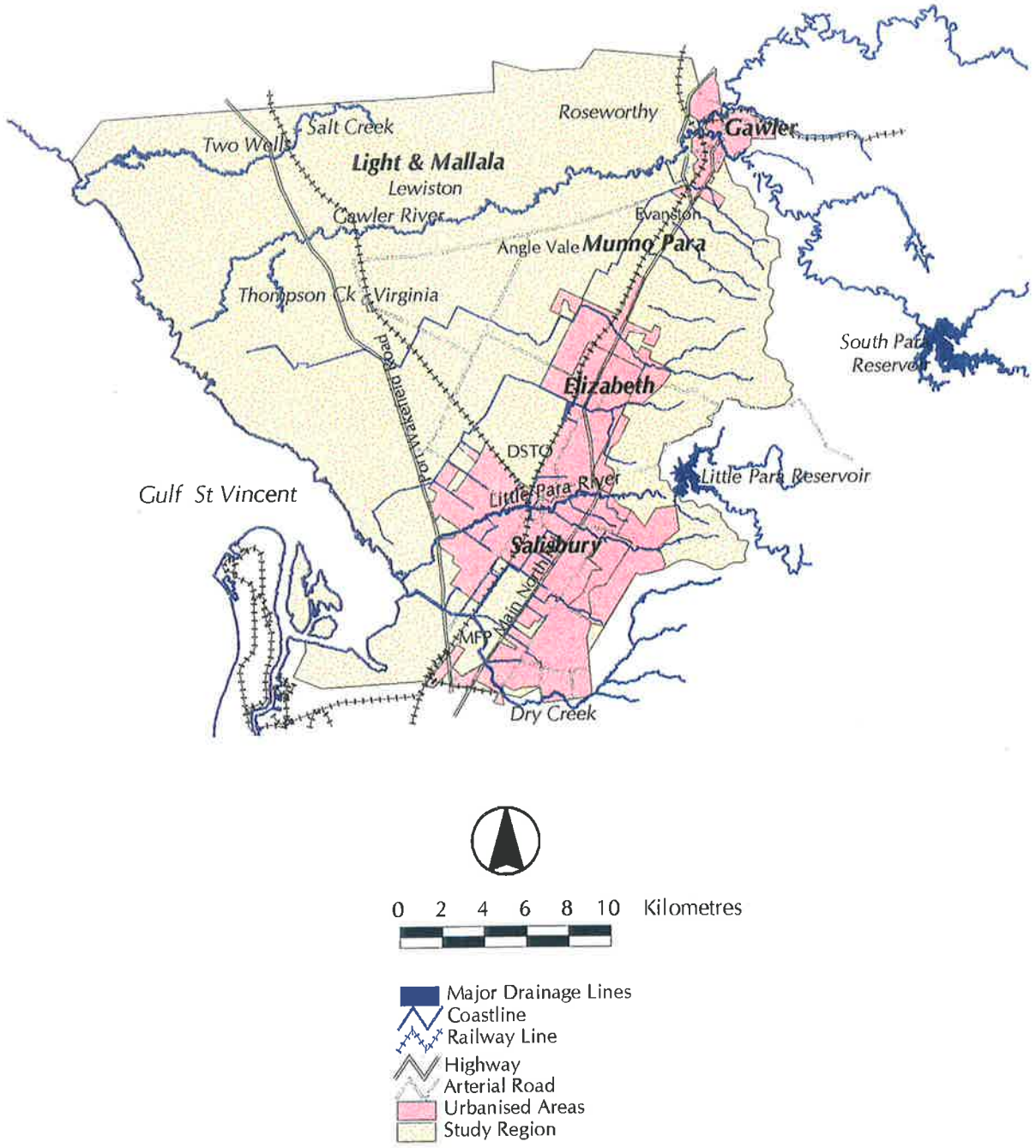


Figure 11.1

Northern Adelaide Plains Study Region

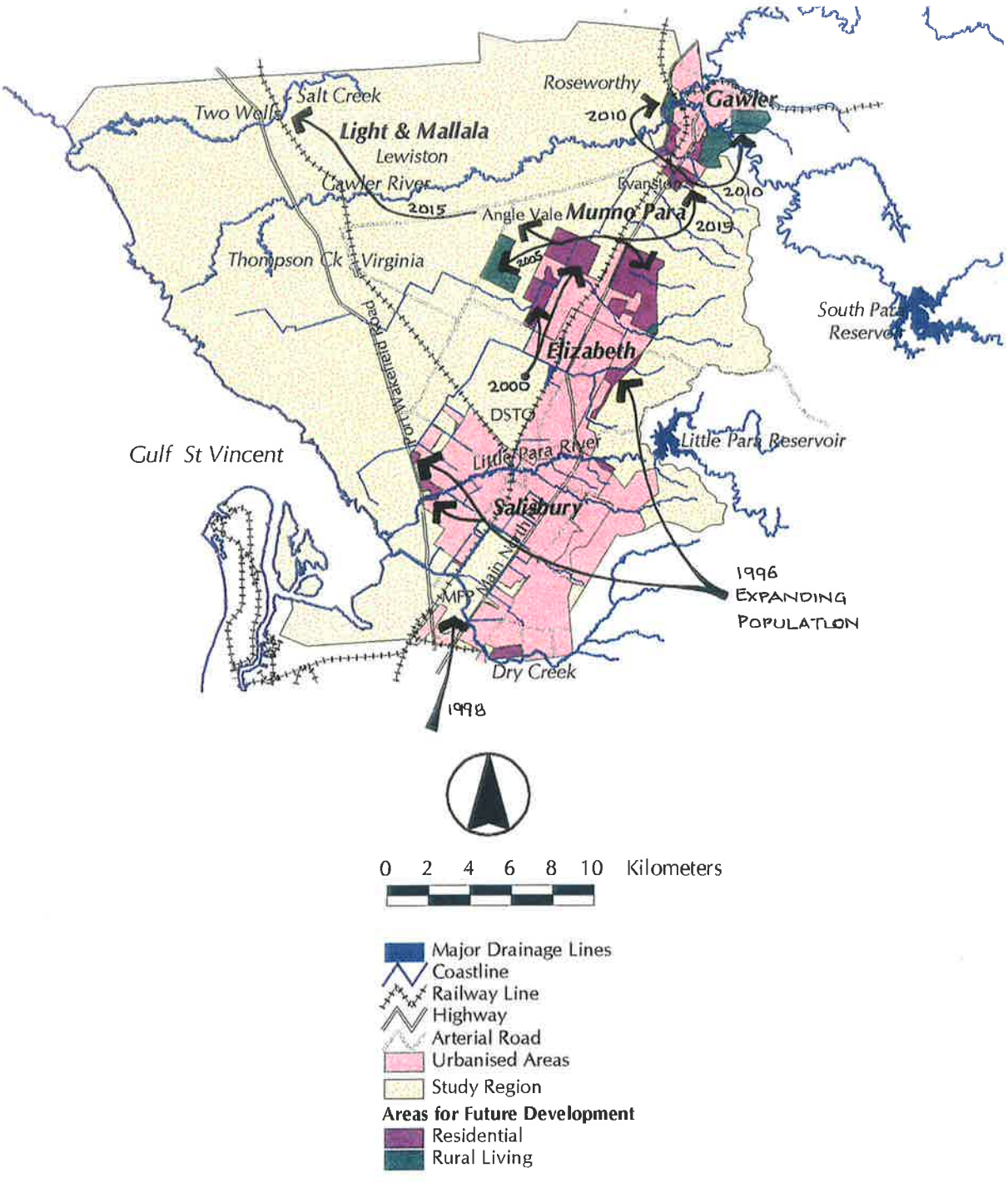


Figure 11.2

Scenarios A & B: Direction of Future Urban Growth

- continued expansion within Salisbury but with a state of full development reached during the first 10 years;
- a significant and additional population influx associated with the MFP Australia development at Greater Levels;
- ongoing development at Golden Grove (outside the Study Area);
- development at Smithfield in parallel with Golden Grove following completion of development within Salisbury;
- development of Munno Para West; and
- deferred development of Evanston until development in Smithfield is substantially complete.

The region will see growing numbers of families with young children resulting in continuing demand for family housing and services. An increasing number of elderly people will live in the outer northern suburbs.

The establishment of an urban-rural boundary with the horticultural area to the north west effectively creates a northern growth corridor of approximately 8 km width between the horticultural area and the Hills Face Zone. Extension of this corridor northward of Gawler will be limited by a range of environmental and heritage constraints, including the proximity of the Barossa Valley. This reinforces the growing movement toward residential development at Angle Vale and in the Two Wells–Lewiston district.

11.1.1. Develop urban areas for greater choice in housing styles, effective transportation and community living (Objective 7)

As the population grows, so must the number of dwellings required to house them. There will be a trend toward fewer persons per household, however, meaning that disproportionately more dwellings will be required.

By the year 2020, the population will have increased from around 230,680 in 1996 to 306,150. There will also be an additional population influx of 11,000 people associated with the MFP development of 'Mawson Lakes' at Greater Levels (Thomas *et al*, 1994) raising the population at full development to around 317,150 people.

Urban development will continue at densities typical of the newer forms of development occurring in Munno Para. The area of urban development increases by 3,435 hectares from 11,823 to 15,258 ha, of which 1,485 ha or 44 percent will be consumed by housing. In some LGAs, there is a shortfall in the supply of land available to meet this demand requiring rezoning of some Rural Living land to Residential.

The young, single and elderly will initiate a shift in demand for housing away from the common detached house towards more compact dwellings. Nevertheless, this shift will be small compared to the strong and continued preference of the majority of people for owner-occupied detached houses.

Some urban consolidation will be achieved through development of vacant sites and redevelopment of degraded areas. This will provide a number of new and more diverse houses at higher densities, although providing only 5 percent of the number of new dwellings. Even with vigorous consolidation strategies, the character of existing urban areas changes only slowly and the number of houses provided are not be sufficient to divert demand from outer areas.

The Commonwealth land at DSTO Salisbury near Elizabeth will become available for re-development by the year 2000. This comprises around 500 ha and provides the opportunity for the establishment of a higher quality of housing and urban form, making better use of the existing infrastructure in Salisbury and Elizabeth.

SAULT land to the west and north of Elizabeth and Smithfield Plains is the next location for residential development in the areas west of Main North Road.

Further to the north development is focused on the Munno Para centre, east and west of Main North Road, prior to major urban expansion south of Gawler. A significant level of residential development occurs in the Smithfield East and Smithfield West areas over the period to 2005.

Opportunities for infill urban development in and around Gawler are realised in the interim period. In the longer term, there is the inevitable expansion of Gawler from its current urban fringe, but this ensures more efficient use of the existing physical and social infrastructure.

The rural township of Virginia remains essentially the same with only minimal growth. Angle Vale and One Tree Hill experience greater relative growth, but also remain relatively small communities.

Traffic congestion increases noticeably, although relative to other Australian cities Adelaide's road system is relatively flexible in terms of routes, speed and comfort. This ensures that the car remains the dominant form of personal mobility, in turn requiring major investment in the road network to support both the increased population growth and long distance road freight transport to and from the northern and north-western suburbs.

At the same time there is some improvement in the patronage of public transport services. The out-sourcing of public transport leads to improved transit services, although the population density is still insufficient to support a highly efficient and commercially profitable system. Local bus services evolve to provide transit to long-haul bus terminals and links with the rail system, providing more flexible transit alternatives.

Unfortunately, there is little sense of community among the inhabitants of the northern suburbs. The low density, sprawling residential areas accommodate a higher than average proportion of socio-economically disadvantaged people, many who do not have access to a car. These people feel socially isolated, experiencing difficulty accessing public and social services, and recreational facilities. Their level of social and recreational interaction is often insufficient to maintain healthy

lifestyles. Graffiti, ethnic rivalries, violence and crime are common problems, often the result of boredom among the region's youth.

11.1.2. Retain areas of existing habitat and restore other areas for native plants and animals (Objective 2)

Very little remains of the original native vegetation is found to remain on the northern Adelaide plains (EMS, 1994). With attention paid to the few remnants, there is little difficulty in maintaining this vegetation.

In order to expand the native habitat and restore some vegetation, wildlife corridors are established at the metropolitan scale. The Metropolitan Open Space System (MOSS) links the coast with the hills via a series of linear parks (Figure 11.3). These become places of cultural and environmental significance, such as the mangroves of Dry Creek and St Kilda, the Hills Face Zone and Mt Lofty Ranges.

Development of this open space system is linked with extensive native revegetation programmes. However, due to the inadequacy of public open spaces for the expanded population, the MOSS areas serve multiple purposes and very few areas are maintained solely for flora and fauna conservation.

Upgrading of the Bolivar WWTP to reduce plant odours results in the production of higher levels of greenhouse gases (via electricity generation) and still has a significant environmental impact on the mangrove areas through discharge of large quantities of relatively fresh effluent water.

11.1.3. Conserve water, and recycle stormwater and treated sewage effluent for productive uses (Objective 3)

The programme of Commonwealth inspired reforms of public institutions and utilities (the CoAG and Hilmer reforms) that were developed during the early 1990s begin to take effect shortly following the year 2000. The price of water increases only slowly at first, a politically unpopular move particularly with major irrigators and farmers, who feel betrayed by the conservative State government. The marginal cost of water rises from around 90 ¢/kL to 116 ¢/kL (an increase in real terms from 36.1 to 40.2 ¢/kL for a base year of 1980/81).

With the price rises (small in absolute terms but large in percentage terms), reductions in consumption occur, particularly in the residential sector. In accordance with the programme of price reform (and in an attempt to improve the unimpressive commercial returns to SA Water), water prices rise again in 2005 to around 146 ¢/kL (equivalent to 46 ¢/kL in real terms).

The result this time is that a more distinct drop in water consumption occurs, confirming the price elasticity of demand for water reported by Dandy (1987). Most residential water consumers now adopt a variety of domestic water saving devices. Some major industrial consumers resort to greater groundwater extraction (where possible) or implementation of mixed schemes of water recycling and harvesting of

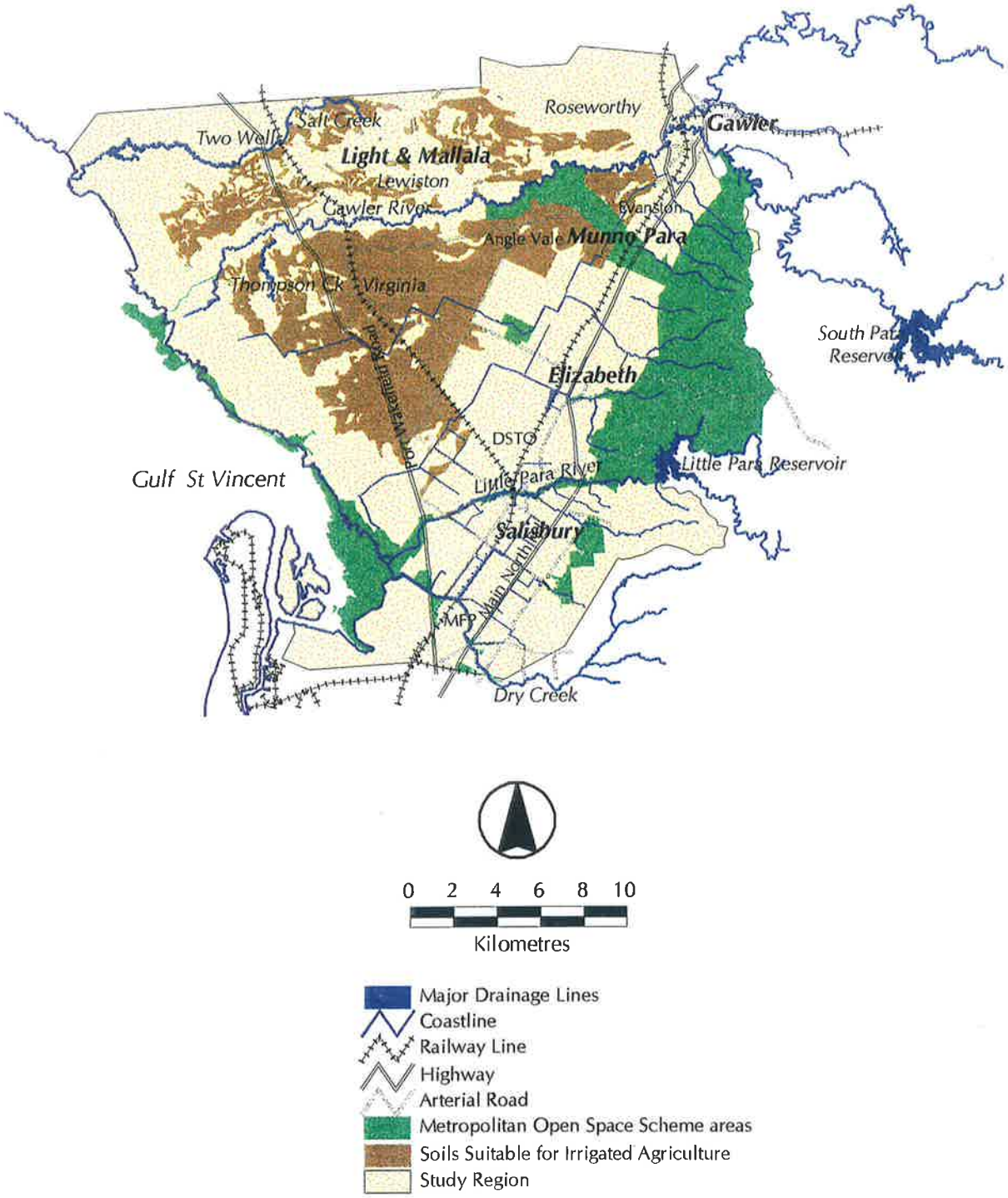


Figure 11.3

Good Agricultural Soils and Valuable Open Space

on-site storm runoff for use, although this practice is not widespread. On a state-wide basis, consumption of mains water consumption is reduced from around 235,000 ML/a to 200,000 ML/a in the space of only a few years. Total water consumption in the region does increase from around 31,460 ML/a to 41,250 ML/a due to the large increases in population, although per capita water consumption is decreasing.

As both the volume of water consumed and sewage discharged decrease, the cost of providing the water services increases on a per kilolitre basis. The infrastructure is used below capacity and inefficiently, yet failures continue to occur due to ageing pipes, plant and machinery. Infrastructure extension at the city fringes becomes even more costly. By 2010 the Government is becoming more concerned by the commercially inefficient operation of SA Water that has occurred for several consecutive years. The costs of both service provision and asset replacement are rising, as customer numbers and revenue decline. Management consider that the administrative efficiency of the SA Water cannot be significantly improved, and the already lean workforce cannot be cut further. The only option is to raise the water price again perpetuating the vicious cycle. A kilolitre of potable water now costs around $3.00.

The replacement of pipes and other infrastructure is delayed as long as possible, much to the dismay of the general public who perceive increasing inconvenience by burst mains and spasmodically poor water quality. Water managers become very concerned about the state of facilities and services, insisting changes must be made. Government recognises that the huge costs of asset replacement must inevitably be incurred, and are experiencing similar difficulties in other areas.

During the same period, the Government has been undertaking detailed planning for the expansion of the city northward beyond Gawler to the Roseworthy-Sandy Creek area. With the Bolivar WWTP unable to accommodate the sewage load from this area, a new WWTP is planned with treated effluent to be used for irrigation, and during winter months, the excess discharged to the Gawler River.

A great deal of time and technical expertise is applied in planning this new town. Although the hypotheses of the 1990s that good things come in small package plants (or rather small and decentralised is better than big and centralised) is disproved, it is clear that the existing extensive infrastructure is also inefficient. Sub-regional schemes, not regional nor community based schemes, are most efficient in providing almost all services, particularly those of water supply and sewerage.

SA Water embrace the concept, pleased that the notion of community based schemes dotted throughout Adelaide is finally quashed, and also in the light of a cost effective solution to their asset replacement problem. Plans are efficiently developed along the lines of the Roseworthy-Sandy Creek model, with local contractors commencing on redevelopment works in 2015. Most of this work occurs in the eastern, central and western suburbs of metropolitan Adelaide however. Interim repair measures, or strategic asset replacement, occurs in the northern Adelaide suburbs during the period until 2025 when more extensive renovation occurs.

The volume of water that must be pumped from the River Murray increases from around 8,300 ML/a to 19,000 ML/a, rising to as high as 28,500 ML in very dry years. The additional pumping is accommodated within the existing headworks system at relatively low marginal costs until 2020, at which time a new pipeline from the River Murray is required (EWS, 1989a). The new pipeline involves major impacts on the Lakes Alexandrina and Albert, reducing the water levels and increasing salinity. Irrigation users are also adversely impacted as is the management of the Murray-Darling Basin as a whole (EWS, 1989b).

Stormwater management becomes the sole responsibility of Integrated Catchment Management Boards (ICMB), established under the bold and forward thinking Water Management Act of 1997. Operations of the Boards are funded through a levy collected by local government and grants from the Department of Transport. The resource value of stormwater has been recognised for several years and attempts are made to utilise this water wherever possible.

Numerous stormwater collection and use schemes become established throughout Adelaide, although the total volume used is not large. Some storages are located in the large industrial complexes of major water consumers, but most are in public space areas. Stormwater is typically treated in wetlands or collected in retention basins and used for open space irrigation. Local councils are the main consumers of stormwater, although this is largely opportunistic as stormwater storages are typically designed for the primary purpose of flood control. The storage capacity of the wetlands and flood control parks increases from 2,513 ML in 1996 to around 3,683 ML by 2020; refer Table 11.1. Many smaller ponds and wetlands have storage capacity which is under- or non-utilised for stormwater capture and reuse purposes.

Due to the limited area for surface storages, many storages cannot hold sufficient water to meet irrigation throughout summer, nor provide the desirable attenuation of flood peaks during the latter part of winter when the storages are often full. In fact, many of the admirable goals for stormwater use set in the early 1990s do not come to fruition because the powers of ICMBs are restricted by State Government preventing truly integrated management of all land and water resources.

Extensions to the stormwater drainage network follow the traditional form of pipes for street and collector drainage, with pipes or open channels for trunk drainage.

Greater stress is placed on the stormwater drainage system over time as:

- higher levels of flood control are expected by the community, to the stage where even nuisance flooding of gardens is expected to be alleviated;
- increased density of urban development, and redevelopment with the consequence of greater amounts of impervious land generating larger quantities of stormwater runoff; and
- greater emphasis is placed on the disposal of stormwater runoff directly to the street drains as a condition of local government building approval (ECA, 1991).

There is a trend toward marginally higher residential densities, which provides a situation where some courtyard and villa homes have 70 to 80 percent (BC Tonkin,

c1992) of an allotment developed as impervious surfaces, by comparison with less than 50 percent in the case of conventional allotments.

Table 11.1
Wetlands and Stormwater Control Ponds

Local Govt Area	Storage Description	Year of Construction	Catchment Area, ha	Storage Volume, ML
Salisbury	Lake Windermere	1974	58	5.66
Salisbury	Paddocks Wetland	1975	60	2.54
Salisbury	Greenfields Stages 1 and 2	1990-93	200	110
Gawler	Evanston Gardens F.C. Ponds	c.1992	360	170
Salisbury	Whites Rd / Bolivar	1992	290	127
Salisbury	Kaurna Park	1994	58,700	762
Salisbury	DSTO Salisbury	1994	29,200	380
Salisbury	South Road Connector	1995	306	344
Munno Para	Fradd Road Flow Control Park	c.1995	32,900	396.3
Munno Para	Stebonheath Flow Control Park	c.1995	31,600	138
Salisbury	Walpole Road	1996	114	46
Salisbury	Burton Road Wetlands	1996	270	26.1
Salisbury	Swan Alley Wetlands Stage 1	1996	104	5.67
Capacity Existing in 1996				2,513.27
Munno Para	Heaslip Road Flow Control Park	Proposed	-	900
Munno Para	Kudla Creek Flow Control Park	Proposed	-	270
Total storage capacity at full development				3,683.27

At a regional level, this increase in residential impervious area translates to a total impervious surface increase of around 4.5 percent. The amount of impervious surface within urban areas increases from around 55.3% to 57.8% as a result; the fraction of impervious connected areas (those considered to be effectively hydraulically connected to the drainage network) increases by around the same magnitude.

There is a corresponding increase in stormwater yield, which coupled with the expanding urban area, results in an increase of between 3,090 and 5,025 ML per year depending on the climatic conditions. Mean annual runoff (upstream of Port Wakefield Road) increases from 32,392 to 36,209 ML per annum. Even with the existing flood control ponds and construction of new facilities, the increase in the magnitude of flood peaks and total yield mean that some of the older facilities are under capacity. Coupled with the somewhat disappointing impact of seemingly improved catchment management practices, the contribution of suspended solids, heavy metals and nutrients from stormwater is reduced little.

There is some increase in consumption of treated sewage effluent, although nowhere near the volume that was sought by the State Government or offered through the un-implemented Virginia Pipeline Scheme (VPS). The Bolivar WWTP is upgraded for biological nutrient removal, but without some financial support from

government, effluent reuse schemes are commercially unviable. Only a few irrigators within close proximity to the effluent outfall channel elect to use the improved quality of effluent to supplement their groundwater quota. This reuse can sometimes be spasmodic, and the irrigators complain of rising effluent salinity, a result of increasing leakage of saline groundwater into the sewers. Effluent reuse remains roughly static over the period 1996 to 2050 at around 6 percent of the total volume of treated effluent.

The consumption of reticulated potable water increases prior to the year 2000 as many unserviced properties on the plains are connected to the mains. Indeed, a major ongoing programme of mains construction is implemented around 1997, with most work focussing on the Munno Para, Macdonald Park, Angle Vale and Two Wells–Lewiston areas. Consumption grows steadily thereafter with the growing population from around 30,000 ML/a to 41,250 ML in 2020 (under conditions of average rainfall). The volume of water pumped from the River Murray approximately doubles over the same period to maintain the same reliability of supply.

11.1.4. Ensure easier access to public services, recreational and open space (Objective 10)

The requirement of 12.5% open space remains a standard feature of residential developments. In many cases, this open space is provided almost entirely along a drainage course or around a wetland, with leisure and recreational facilities such as BBQs, picnic seating, basketball courts and playgrounds. A car park is also frequently provided, reflecting the dependency of many people upon a car to reach this open space.

A few developers attempt to provide some public services and a 'corner shop' within their residential developments. Unfortunately, the dwelling density is too low to provide a sufficient consumer base to maintain many of the shops, and only delicatessens seem to remain profitable.

Otherwise, the majority of retail shops, supermarkets, banks and government services are concentrated in large shopping complexes located on arterial roads.

There is some improvement in the local bus services in terms of access to these centrally located services and the Adelaide city centre, particularly for the elderly. The private operators have needed to introduce higher trip fares to cover their costs, which in turn prevents increase in ridership. In fact, the patronage on many bus routes drops away so significantly during evenings (largely due to safety concerns of the elderly patrons) that buses eventually cease operation during the night apart from limited services provided on shopping and Saturday nights.

11.1.5. Use land with fertile soils for agriculture, not urban development (Objective 1)

The importance of the Northern Adelaide Plains horticultural region to Adelaide and the State is finally formally recognised through local government Supplementary Development Plans, as well as at a strategic level through the planning initiatives of State Government and the ICMBs. This ensures its survival and protection against encroachment of suburban development. With greater certainty about the permanence of the horticultural area, growers and industries seek to consolidate their position in the local market place and expand their export markets.

Although there is approximately 11,800 ha of high quality horticultural land on the NAP (Roger Stokes & Associates, 1995a), horticultural plantings remain limited to 3,500 ha by the non-availability and quality of irrigation water. Growers respond by changing the types of crops grown and irrigation methods, resulting in increased yields and continued economic survival.

The urban development that continues to occur throughout the Munno Para area and the previous Commonwealth land at DSTO Salisbury does consume land that would otherwise be highly suited to cropping and other agricultural activities, while less suited land within the Virginia and surrounding areas is set aside for horticulture. Around 3,435 hectares of previously open space or rural land is transformed by urban development, half of this in the foothills to the east of Main North Road.

11.1.6. Support growth in 'clean' industrial development and employment (Objective 6)

The expanding population within the region also requires the simultaneous development of centres for economic and social activities.

The Elizabeth regional centre undergoes major expansion in employment and services. Land within the current centre is developed to accommodate further retail and business activities, but the long term parking needs of this area are a problem requiring particular attention.

From Technology Park through to Port Adelaide, new industries take advantage of industry clusters and the new service and transport infrastructure that has been built or programmed to support this projected economic activity. Some new transportation options develop as a result of MFP related businesses, providing direct access by road, air, sea and rail to export markets.

11.1.7. Use groundwater no faster than it can be naturally replenished (Objective 5)

The groundwater resources of the northern Adelaide plains remain under strict license control by the State Government, but quotas are not reduced to bring groundwater extraction within the rate of natural replenishment.

A small number of the larger growers secure attractive contracts to export fresh produce to Asian markets. These growers progressively replace traditional crops with higher value export crops, but are constantly frustrated by a lack of water which would enable them to expand their operations and capture a far more significant share of the export market. In general, the groundwater problems initially slowed expansion by growers and threatened growth of a prosperous export market which developed during the mid 1990s.

Under strong pressure from these growers wishing to develop their export markets, annual extraction is permitted to increase marginally to around 19,000 ML per annum, roughly 3 times the sustainable annual yield of the tertiary aquifers. Extraction ranges between 20,400 ML in dry years down to 17,000 ML in the wet. The potentiometric level continues to decline with significant but localised salinity increases. In some areas, farmers with high value crops are consuming more mains water, although groundwater remains by far the dominant water supply source. The longer term sustainability of the horticultural industry is not guaranteed due to increasing pumping costs and declining water quality.

Aquifer storage and recovery (ASR) does not proceed for many years on any large scale as the Government and regulatory authorities grapple with water quality requirements, the potential for pollution of aquifers – a particularly challenging problem in the increasingly litigious society – and the problem of reaching agreement in the interpretation of geological data, upon which legislation would ultimately be based. The SA EPA are also reluctant to move on the matter, citing the 'precautionary principle' as their main reason. In addition, those early practitioners within government who held most local and practical knowledge on ASR have retired or moved elsewhere, and have not been replaced, as the Government's policy of out-sourcing and staff cut backs left no junior staff to 'learn the ropes'. Only a few ASR scheme are established where local governments are prepared to accept much of the responsibility and the source water (often stormwater) is treated to a high standard prior to injection.

11.1.8. Reduce the impact of wastewater disposal on the coastal zone including fishing grounds (Objective 4)

In the *Statement on the Environment* released by the Premier on 9 April, 1995 the Government announced the policy of phasing out the discharge of sewage effluent to the marine environment wherever it could be shown to be economically and environmentally sustainable.

SA Water and the SA EPA developed an Environmental Improvement Programme (EIP) for the Bolivar WWTP. The EIP published in September 1995 indicated the requirements of SA Water for the plant to be:

- reduction of nutrients in wastewater by at least 80 percent;
- minimisation of odour and noise;
- summer reuse of recycled water wherever commercially feasible;
- winter marine disposal through new outfalls for improved dispersion;

- expansion of summer reuse to full land disposal where practicable and commercially feasible;
- continue with current trade waste discharge policies of waste minimisation including integration with the EPA cleaner production initiatives; and
- initiation of an information programme to promote community involvement in minimising inappropriate sewer discharges (SA Water, 1995).

Regardless of the combination of options ultimately selected, the purpose was to return 'borrowed' water back to the hydrological cycle via evapotranspiration or discharge to receiving waters.

Nitrogen was the prime nutrient of concern at Bolivar WWTP and was targeted for removal. It was also desirable for some biological phosphorus removal, but it would only pursued if it could be achieved at no additional cost.

SA Water adopted their preferred position of nitrogen reduction prior to disposal to the marine environment, while notionally supporting land based effluent recycling through the Virginia Pipeline Scheme (VPS) but without financial commitment required from the Government. This approach was considered to be a cost effective proposal to reduce the impact on the marine environment, minimise odour and provide greater opportunity to incorporate groundwater storage and retrieval to maximise reuse.

Despite the adoption of this position, SA Water (1995) considered that land based reuse of recycled effluent would be complicated by the salinity of Adelaide's sewage. The salinity of the sewage rises during winter due to intrusion of rising saline groundwater levels into the sewers from an ageing sewerage system. Preventing groundwater intrusion via sewer grouting was considered to be an excessively expensive option which would not be pursued.

Consultants reports also indicated that full land based disposal or zero discharge options were consistently more expensive than options involving marine discharge.

These findings lead SA Water to conclude that full land-based disposal, potentially including groundwater recharge, was not practicable (SA Water, 1995). Limited summer reuse was acknowledged as perhaps the only viable option.

Plant modifications to achieve 80 percent nutrient removal were therefore considered necessary under any 'viable' scenario, as this level of treatment would be required for any discharge during winter when the effluent could not be applied to land. The final position that was adopted was:

- plant upgrading to reduce the median concentration of nitrogen in the effluent to 10 mg/L;

with recognition that it would be desirable to achieve:

- additional treatment and a pipeline to the Virginia Vegetable Triangle (VVT);
- 50 percent effluent reuse by the year 2001 (KME, 1996).

Independent studies found that to simply reduce the proliferation of troublesome algae to manageable levels, *not* to achieve a pristine marine environment, nitrogen and phosphorus concentrations in the effluent from Bolivar would need to be reduced by approximately 90%. Yet the Government's consultants recommended that only nitrogen be reduced and that phosphorus removal be considered as a subsequent treatment option (CMPS&F, 1993). SA Water therefore committed to removing 80% of the nitrogen as an initial target. The SA EPA reluctantly accepted this target, but stated that a new marine outfall and diffuser system was required, a position that was hotly disputed by SA Water.

Over the period 1996 to 2020, the volume of effluent generated by consumers of the northern Adelaide plains (and discharged to the Gulf) rises from 17,300 ML to around 23,100 ML. This comprises only a portion of the effluent from the entire Bolivar WWTP catchment. Consumption of effluent from the Bolivar outfall channel remains relatively constant at around 2,500 ML/a. However, on a state-wide and metropolitan basis, particularly in areas where there is little population growth, the total volume of effluent decreases with the falling level of mains water consumption.

11.1.9. Ensure that the project is commercially beneficial (Objective 8)

The economic impact of this pattern of growth is generally negative, upon both public and private enterprise, particularly when viewed from an holistic perspective. Table E.2 provides a summary of the major costs of infrastructure development and maintenance during the period 1996-2020.

Potable water continues to be supplied through the ageing water reticulation system, which is in increasing need of repair as burst mains become more common. The metropolitan area becomes more dependent upon the River Murray as a source of water as the population expands, increasing pumping costs and the effects of salinity upon the headworks and consumers' appliances.

The cost of salinity to domestic, industrial and agricultural consumers in metropolitan Adelaide of the reticulated water supply is estimated to range between $70,000 and $82,000 (in 1988 dollar terms) per change of one EC unit in the average salinity at Morgan on the River Murray (in Maier & Dandy, 1993 after EWS, 1990 and Mackay & Eastburn, 1990).

With the economic life of water and sewer pipes of around 80 years, those laid prior to 1940 become targets for repair and replacement. (It can be seen from Figure 11.4 that the major part of infrastructure for water services was constructed after 1950.) The replacement of existing pipes with equivalent pipes requires the commitment of $9.65 million (PV of $7.40 million in 1996). Approximately $14 million is also spent of extension of the existing water mains between 1996 and 2020 (with a PV of $7.29 million), with expenditure of $12 million on duplication of the Gawler to Elizabeth trunk sewer.

The Urban Land Trust also owned significant land holdings within the Town of Gawler. These holdings were zoned Rural A, and lie in the area south of Evanston and north of Dalkeith Road. While these areas were not zoned for residential

development, they were ultimately released and rezoned for urban development. Establishment of the water supply network in this area required expenditure of approximately $6.1 million (BC Tonkin & Associates, c1992) around the year 2006 in preparation for a land release during 2008.

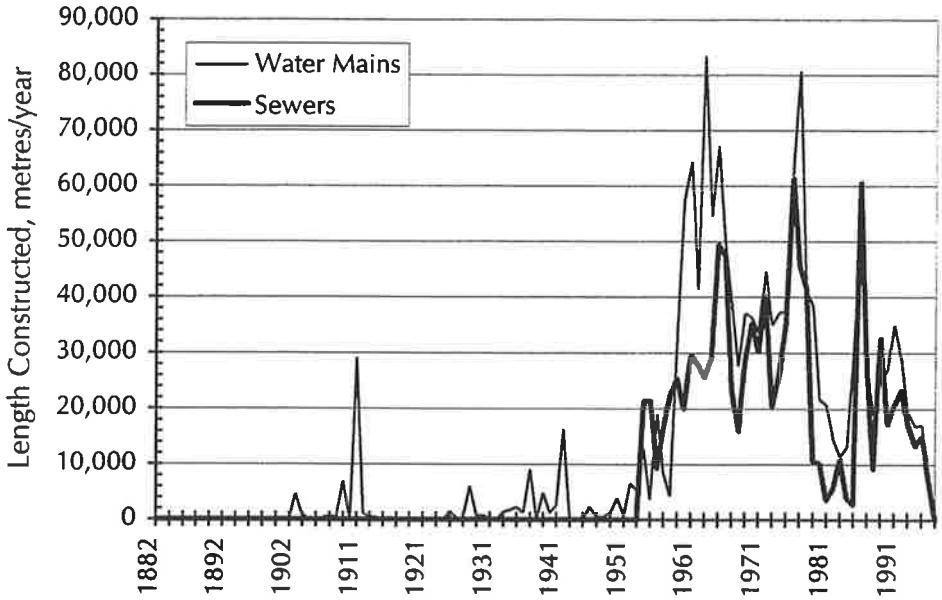


Figure 11.4
History of Water Main and Sewer Construction on the NAP
(based on available data on construction year)

As previously mentioned, the Bolivar WWTP required plant upgrades to meet environmental protection requirements. SA Water (1995) indicated that the capital cost of plant upgrades for biological nutrient removal to achieve 80 percent nutrient reduction were in the order of $41 million. While no data was provided on ongoing operation or maintenance costs as a result of such plant upgrades, it was indicated that an additional $0.15 million per year would be required for other environmental improvement initiatives. Roger Stokes & Associates (1995b) estimated that to achieve a reduction in the biochemical oxygen demand (BOD), suspended solids and nutrient loading to the gulf comparable to the Virginia Pipeline Scheme, the capital and O&M costs would range between $38.4–43.4 million and $2.0–2.5 million per annum respectively, dependent upon whether phosphorus reduction was sought simultaneously with nitrogen reduction. (A comparable level of reduction as the 100% effluent reuse case would cost around $101 million in capital and $8.4 million per annum in operating costs.) These costs are additional to current Bolivar costs.

Later work indicated that the capital and operating costs for nutrient removal according to the agreement between SA Water and the SA EPA was $54.0 million and $2.86 million respectively (KME, 1996). These costs were calculated on the basis of 50 percent reuse of reclaimed water, and a total nitrogen concentration of 10 mg/L from the BNR plant.

In order to satisfy environmental concerns, the nutrient removal upgrading also involves a marine outfall at a cost of $40 million. Further expenditure was also required to achieve the necessary reduction in odour generation from the Bolivar WWTP. Odour control measures were required on the trickling filters at a capital cost in the order of $20 million. Operating costs would be of the order of $200,000 per annum (CMPSF, 1993). These works are constructed during 1997-98, beginning operation during the first quarter of 1999.

Stormwater management continues to make a substantial contribution to the infrastructure costs associated with urban and residential development. The level of expenditure on the construction of stormwater drainage infrastructure increases in response to the rapid rate of urban development, particularly residential subdivisions.

During the mid 1990s, the level of expenditure for the construction and maintenance of stormwater drainage in metropolitan Adelaide was around $19.8 million per annum. This consisted of expenditure of $5.65 million per annum on trunk drainage, $9.91 million per annum on street and collector drains, with around $0.707 million per annum on maintenance for each of these systems (based on data from ECA, 1991; Rolls, 1995). With a full state of urban development likely to occur around the year 2020 (according to current land zoning, and taking into consideration some re-zoning of Rural Living land), the annual expenditure for the northern plains initially rises to around $13.03 million and progressively reduces to around $4.81 million. This expenditure is determined on the basis of the current levels and proportions of expenditure (ECA, 1991; Rolls, 1995), and that necessary to meet the construction and maintenance requirements to achieve a full state of development, matching development with the rate of population growth. In total, an additional $228.58 million was spent between 1996 and 2015 (PV of $112.79 million in 1996).

Following establishment of the major public infrastructure, the remaining large cost component associated with development of the region was minor infrastructure within land parcels released for development. Residential development 'at the fringe' typically cost around $15,000 per 450 m² allotment for basic infrastructure construction which rises to around $21,000 when all engineering, consultancy and government fees are included (Anon, 1992, 1993; Collie Planning & Development Services *et al*, 1989; SAHT, 1997). By comparison, infill housing costs only $1,000 per 300 m² allotment, because all existing infrastructure is established and there is little need for duplication or capacity expansion (with the exception of storm drainage facilities where on-site detention measures were not required by council).

11.1.10. Charge a price for a product or service that reflects the true or full cost of provision (Objective 9)

As previously mentioned, the marginal price of water increases significantly over the period to 2020, in response to Commonwealth reforms and the need to cover the escalating asset replacement burden. While the price rises result in a 20 percent drop in state-wide consumption, there is a substantial increase in revenue to SA Water, sufficient to cover all asset replacement costs that arise; refer Figure 11.5.

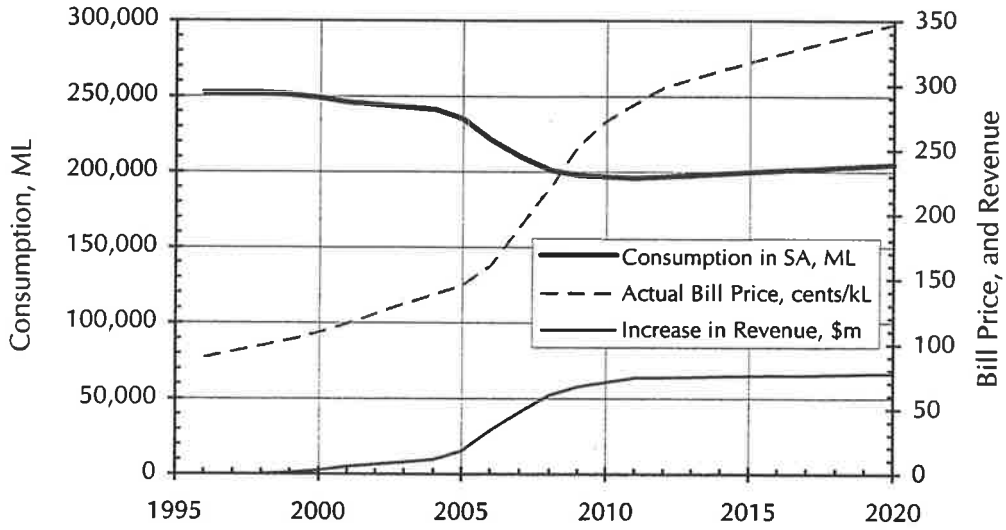


Figure 11.5
Variation in Water Consumption, Price and Revenue Raised in South Australia in Response to Commonwealth Reforms: Scenarios A & B

The cost of groundwater extraction by NAP irrigators remained of the order of 5 to 6 cents per kilolitre, a price which neither promoted efficiency in use or preservation of the quality of the resource. While this provided an economic edge to growers who export their produce, there was no distinct benefit at the local level as all growers pay the same rate. (The costs associated with management of groundwater and licensing of consumers are estimated to be approximately $920,000 per year and the related income to the State Government is around $160,000, resulting in a net deficit of $760,000.)

Transport service prices rise and reflect full commercial rates, a results of the commercialisation of most bus routes and some rail services.

11.2. Scenario B: Virginia Pipeline Scheme

In most respects, this development story is also about 'business as usual', as described in Scenario A. Urban development continues in a conventional manner, within a northern growth corridor between the horticultural area and the Hills Face Zone.

The twist to this plot is the introduction of a major pipeline for the productive reuse of treated sewage effluent in horticulture. Years after the concept was first conceived and following many intensive studies, the scheme is no longer plagued by a lack of funds and a poor projected economic return. The scheme is demonstrated to be economically viable, and proceeds after fierce lobbying of the State Government, resulting in the opening of further tracts of land north of Gawler River for more intensive irrigated cropping.

The impacts on the region are generally considered to be the same as those of Scenario A described in Section 11.1. Where any *additional* impacts arising due to the implementation of the pipeline scheme are identified these are discussed below.

11.2.1. An Introduction to the Virginia Pipeline Scheme

11.2.1.1. An Historical Perspective

The Virginia Pipeline Scheme is not a new initiative and has been a defined project since the inception of the Bolivar WWTP in the mid 1960s. The use of Bolivar effluent water for irrigation was first proposed by Hodgson (1959).

In 1967, a Committee of Inquiry investigated the possible uses of the effluent and recommended the establishment of an experimental farm to study, among other things, the effects of effluent irrigation on soil characteristics over a period of 2 to 3 years (Anon, 1967). These investigations were commissioned by the South Australian government in 1971 and were subsequently reported by Matheson *et al* (1972-1974).

Detailed engineering investigations of the potential for irrigation with effluent were conducted by Kinnaird Hill deRohan and Young (1976a, 1976b) for the South Australian government. The study found that there was sufficient effluent available, if used in conjunction with groundwater at reduced extraction rates, to maintain the major part of the agricultural industry and the aquifer system. It was proposed that a single reticulation scheme should supply nearly all growers with a single quality of disinfected effluent. However, with a benefit-cost ratio (based solely on economic considerations) of 1.1 on a regional basis and 0.5 on a national basis, the scheme was economically unattractive and did not proceed.

Some 10 years later, Desmier (1987) reported that since the previous investigations, an increase in fuel costs and the continuing decline in the potentiometric head of the aquifer had made groundwater extraction a more expensive practice and therefore any effluent reticulation scheme more financially attractive. Yet it was not until the early 1990s that the scheme was seriously reconsidered and given State government support (Altmann, 1995).

During the early 1990s, SA Water was also preparing programmes for improvement of the State's wastewater treatment plants to minimise adverse impacts upon the environment – a requirement under the *Marine Environment Protection Act 1990*. While the Act was replaced by the *Environment Protection Act* in 1995, the requirements under the latter remained essentially the same. Discharges from WWTPs are required to be licensed and reviewed regularly, a condition of the license being the preparation of an Environment Improvement Programme (EIP). The aim of the EIP is to outline a strategy to produce compliance with the receiving water guidelines by 25 March, 2001 and other environmental objectives relating to energy, air and land (SA Water, 1995).

In parallel with EIP planning of SA Water, the State Government, through MFP Australia, commissioned the Virginia Pipeline Committee (VPC) to document a reuse

scheme and Business Plan whereby 80 percent of the treated effluent from Bolivar WWTP is removed from the Gulf. The findings of these studies (reported by Roger Stokes & Associates in association with Gutteridge Haskins & Davey Pty Ltd, 1995) were supported by other investigations into various aspects of the effluent reuse concept (CSF, 1992; Kinhill Engineers, 1993; EMS, 1994).

In the *Statement on the Environment* report released by the Premier on 9 April, 1995 the Government announced a policy of phasing out all discharges of sewage effluent to the marine environment where it was economically and environmentally sustainable.

With the release of the EIP for Bolivar WWTP in October 1995, and with an understanding of the reuse scheme proposed by the VPC, SA Water stated that their preferred position was for nutrient reduction, with 'a commitment' to the Virginia Pipeline Scheme for land based use of recycled water. It was the opinion of SA Water (1995) that full land-based disposal was not practicable, but conceded that "there is scope for summer reuse where economically feasible and when existing water resources are inadequate or overused". The Government ultimately gave an agreement, in principle, to the combined nutrient reduction and reuse scheme. The Government elected to upgrade the Bolivar WWTP for biological nutrient removal (BNR) to achieve the required 80 percent reduction in nutrients, and at the same time taking steps to control the nuisance odours. Not only would this make the effluent suitable for discharge to the Gulf, but the recycled water would then be of a much higher quality than lagoon water. As such, the water could be used without further treatment (other than disinfection) on all crops other than salad crops that would be eaten raw.

The VPC subsequently reviewed their Business Plan and elected to adopt more stringent quality standards for the reclaimed water to ensure that there would be no barriers to export of produce. Further investigations were conducted by KME (1996) to determine the most appropriate treatment facilities.

Sufficient information was available by 1996 to confirm the financial viability of the scheme, and an Heads of Agreement was entered into between MFP Australia, SA Water, Virginia Irrigation Association (VIA, formerly the VPC), Euratech and the NSW Water Administration Ministerial Corporation (for Water Resources Consulting Services, WRCS). The Malaysian-Australian consortium of Euratech Ltd and WRCS are responsible for implementation of a build, own, operate and transfer (BOOT) scheme to distribute treated effluent from Bolivar WWTP through a piped reticulation scheme to some 600 irrigators on the NAP (Anon., 1996).

11.2.1.2. The System Design and Operation

A single quality of treated water will be available to the growers, consistent with their overwhelming desire for uniformity of supply. By providing a good quality, single source of reclaimed water, the potential for loss of market share due to perceived water quality problems is eliminated. The difficulty in policing and management, as well as the cost, complexity and risk of additional on-farm water treatment is also avoided.

The average irrigation demand in the Virginia area is 40,000 ML per year. This is based upon survey work conducted by the VPC and allows for some growth in demand that is expected to occur when the water becomes available.

Around 2,000 ML of short term storage capacity for raw effluent is required. A cost effective storage solution is achieved by level variation of the existing Bolivar effluent lagoons (with a nominal capacity of 4,000 ML).

A minimum effluent treatment plant capacity of around 120 ML per day is required in conjunction with the raw effluent storage to achieve 80% utilisation of the existing Bolivar effluent flows in an average year.

To achieve 100% utilisation of the effluent in an average year, significant balancing storage for the treated effluent or substantial winter irrigation is required. The available options include:

- storage of treated water at a northern location;
- storage and treatment of raw effluent at a northern location;
- storage of raw effluent at Bolivar;
- aquifer recharge; and/or
- hardwood irrigation.

Economic analysis indicated that raw effluent storage at Bolivar and aquifer recharge are by far the most financially attractive options, with aquifer recharge being the least cost option. Raw effluent storage in raised lagoons at Bolivar required the treatment plant and distribution system capacity to be increased to 160 ML/day, at considerable cost.

A detailed review of the standards required for the use reclaimed water for horticulture and livestock grazing was undertaken in conjunction with the SA Health Commission. It concluded that effluent treatment should consist of full secondary treatment, followed by 16 days or more of lagoon detention, coagulation, filtration and disinfection. The physical and microbiological criteria are Faecal Coliforms at a (90 percentile) concentration of not more than 100/100 mL, and mean Suspended Solids concentration of not more than 20 mg/L. The quality of Bolivar effluent and the effect of treatment is presented in Table 11.2 (after Roger Stokes & Associates, 1995a).

No assessment was made of the impact of salts, nutrients and other constituents of the treated effluent on irrigation practices, soils and plants. This was because an understanding already existed, through discussions with the Department of Primary Industries, that the effluent was suitable for irrigation provided that it is managed appropriately (Roger Stokes & Associates, 1995b).

Table 11.2
Bolivar Effluent Quality Before and After Tertiary Treatment and Disinfection

Parameter	Mean Effluent Quality[1]	Predicted Quality After Treatment[2]
Faecal coliforms, no./100 ml	7,000	< 100
Total BOD, mg/L	67	18
Soluble BOD, mg/L	11	UC
Suspended solids, mg/L	85	< 20
Acidity, pH	7.7	6.5
Total dissolved solids, mg/L	1,200	1,260[3]
Ammonia, mg/L as N	19.5	UC
TKN, mg/L as N	30.6	25 - 30
NO_x, mg/L as N	5.1	UC
Total phosphorus, mg/L	6.9	1
Soluble phosphorus, mg/L	3.9	UC
Total organic carbon, mg/L	55	UC
Surfactant, mg/L MBAS	0.44	UC
Alkalinity, mg/L $CaCO_3$	285	210[3]
Chloride, mg/L	423	UC
Sulphate, mg/L	149	210[3]
Sodium, mg/L	324	UC
Potassium, mg/L	40	33
Sodium Adsorption Ratio	8.9	UC

(1) Mean concentration over the period 1989-1993
(2) UC: indicates that parameter concentration is either unchanged or reduced.
(3) Based upon an alum dose of 150 mg/L which is above the expected average.

11.2.1.3. Population and Area Served

An extensive survey of existing and potential water consumers (principally growers) on the NAP confirmed that there is significant demand for additional water supplies. The categories of applicants for reclaimed water are presented in Table 11.3 (after Roger Stokes & Associates, 1995a).

Table 11.3
Applications for Supply of Treated Effluent

Applicant	Number of Applicants	Volume Requested (ML/yr)
Licensed NAP Groundwater Users	226	31,650
Licensed Bolivar Effluent Users	14	1,720
Others (non-irrigators, local govt, etc.)	189	6,960
Total	429	40,330

Table 11.3 indicates the water demand associated with land owners who lodged an application. However, it is considered that even with a substantial attrition rate from the existing applicants, the demand for treated water from those waiting for the

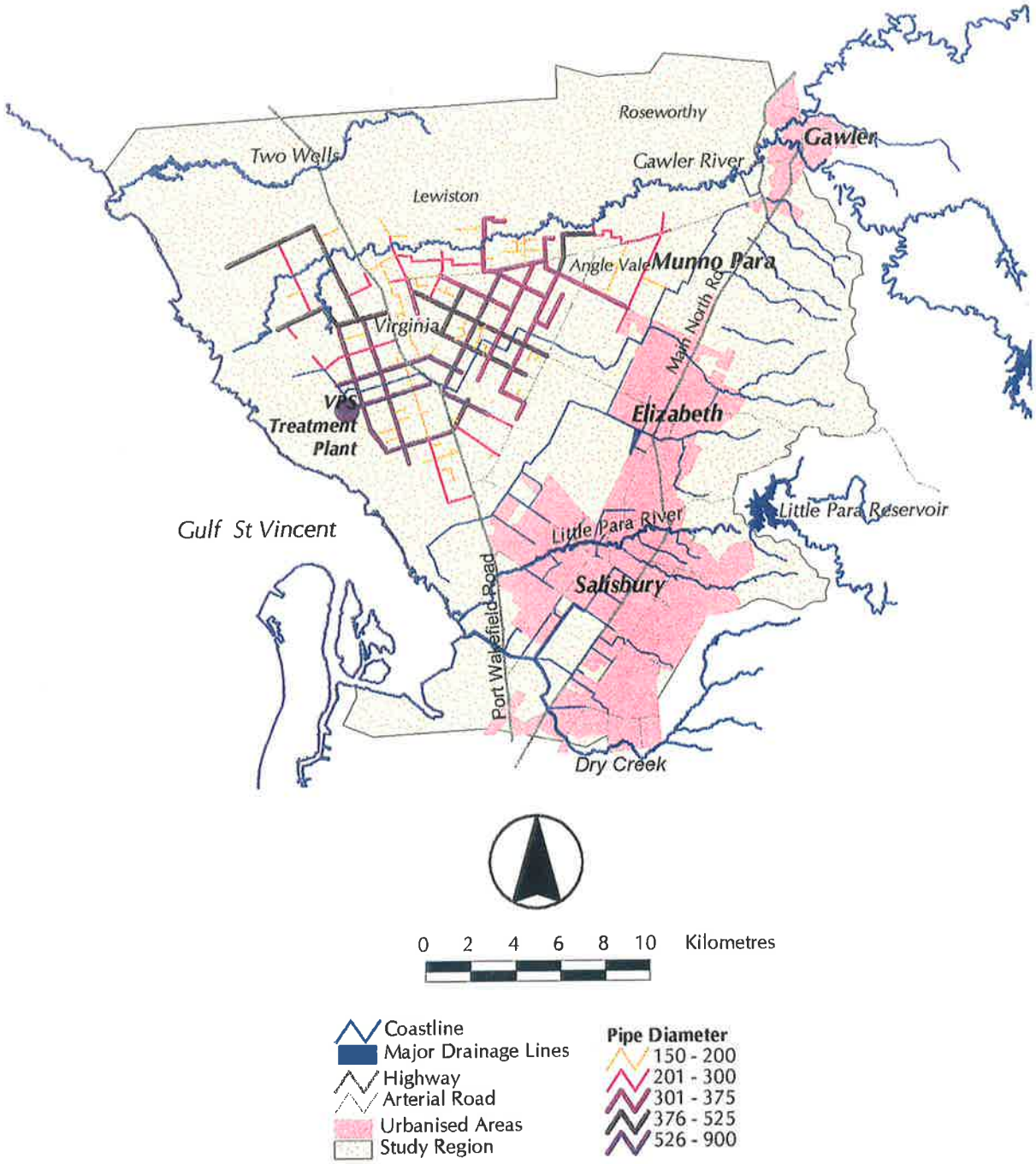


Figure 11.6

Layout of the Virginia Pipeline Scheme

announcement of the construction of the pipeline will easily ensure that demand will exceed 40,000 ML per year. Furthermore, there are other opportunities for use of the water by local councils and also industry (with the emphasis being on non-seasonal demand).

A total of 176 km of pipeline is involved with sizes ranging from 150 mm to 1200 mm in diameter. Because of the relatively low pressures involved, various plastic materials will be used. The orientation of pipelines is depicted in Figure 11.6.

11.2.2. Retain areas of existing habitat and restore other areas for native plants and animals (Objective 2)

The pipelines are constructed along the edges of major road corridors. In many areas of the State, road-side vegetation is the only remnant of the original native vegetation. However, EMS (1994) report that very little remains of the original native vegetation, particularly on the plains. Hence, there was little difficulty in avoiding existing remnants.

11.2.3. Conserve water, and recycle stormwater and treated sewage effluent for productive uses (Objective 3)

The average irrigation demand in the VVT is 40,000 ML per annum, allowing for some growth in demand that typically occurs when suitable water becomes available. This compares favourably with the annual outflow of treated effluent from the Bolivar WWTP of just over 40,000 ML (equivalent to an average daily flow of 110 ML). The volume of outflow is approximately 20 percent less that treated annually due to evaporation losses and significant amounts of leakage from the ponds, amounting to around 10,000 ML per annum.

From a public health point of view, the effluent required additional treatment, involving:

- full secondary treatment, with 16 days (or more) lagoon detention; Bolivar WWTP already provides this level of treatment;
- followed by coagulation, filtration and disinfection;
- physical / micro-biological criteria of: faecal coliforms < 100/100 ml at the 90 percentile; and suspended solids < 20 mg/l on average.

Treatment is achieved using an activated sludge plant with biological nitrogen removal (BNR) followed by deep bed dual media direct filtration, and disinfection by chlorination (KME, 1996). This replaces the dissolved air flotation and filtration (DAFF) plant and disinfection by UV irradiation originally proposed by the VPC. The BNR plant was installed and operated by SA Water as part of their obligation to reduce nutrient discharges to the Gulf.

The provision of around 2,000 ML of raw storage capacity provides a balancing storage; this is achieved by using the existing lagoons (with a capacity of 4,000 ML) and drawing these down but not fully emptying them.

The treatment plant has a capacity to treat 160 ML of effluent each day. The multiple-lift pumping system has a capacity of 120 ML/day (corresponding to 80 percent utilisation) with the capability to increase to 160 ML/day by the provision of additional pumps. On farm storages minimise demand fluctuations and ensure uniform water usage throughout the entire day.

This provides a reclaimed water quality equivalent to the SAHC Class A for unrestricted irrigation of crops eaten raw. The water quality is also sufficiently high to enable relaxation of controls on beef and dairy cattle grazing pasture irrigated with the reclaimed water.

KME (1996) estimated that, with full development of the Virginia irrigation area, in an average year around 77 percent of the Bolivar plant effluent could be irrigated without having to resort to aquifer recharge. In fact, ASR does not proceed in any major way due to a lack of momentum on the issue. With confidence lagging in the ability to solve clogging problems, with little pressure from within government for further reduction of marine discharges, and ongoing substantial and productive reuse of effluent without additional storage provided by ASR, the incremental benefit to be gained from ASR seems too low to warrant its implementation.

There are, however, a number of threats to the long term viability of the Virginia Pipeline Scheme. With the escalating price of mains water and corresponding reduction in water consumption, the volume of effluent generated also decreases. While the increasing population on the NAP means that total consumption will increase over the study period, consumption is likely to decline in the other established areas within the Bolivar catchment area. Therefore the volume of sewage draining to Bolivar may decrease in the long term, reducing the volume of water available for reuse.

The physical condition of the sewers introduces two opposite but important threats. Should replacement or repair of aging sewers be delayed for financial reasons, the continuing infiltration of saline groundwater to the sewers may continue to raise the salinity of the sewage. Salinity is not reduced during treatment and with ponding prior to discharge or reuse the salinity increases through evaporation losses. With the period of ponding also likely to increase under the operating conditions of the VPS, salinity would rise further, which may bring into question the suitability of the effluent for irrigation of some crops.

If, on the other hand, aging sewers were replaced, the volume of sewage reaching Bolivar WWTP may still reduce. Clark & Desmier (1991) estimate that 25% of the total sewage flow into metropolitan wastewater treatment plants results from sewer infiltration. If the contribution from infiltration were to be halved between 1996 and 2020, this would mean a reduction in sewage inflow by 6,250 ML per annum. Following treatment and ponding, with losses due to evaporation and seepage, the available volume of effluent for reuse would be around 35,000 ML which is less than the estimated annual irrigation demand of 40,000 ML. This is also on the assumption that there is no change in water consumption and therefore sewage generation patterns.

Further development of technologies to enable on-site or localised treatment and reuse of sewage effluent (e.g. sewer mining) also have the potential to reduce sewage flows. Indeed, practices such as sewer mining would most likely be adopted by large water users such as industry for cooling water, or local councils for irrigation of public open space. Such uses could remove potentially large volumes of sewage effluent, returning only the sludge to the sewer following effluent treatment.

11.2.4. Use land with fertile soils for agriculture, not urban development (Objective 1)

The VPS did not serve to protect existing horticultural properties from development, nor make productive marginal farming land. The reliable and expanded water supply provided by the scheme did however offer the opportunity for continuation and expansion of agricultural production on existing properties. This was significant in areas with limited water, such as those properties north of the Gawler River.

The quality of the reclaimed water and its long term effect on the soils of the region had always been an issue of concern. Potential effects on soils included salinisation, groundwater contamination and toxicant accumulation (such as heavy metals and trace organics).

The experience of growers who had been irrigating with effluent from the Bolivar outfall channel for many years, and from other studies, suggested that the treated effluent was suitable for irrigation provided that it was properly managed (Desmier, 1987; CSF, 1992; EMS, 1994).

Yet, the salinity of Bolivar recycled water was marginal at 1,300 to 1,500 mg/L. Many crops showed some reduction in yield at these salinity levels. The additional treatment provided to the effluent was found to result in an increase in effluent salinity by about 5 percent.

Nevertheless, the additional water supplies ensured rising agricultural production in this area adjacent to the city, providing efficient production of crops close to markets. Coupled with the trend in the region toward the production of higher value vegetable crops with export potential, increasing land values and the high investment levels of many growers (EMS, 1994), the continuance of valuable horticultural production in the region was assured.

11.2.5. Support growth in 'clean' industrial development and employment (Objective 6)

The pipeline scheme provided the impetus for expansion of employment in the horticultural and support industries. Not only were jobs created for more market gardeners and produce packers, but also during the construction of the pipeline, and afterwards in the areas of irrigation technology, aquifer storage and recovery research, pipeline operation and maintenance, and export marketing.

The construction of the pipeline created around 500 direct and indirect jobs (MFPA, 1995), while in market gardening around 1,300 jobs were created. Independent economists and horticultural experts estimated that the pipeline would create a total of between 1,200 and 3,100 new jobs throughout the State (MFPA, 1996a), and this forecast was largely fulfilled.

11.2.6. Use groundwater no faster than it can be naturally replenished (Objective 5)

The pipeline scheme resulted in significantly reduced impact of horticulture on the groundwater systems of the region. Where withdrawals once averaged 18,000 ML per annum, the supply of up to 40,000 ML of effluent per year enabled a substantial reduction in groundwater consumption to around the sustainable yield of the tertiary aquifers of 6,000 ML/a.

With the construction of the VPS will came the formation of the Virginia Irrigation Trust Inc. This body has the responsibility for conjunctive management of the groundwater and reclaimed water. With the interests of the growers and the management of the water resources being administered by this body, the long term sustainability of the industry and water resources which sustain it are being seriously addressed.

Reclaimed water supplied through the pipeline has become the major water source for the majority of growers, encouraged partially through the system of pricing for reclaimed water and groundwater. Only in peak summer, when irrigation demand is in excess of treated effluent capacity is water supplied by pumping from aquifers.

With the reduction in total extraction due to irrigation directly from the Bolivar-Virginia pipeline, there were benefits to the area in several ways as follows (Gerges, 1995):

- The water levels in the tertiary (T2) aquifer recovered to a position equal or higher than the overlying aquifers. This resulted in a reduction in salinisation of the aquifer by (i) reduced downward leakage from degraded wells; (ii) reduced upward leakage from the underlying tertiary (T3) aquifer (as its head was around 55 m above that of the T2 aquifer in the centre of the cone of depression); and (iii) reduced lateral flow from the saline aquifer margins. Furthermore, the movement of injected water in the overlying saline Quaternary aquifers via corroded well casing resulted in the waiving of the enforced backfilling of some wells. There was also a reduction in pumping costs.

- Reduced restrictions on irrigators.

- The utilisation of the groundwater resources in a more sustainable manner.

- Increase property income and value as a result of an augmented and more dependable water supply.

In case of a failure of the system or water of an unsuitable quality for treatment coming from the Bolivar WWTP there will be an ability to switch to the extraction bores in the same way they would be used at peak demand times.

11.2.7. Reduce the impact of wastewater disposal on the coastal zone including fishing grounds (Objective 4)

While the level of wastewater treatment provided in Adelaide's plants generally exceeded the minimum requirements detailed in the *Australian Water Quality Guidelines for Fresh and Marine Waters* (ANZECC, 1992) and the *Guidelines for Sewerage Systems - Effluent Management* (ANZECC, 1994), the discharge of high levels of nutrients to the Gulf remained a concern.

Comparison of the volume and pollutant loads of treated sewage effluent and stormwater clearly shows that effluent is by far the major contributor of nutrients to the Gulf; refer Table 11.4. The removal of large volumes of effluent from the Gulf will thus have a significant positive impact on the coastal zone.

Table 11.4
Comparison of Discharges to the Gulf St Vincent from the Northern Adelaide Plains[1]

Characteristic	Bolivar WWTP Effluent		Stormwater		Total Pollutant
	Tonnes	%	Tonnes	%	Load, tonnes
Flow, ML/a	37,992	47	42,367	53	80,359
Nutrients	3,009	98	63	2	3,072
Heavy Metals	23	40	36	60	59
Suspended Solids	3,153	33	6,459	67	9,612
All Pollutants	43270	82	9684	18	52954
All, Equal Flow[2]	48,253	83	9,684	17	57,937

(1) Water quality data sourced from EWS (1992), Harbison (1992), Tomlinson et al (1993), EMS (1994), Thomas et al (1994), AWQC (1996), and others.
(2) Annual pollutant load for equal flows of stormwater and treated effluent.

During an average year, around 80 percent of the available effluent is consumed through the VPS. While BNR was to be provided by SA Water as part of their EIP for the Bolivar WWTP, effluent treatment and reuse was considered to be more reliable than nutrient removal and discharge in achieving the desired nutrient reductions (Roger Stokes & Associates, 1995a).

It should be noted though that none of the approaches proposed by SA Water or the VPC to reduction in nutrient discharge to the Gulf are without actual or potential environmental impacts. Some general statements can be made:

- From the resource conservation point of view, recycling to land has the overall advantage. Significant quantities of nutrients are directly recycled into agriculture along with the effluent, and electrical energy consumption is less, thereby conserving coal and gas and contributing less to greenhouse emissions.

Power costs with the reuse scheme total less than $1.0 million per annum while activated sludge options vary from $2.0 million upwards.

- As effluent continues to be discharged at the shoreline, even though nutrients are removed, there still continues to be a significant impact in the vicinity of the discharge point. Elimination of environmental impacts in this respect required discharge to the Gulf via an extended outfall and diffuser. The cost of a 5 kilometre outfall was around $40 million.

- Reliability of operation favoured the reuse scheme. Plant upsets at Bolivar occurred with the biofilters and these became more troublesome than with the activated sludge type plants. The nutrient removal activated sludge plants were even more sensitive to toxic substances in the sewage as well as to slugs of high BOD material. BNR plants operating interstate were known to require a very high level of operator control, and even with relatively non-industrial type sewage, consistent removal efficiency was difficult to achieve (Roger Stokes & Associates, 1995a).

11.2.8. Ensure that the project is commercially beneficial (Objective 8)

The capital and operating costs of the 80% utilisation scheme are summarised in Tables 12.5 and 12.6 respectively. These costs include provision for engineering and a 15 percent contingency sum.

In addition to these costs are those incurred by SA Water for the upgrading of treatment facilities at Bolivar WWTP. The capital and O&M costs associated with installation of the activated sludge BNR plant are $45.04 million and $2.86 million respectively (KME, 1996). These costs are calculated on the basis of 75 percent reuse of reclaimed water, and a total nitrogen concentration of 20 mg/L from the BNR plant.

The total costs of upgrading Bolivar WWTP to provide the effluent suitable for irrigation, as well as construction and operation of the pipe reticulation network are presented in Table 11.7.

Table 11.5
Capital Cost of the 80% Effluent Utilisation Scheme

Item		Cost, $m
Effluent treatment plant[1]		9.500
Distribution pipework[2]	- VPC Area 1	22.180
	- VPC Area 2	2.090
Service connections[2]		2.210
Pumping stations[2]		3.660
Balancing storages[2]		1.960
Total		**41.600**

(1) Modified treatment plant cost according to KME (1996)
(2) Cost data sourced from Roger Stokes & Associates (1995a)

Table 11.6
Operating and Maintenance Cost of the 80% Effluent Utilisation Scheme

Item	Cost, $m
Treatment	
- Filtration plant operation and maintenance[1]	0.270
- Labour[2]	0.040
- Testing[2]	0.010
- Disinfection (including power), estimated[2]	0.300
Sub-Total	**0.620**
Distribution[2]	
- Power	0.255
- Maintenance	0.150
- Miscellaneous	0.020
Sub-Total	**0.425**
Total	**1.045**
Equivalent O&M cost per kilolitre of water supplied[3]	3.3 ¢/kL

(1) Modified treatment plant cost according to KME (1996)
(2) Cost data sourced from Roger Stokes & Associates (1995a)
(3) Based on utilisation of 80% of the available 40,000 ML of treated effluent per year

Table 11.7
Summary of Effluent Treatment and Distribution Costs

	Capital Cost, $m	Operating & Maintenance Cost, $m
80% Effluent Reuse Scheme		
Activated sludge BNR upgrade for Bolivar WWTP to meet EIP requirements	45.04	2.860
Additional filtration and disinfection plants	9.50	0.620
Reticulation pipeline, pumping stations, connections and non-farm storages	32.10	0.425
Expansion to 100% Reuse using ASR		
Construct 50 of 1.5 ML/day recharge and recovery wells throughout the region[1]	4.00	0.276
Funding Contributions		
Commonwealth Better Cities funds	10.80	-
Annual State Government contribution[1]	4.00	4.00

(1) State Government to provide additional funding of $4 million per year only which could be used to cover capital costs in the first year.

The Commonwealth Government allocated $10.8 million of Better Cities funds to the project with most of the remaining cost met by the private sector developers (MFPA, 1995). An annual State Government contribution was required for the period of debt funding of the project, in the order of $4.0 million (at 1995 price levels). By around 2015 and roughly 20 years after commencement, the project was financially self sustaining (Roger Stokes & Associates, 1995a). Thus, the project

provided a sufficiently attractive and certain revenue stream to ensure that the bulk of the necessary finance was obtained from sources external to State Government.

Independent economists and horticultural experts estimated the pipeline will enable farm-gate value of production to at least double, adding in excess of $100 million a year to the State's economy (MFPA, 1996a).

11.2.9. Charge a price for a product or service that reflects the true or full cost of provision (Objective 9)

With the construction of the pipeline scheme and formation of the administrative body of the Virginia Irrigation Trust Inc. came the opportunity to ensure effective use of all water resources by virtue of control of pricing mechanisms.

Users were required to enter into a 'take and pay' arrangement with the irrigation Trust which bound them to using roughly 75 percent of their indicated annual demand, with the remaining 25 percent kept available for use for a given period, after which it was re-allocated to another user. This ensured equitable use of the water but without committing users beyond reasonable commercial terms (Roger Stokes & Associates, 1995a).

The average price of 9 cents/kL (with a range between 6.5 and 25 cents/kL) is the maximum the irrigators pay, which is sufficient to cover the true cost of providing the service. This compares with the original cost of extracting groundwater of 5 to 6 cents/kL. In order to make the use of reclaimed water economically attractive, the State Government, through the Trust, impose a minimum 'resource charge' of 3 cents/kL for all groundwater withdrawals in the NAP, so as to ensure a competitive edge for the reclaimed water.

Connection fees are charged on a once only basis to all classes of users with the basis of the calculation relating to the type of user and the volume the user is allocated. In addition, an annual license fee of $300 per user of reclaimed water is charged.

Annual Access Fees are also charged to all users (other than NAP license holders) to reflect the cost of establishing and maintaining groundwater bores, and in turn placing all users on a relatively even financial footing.

The cost of wastewater treatment at the Bolivar WWTP increases due to the construction of advanced treatment processes, odour control facilities and a new outfall. This cost is not passed on to the growers consuming the treated effluent but distributed over all users of the metropolitan Adelaide sewerage system. The cost of wastewater treatment rises (in real terms) from around 10 ¢/kL to 23 ¢/kL (assuming a 50 year economic life of the new infrastructure and a discount rate of 7.95%).

There is also a net financial gain to State Government and tax payers by virtue of being relieved of the costs of licensing and management of groundwater users, costs which currently exceed the revenue accrued therefrom (refer to Section 11.1.10).

11.3. Scenario C: A Rejuvenated Urban Form

This scenario assumes that the problems associated with conventional development patterns have been recognised by government and the general public, and that the public and political will exists to carve out a higher quality of life that is more environmentally and socially responsible.

A number of local governments adopt and implement the 'utopian' development principles that had been espoused in State Government planning documents for many years. The benefits of integrated planning and development quickly become evident and set an example for the more conservative councils. Conventional patterns of residential and urban development are progressively abandoned in favour of 'eco-city' patterns that are yielding many social, environmental and (surprising to many) economic benefits.

The northern Adelaide plains will experience continued growth as discussed under the 'business as usual' scenario (Scenario A). Growing numbers of families with young children result in continuing demand for family housing and services. An increasing number of elderly people also raise demand for a range of aged services, facilities and housing.

The establishment of an urban-rural boundary with the horticultural area to the north-west effectively creates a northern growth corridor between the horticultural area and the Hills Face Zone. Urban growth will continue along this north-south axis. With reference to Figure 11.7, there will be:

- continued expansion within Salisbury;
- a significant and additional population influx associated with the MFP Australia development at Greater Levels;
- ongoing development at Golden Grove (outside the Study Area);
- development at Smithfield in parallel with Golden Grove;
- development of Munno Para West and Evanston.

The significant difference to the urban growth pattern of Scenario A is the form of urban development. Sprawling, low density residential suburbs will be transformed into a series of generally higher density urban villages.

The research and development functions of the Department of Defence are consolidated into a smaller parcel of land so that around 500 ha of the DSTO Salisbury property is released for urban development around the year 2000. The land is most effectively transformed into a series of urban villages, accommodating more people than under the conventional development Scenario A and providing a 'show case' of modern thinking and technologies while also making good use of the existing infrastructure in Salisbury and Elizabeth.

During the first several years, diverse new housing is provided mainly through development within Munno Para and targeted urban consolidation. However, in later years, much of the new housing arises through redevelopment of older suburban areas. Comprehensive redevelopment of older areas of Salisbury and

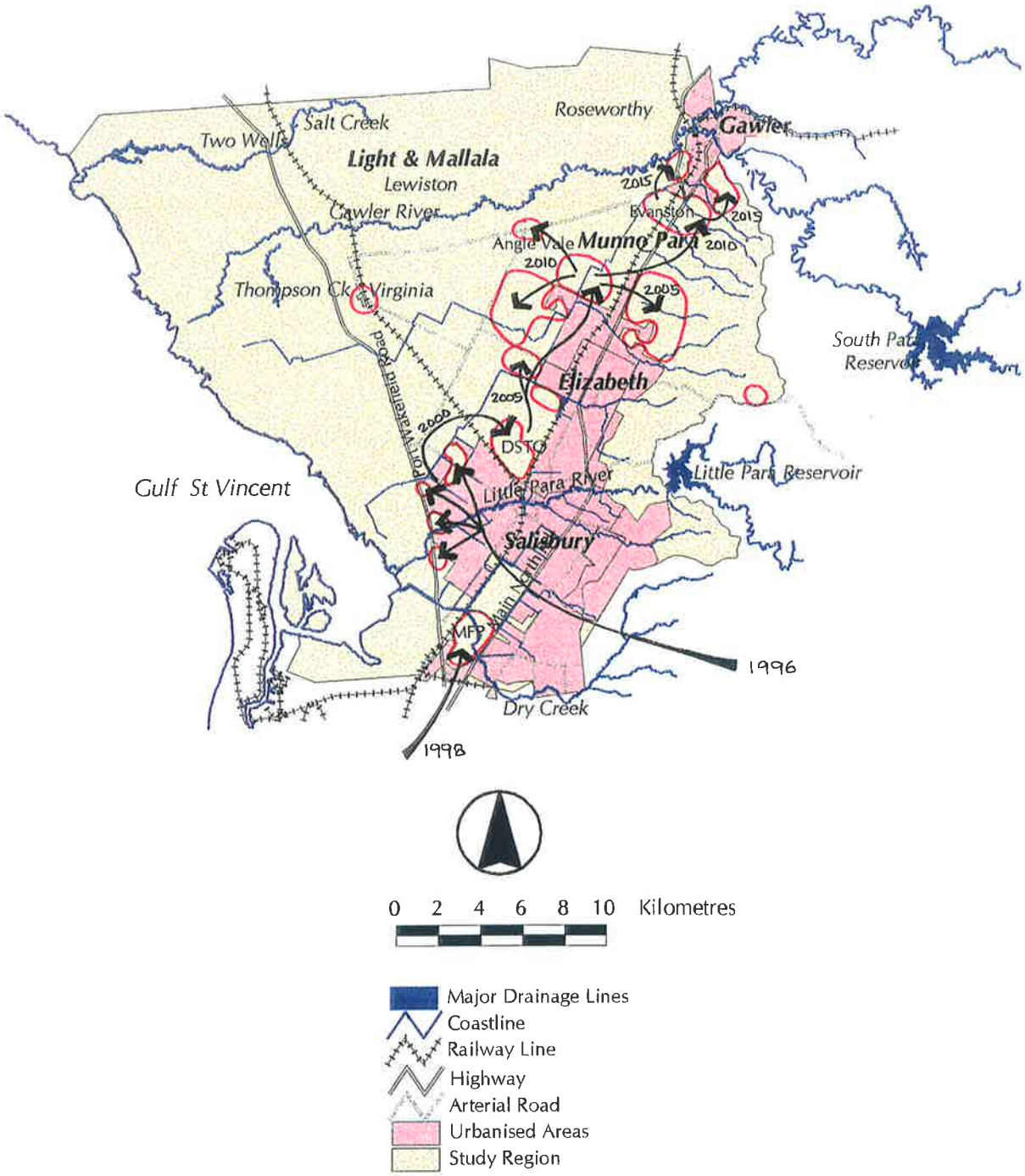


Figure 11.7

Scenario C: Direction of Future Urban Growth

Elizabeth occurs during the second decade (i.e. 2006-2015). The older areas of Munno Para comprising extensive tracts of public housing are also targeted, transforming the image of the area. In general, urban renewal is concentrated at higher densities around centres of activity and along major transport routes.

While the higher densities preclude the need for extension of the urban corridor beyond Gawler, this is not to say that Gawler remains untouched by new development.

A buffer of non-urban land between Munno Para and Gawler is retained, creating a distinct, contained community with an individual focus, and assisting the preservation of Gawler's unique identity and character. Expansion of Gawler effectively occurs through the establishment of a number of urban clusters around the Gawler town centre, thereby increasing the economic activity experienced by the town and ensuring more efficient use of existing infrastructure, while not significantly affecting its country town appeal.

The communities of Angle Vale, One Tree Hill and Virginia become fully developed according to tightly controlled development plans, which ensure distinct boundaries between the urbanised and rural areas. The larger town populations ensure strong local economies, while reinforcing the cultural diversity and ensuring interesting and vibrant townships with individual identities.

Where the Sandy Creek–Roseworthy region to the north of Gawler was previously considered to be required for urban development around 2000-2001, it is no longer a consideration for urban development within the planning time frame.

Primary objectives in the development (and re-development) of the new urban form are creation of employment centres closer to where people live, provision of a satisfactory residential environment, protection of areas of ecological importance, conservation of natural resources, redressing of inequities in urban areas, preservation of the essential character of Adelaide, and reduction in energy use and transport demand.

11.3.1. Develop urban areas for greater choice in housing styles, effective transportation and community living (Objective 7)

As the population grows, so does the number of dwellings required to house them. There is a trend toward fewer persons per household, meaning that disproportionately more dwellings will be required. A diverse range of housing options become available, where the single detached dwelling remains a feasible but non-dominating option.

By the year 2020, the population has increased from 230,680 in 1995 to 317,150, inclusive of the population of 11,000 at the MFP development of 'Mawson Lakes' at Greater Levels. The area of urban development initially increases, but ultimately reduces by 3,294 hectares from 11,823 to 8,529 ha, of which 1,482 ha or 45 percent will be consumed for purely residential development, as distinct from mixed use (residential, retail and commercial) areas.

It is not only the young, single and elderly who initiate a shift in demand for housing away from the common detached house towards more compact dwellings. Young families also tend to seek dwellings on smaller allotments, partly because open spaces are designed for more effective use, and also because traffic calming and other transit oriented measures make streets safer places for children to play.

While Adelaide's road system provides relatively little congestion, flexibility in choice of routes, speed and comfort, it is recognised that the dependency upon cars for mobility, and the conventional form of urban areas which drives this dependency, are causing serious environmental problems. Through a programme of taxes, subsidies and education, the Government initiates a shift away from the car to a public transport system with two main elements. The first is a system of local transport focussed on centres of commercial, shopping and social activity which serves the needs of each local community. The second is a mass transit and freight system joining the main industrial and metropolitan centres together.

The road network continues to develop with the evolving urban areas. However, the form of the network also changes. Residential streets are narrower and designed for slower speeds. There are fewer *cul de sacs*, with greater inter-connectivity of streets providing flexibility in route selection and less congestion. Major roads are retained, although as time goes on, their width is often reduced as the traffic volume decreases in response to more comfortable and efficient local and mass transit systems.

11.3.2. Retain areas of existing habitat and restore other areas for native plants and animals (Objective 2)

The sacrifice of the natural environment to urban sprawl stopped. The emerging emphasis on the environment and quality of life provide impetus for greening the northern plains.

Local political boundaries are redrawn to follow bio-regional (or catchment) boundaries, making the inhabitants of a bio-region also the custodians of the region, those who will reap the benefits of its care and restoration.

The more compact urban form returns tracts of land to public open space and recreational facilities, which are interwoven with the restoration of the indigenous environment. Integrated planning efforts enable the Metropolitan Open Space System (refer Scenario A) to be strategically expanded but subtly integrated through urban areas and farming lands without consumption of vast tracts of land. A network of walking and cycling trails often form these extended links. New areas of open space area also transformed into native grasslands, urban forests and local farms, providing pleasant views and effective buffers between urban centres.

Opportunities are limited for development of coastal recreation and leisure other than at St Kilda, so that the sensitive ecology of the mangroves, wetlands and fauna habitats are conserved and available as resources for education and eco-tourism.

The open land separating Gawler from Munno Para will be retained, as will the productive market gardens of Virginia. The Gawler racecourse is relocated to a site within the MOSS.

11.3.3. Conserve water, and recycle stormwater and treated sewage effluent for productive uses (Objective 3)

Water management assumes a level of importance that is unparalleled with any other time other than perhaps during the earliest years of the nation and State.

Significantly, there is a move away from the once through 'use and dispose' system to a system based upon water conservation and wastewater reuse and recycling. Where necessary, wastewater is disposed to land or natural water bodies, but only after appropriate treatment.

But perhaps the most fundamental change occurs when the State Government amends the *Water Resources Act 1997* to enable the transfer of land and water management responsibilities to (bio-regional) local government. The previous catchment boards are devolved and continue their role within local government, but now charged with the responsibility for provision of almost all water services – drainage, flood control, stormwater harvesting and reuse, sewage collection and treatment, and treated effluent reticulation. Only potable water supply remains within the realm of State Government, although with significant input requested of and provided by local government.

Demand management and conservation of potable water is highly successfully, achieved as a result of:

- public education,
- adoption of many existing water conserving technologies, including dry toilets which gain increasing acceptance;
- rain water collection from roof tops becomes more common, particularly in multiple dwelling housing;
- improved opportunities for implementation of technologies through urban renewal;
- reduced domestic consumption for outdoor applications (e.g. lawn watering);
- economically attractive sub-potable water supplies provided by dual supply systems; and
- a significant increase in the price of potable water to cover the true costs of supply (including asset replacement).

All new developments are required to incorporate household sprinklers for fire fighting; urban lakes or similar water features are also strategically located to serve as pumpable water sources for fire fighting if required. These new fire fighting measures, coupled with reduced lawn areas, dry landscaping or wastewater irrigation to avoid high summer demand, means that the need for large diameter mains is significantly reduced with commensurate cost savings to government. The replacement of old mains with newer, smaller mains is also a big step in reducing system losses, which progressively reduce to around 5 percent of total consumption.

Innovative technologies are developed for water reuse, and this becomes a highly competitive area of business. Most local governments adopt wastewater treatment at a community level (e.g. around 20,000 dwellings or 50,000 people), and employ private contractors for fixed periods to privately operate and maintain these systems to strict standards. A number of plants utilise engineered ecosystems (wetlands) as a component of the waste-water treatment train.

With reduced potable water consumption and supply of reclaimed effluent for non-potable purposes, the water distribution pipes are progressively replaced with smaller diameter pipes, saving millions of dollars. Most of the existing sewers pipes have only reached the middle of their productive lives, and do not need replacement. In new urban areas, the size of sewers are not much different to the conventional sewers because although potable water consumption has reduced, the combined sewage flows from potable and non-potable sources is only less.

Markets quickly develop for the recycled water, particularly within the industrial and horticultural segments. Technologies are developed to provide additional conditioning of the effluent particular to the end use. Cheap and efficient water quality monitoring equipment is also produced to provide real time confirmation of water qualities fit for purpose.

The high effluent reuse means that little inter-connectivity between catchments is required. A limited network of large diameter sewer mains from the original centralised system are maintained, however, upgraded to minimise leaks and then serve as a distribution medium between local government areas. These mains are used when an excess of treated effluent is available and can be sold to a consumer in another district. Around 9 ML of treated effluent can also be stored for short periods within this network of pipes.

The issues of flooding and drainage continue to be addressed by local government, but now within a mindset of resource management rather than waste disposal. The objective of reducing discharge of polluted stormwater to sea is reinterpreted as storage of cleansed stormwater for productive uses. Environmental flows are, of course, a 'productive use' and is the first use component to be accounted for in any stormwater management plan.

Drainage measures are typically designed to simultaneously provide for water quality improvement, recreational space and new habitat. Swales, ponds, urban lakes and wetlands become common features. These provide flow attenuation and water quality improvements, as well as water for groundwater recharge and irrigation of local parks and market gardens. Stormwater is infrequently used as a source of supply for industry as its supply or quality cannot be guaranteed with the same degree of certainty as treated wastewater.

On-site detention (OSD) using infiltration devices is uncommon, contrary to the prevailing practice in the eastern States and Western Australia. This is largely because the expansive soils of the Adelaide plains are inappropriate for such devices, and would threaten the structural integrity of buildings, particularly in a

more compact building environment. Studies also find that the optimum scale for water retention is at the cluster or village level, rather than an allotment, because:

- it is more economic to harvest the resource at the larger scale; and
- although the volume of runoff generated at the cluster scale is larger than for a conventional development of the same area (due to a higher percentage of impervious area), the use of swales and natural storage facilities maintains peak flows at or below the present level.

Urban development is also precluded or progressively removed from areas lying within the predicted 1 in 100 year flood plain for the Gawler and Little Para Rivers. In many instances, this land is returned to productive market gardening or open space.

A modest improvement in irrigation efficiency of 20 percent is also made in agriculture (Thomson, 1996). This enables expansion of irrigated crops and more efficient use of available fertile land, above that possible through new water sources.

The State Government, now largely released from its role as water service provider, assumes an advisory, regulatory, research and training role. The Water Resources Group (WRG) of the Department of Environment and Natural Resources and the Department of Mines and Energy undertakes practical, site specific research supported by the baseline research of local Universities, CSIRO, CRCs and other organisations. The WRG research staff are also trained in the fields of water resource management and engineering, in line with the Government's policy of recognising its training responsibility. The research findings provide the basis for ensuring continuous improvement, as staff regularly advise local government, and as policy guidelines are amended.

11.3.4. Ensure easier access to public services, recreational and open space (Objective 10)

A key objective to be achieved by new urban development is the reduction in the demand for travel. To achieve this services are made more accessible by locating them in neighbourhood, district and regional centres (as appropriate), and ensuring that they are well served by public transport.

The State Government has had to decentralise many of its functions where public interaction is necessary, such as social services, rate payments and enquiries, often using staff who live in the region to provide friendly service to their neighbours.

Some of the most notable and positive changes are provided by private enterprise, however. With the establishment of many new urban clusters and villages, the 'corner shop' and other convenience stores re-emerge at the local level. There is a huge and sustained boost in economic activity as this new demand is met by local supply. The huge shopping malls lose their grasp over their car dependent shoppers who can now buy most groceries, music and books, have their hair cut, or see a movie within a few minutes walk of their home. This all comes courtesy of the new condensed urban form.

The condensed form caters for the needs of women, the elderly, children and those people disadvantaged in terms of socio-economic status, transport need and health. A more vibrant community atmosphere is generated with more local interaction, where there is greater safety on the streets during the day and night. Private enterprise often provides child care and aged services at the local level employing local staff. Many elderly citizens find they can live active and interesting lives within their new neighbourhoods for many years longer, not having to move to retirement villages or nursing homes to receive the support needed (as would often have been the case under Scenario A).

Increasing the visual and environmental amenity of the region is a priority. A linear park, as part of the MOSS system, is designed to connect through the DSTO Salisbury land to the west of the Elizabeth city centre, linking flood control and open space areas to the west.

The original 12.5% open space requirement for residential areas is relaxed, enabling developers and local governments to establish site specific requirements. Initial public concern is quickly put to rest; although the percentage of open space is reduced, those open spaces that are provided have been designed more sympathetically and are found to be more effective for passive and active recreation. Smart design leads to the consumption of less open space in wide median strips along roads; footpaths and drainage swales are provided on only one side of a residential street; and traffic calming measures make streets much safer places for children to play. In many instances, back-streets once again become the domain of the pedestrian where cars can also venture but at much reduced speeds. Developers also find that it is in their best interest to provide effective open space and good views, as these allotments command a higher price.

11.3.5. Use land with fertile soils for agriculture, not urban development (Objective 1)

The economic, social and agricultural importance of the Virginia Vegetable Triangle (VVT) and surrounding horticultural activities is recognised. Strategic planning identifies all areas with soils suitable for irrigation and horticultural pursuits, leading to the establishment of new land use plans which preclude urban development from these areas.

Other areas that are within the VVT that have unsuitable soils for cropping are considered for other forms of development, and generally those that are supportive of the horticultural industry, such as processing and packing centres, surface water storages, and so on.

With the permanence of the horticultural area and the families it supports, growers seek to consolidate their position in the local market place and expand their export markets.

Even though licensed groundwater withdrawals are reduced, the level of production is expanded, made possible by improved irrigation efficiency, renewed availability

of a portion of 3,294 ha of productive land for agriculture, and treated effluent and stormwater for unrestricted irrigation.

11.3.6. Support growth in 'clean' industrial development and employment (Objective 6)

Development occurs so as to maximise the economies of scale in the use of major infrastructure items and existing commercial centres. The Elizabeth and Munno Para Centres become focal points for more specialised business and commercial services, and a new centre emerges in Salisbury.

The MFP development of 'Mawson Lakes' at Greater Levels encourages significant local investment in the clean, high technology areas of electronics, information technology, education and environmental management bringing with it many new jobs and export dollars.

New industries establish throughout the region, taking advantage of the new infrastructure and technologies arising in part from MFP related businesses. The efficient transit and freight services which link with air and sea terminals provide effective links to export markets, providing much greater flexibility in determining a suitable geographic location. Indeed, with relaxation of the land zoning provisions of many local government Development Plans, industries tend to move to their employees, to suitable sources of water, and to locations near their raw materials, rather than having them freighted in.

Mixed urban land uses become more common, with industry able to be located quite near residential areas. Rather than zoning these land uses apart, industrial land use is subject to environmental 'performance' standards and heavy penalties. Closed loop production systems and a high level of recycling become the goal of industry as required by the SA EPA.

Some major industries are modifying their processes and products to be more environmentally responsible, and are often finding these alterations result in more efficient production and economic rewards. At the same time, some older and out-moded industrial areas are gradually turned over to residential, community and recreational purposes. In some instances, the loss of some long standing industrial facilities results in large job losses and the need for the workers to undertake retraining.

At the local level there are many more permanent and part time job opportunities, particularly for women and the elderly. The decentralisation of many government functions, as well as the establishment of retail and service industries at the local level translate to many more jobs. Even some crude barter systems become re-established within urban clusters, and markets become a regular and popular community event.

11.3.7. Use groundwater no faster than it can be naturally replenished (Objective 5)

Due to the different boundaries of surface water and groundwater basins, and the difficulty of equitable allocation of responsibility for management of groundwater resources, groundwater management remains a State Government affair.

Groundwater management boards are maintained (or established) much along the lines of the early (surface water) catchment management boards, with representation from State and local government, industry, agricultural and other interest groups.

Groundwater extraction from the tertiary aquifers is reduced over time to the rate of natural replenishment (or sustainable yield). Additional extraction is allowed to occur where aquifer recharge schemes are implemented, with operators allowed to extract 80 percent of the injected water volume, the remaining 20 percent contributing to restoration of the previously over-exploited aquifer.

Aquifer storage and recovery systems therefore become widespread, with treated effluent and stormwater injected under pressure using dual injection-recovery well systems. In excess of 6,000 ML is recharged each year during a 4 month period through a system of over 60 recharge bores injecting at a rate of around 15 litres/second. There are many problems during the first few years, particularly with clogging of the injection wells. On one or two occasions, contaminated water was introduced into the aquifer (but this problem was fortunately solved through an expensive but successful remediation programme). It is not long, however, before these problems are solved through improved designs and operational procedures.

11.3.8. Reduce the impact of wastewater disposal on the coastal zone including fishing grounds (Objective 4)

With a new ethos of water management prevailing in the region, where stormwater and wastewater are viewed as valuable economic resources, only a fraction of pollutants that once entered the Gulf continue to do so. Around 50 percent less nutrients and heavy metals, and 60 percent less suspended solids are discharged to the Gulf each year.

The EPA continue to monitor the ecosystems of the regional rivers, estuaries and Gulf in efforts to determine the carrying capacity of these water environments. The ultimate objective is to establish a system of tradeable release permits for waste discharge, so that the ecosystem of the receiving water drives the technologies used in the urban setting.

Much less sewage effluent enters the Gulf containing the levels of nutrients, heavy metals or other harmful substances that was typical of the conventional operation of the Bolivar WWTP. With treated effluent now such a valuable resource, little is discharged as waste water, and when it is, the level of treatment is sufficient to ensure that the environmental impact is reduced.

11.3.9. Ensure that the project is commercially beneficial (Objective 8)

A range of economic benefits are found to accrue from the shift in water management philosophy. Reduced potable water consumption results in:

- Reduction in the volume of water pumped from the River Murray, so that by 2020 and under average rainfall conditions, almost no water need be pumped, saving around $2 million per year in pumping costs. In a dry year, only one quarter of the volume need by pumped compared with Scenario A (i.e. 6,358 ML instead of 25,229 ML).

- Reservoirs are consistently able to operate at lower storage levels without any significant increase in risk of water supply failure, thereby reducing water losses through evaporation.

- Reduction in the costs of water filtration and purification by around 20%.

- Ability to replace ageing water mains with smaller diameter pipes, reducing the immediate and long term replacement cost.

The reduction in sewage treatment costs are more marginal, because the reduction in potable water consumption is largely achieved by provision of another water source, and therefore the volume of sewage is not largely reduced apart through water conservation measures. Sewer pipes are largely unchanged in terms of size requirements.

The main savings with respect to the sewerage system arise through district level treatment and reuse. The load upon Bolivar WWTP is reduced, as is the volume of effluent and associated pollutants discharged to the Gulf. The SA EPA therefore allow the adoption of a cheaper biological nutrient removal (BNR) option, and concede that given such large reductions in effluent discharge, a new marine outfall and diffuser are not required.

A dual reticulation system is constructed to return the tertiary treated sewage effluent to the community for use, mainly in industry, but also for open space and some residential irrigation. Storage is required at each plant for balancing of monthly flows, but when necessary the high quality effluent is discharged to local stream courses for indirect capture and reuse in stormwater systems, or ultimate discharge to the Gulf.

The construction costs of trunk stormwater drainage facilities are substantially reduced by adopting multi-purpose, open channel drainage forms. Wetlands are often provided within the same environment, usually constructed to capture and treat runoff from an entire urban district. Street and collector drainage, as well as operational and maintenance costs are considered to remain otherwise unchanged.

Aquifer storage and recovery facilities are progressively installed as suitable water storages become available. Indeed, with slight modifications, many of the existing storages were ideal and quickly made operational. Around 64 wells are ultimately

installed, at a construction cost of $85,000 per well, with annual operation and maintenance cost of $5,500 per well.

The most significant cost is associated with the development of minor infrastructure to service the new condensed urban areas. While the actual costs of construction do not differ greatly from conventional development, it is the demolition costs and planning and engineering fees that increase the overall cost of an allotment. Re-engineering an area for smaller allotments where orientation is important, the addition of dual reticulation, and working within existing infrastructure makes the task more complex. This is reflected in the considerable additional cost of public infrastructure of Scenario C over more conventional urban forms. Urban renewal for residential and mixed use development typically costs around $22,000 per 300 m^2 allotment (Collie Planning & Development Services, RA Young & Associates, 1989; SAHT, 1997). The net present value for the provision of residential infrastructure provided in Table E.2, takes into consideration the costs of stormwater drainage and other services that have been considered separately to avoid double-counting.

11.3.10. Charge a price for a product or service that reflects the true or full cost of provision (Objective 9)

As 'the environment' becomes a mainstream political issue which commands media coverage comparable to that of issues of the economy and foreign affairs, a number of changes occur which affect the costs of production of goods and services.

To the howls and cries of many large industrial companies and trade unions, the State and Federal Governments introduce new taxes and subsidies on the production of goods and services, primarily in an attempt to internalise some of the environmental costs of production. Resource depletion taxes, greenhouse gas emission penalties, wastewater discharge taxes are all introduced. The EPA requires continually improved environmental performance from industry, business and government, also introducing new fees to industry.

Tradeable environmental release permits are sold on the free market (but administered by the EPA). Those who can secure such a permit pay a premium which is often little less expensive than the cost of upgrading waste treatment facilities. Indeed, many companies find the cost of such treatment processes and the resulting process efficiencies save them money, with return periods on their investment not longer than a couple of years.

Because most sub-regional wastewater treatment plants are primarily designed to accept sewage of a domestic nature, industrial facilities are required to treat their wastewater so that the discharged water is of a similar quality to domestic sewage, or alternatively pay for capital and operational costs of upgrades to the WWTP if circumstances allow. In this way the costs of production are retained by industry to the benefit of the community.

At the same time, the revenue raised is handed back to the community through such avenues as grants to establish clean industry, for research to develop new recyclable materials, and to the public to subsidise patronage of mass transit systems.

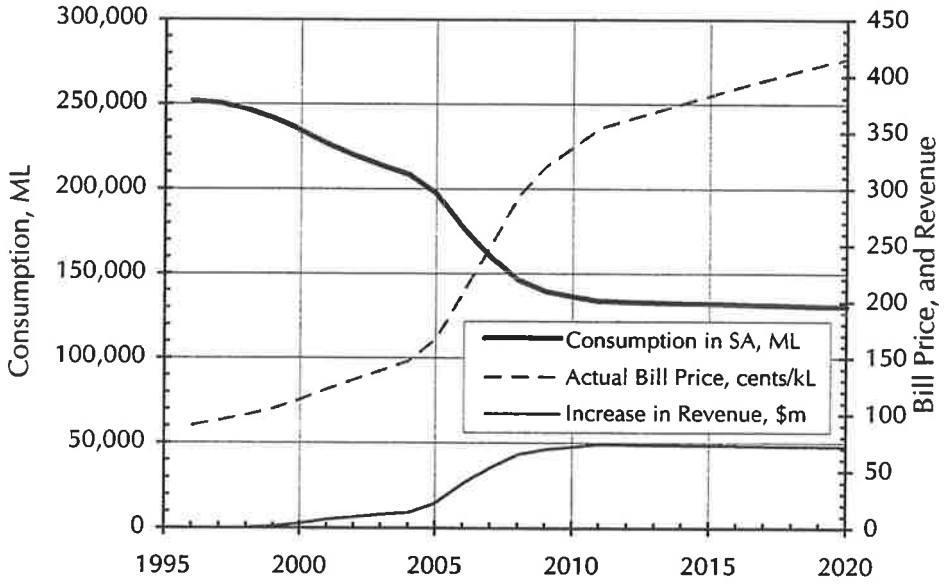


Figure 11.8
Variation in Water Consumption, Price and Revenue Raised in South Australia in Response to CoAG Reforms: Scenario C

Variable pricing is introduced on many goods and services, the most notable being electricity and water supplies. Electronic water consumption metering is introduced along with a policy of variable pricing. Water is more expensive during peak demand periods on a daily and seasonal basis, with special pricing schemes introduced during periods of drought. In this way, prices are more reflective of true production costs, while also flattening out the demand peaks which translates to smaller pipes and system capacities, and over time, lower operational costs and savings to the community.

The marginal cost of potable water rises dramatically, a result of Commonwealth Government reforms and the need to cover the enormous costs of asset replacement or renewal. Indeed, the cost increase is greater than if a conventional form of development and water use had been perpetuated. The effectiveness of water conservation measures means that revenue must be raised from the sale of a smaller volume of water. Over the period 1996-2020, the marginal cost of water rises from around 90 ¢/kL to 415¢/kL (equivalent to a increase in real terms of 191% from 90 ¢/kL to 262¢/kL). As a consequence there is a similarly dramatic drop in total water consumption, as illustrated in Figure 11.8.

Although potable water consumption plateaus at a much lower level (around 52% of 1996 consumption level), the revenue raised by SA Water has increased and covers the costs of asset renewal.

Contrary to initial convictions, consumers also find that they are not so severely affected. Savings in domestic water use coupled with the utilisation of reclaimed water for outdoor applications, means that the rise in their water bills is not so unpalatable, particularly when comparisons are made with the effective price that

many consumers are paying for bottled water. In the long term, it is demonstrated to consumers that their total water bill covering all sources of water supply has actually decreased in real terms.

Innovative urban land developers follow the lead of the South Australian Housing Trust and respond relatively quickly to the emerging market for more condensed living environments. Encouraged by the greater flexibility in terms of the provision of open space, and the new urban design challenge, a variety of interesting, attractive street-scapes and land use mixes appear. Although the development costs per lot are usually higher, the ability to construct some multi-dwelling buildings of 3 and sometimes 4 storeys means that the cost to the purchaser is much the same. There are many instances when the market dictates higher prices for allotments. Developers find allotments adjacent urban lakes and wetlands or overlooking the restored open space and grasslands command higher prices (ECA, 1991; Clark, 1996). The higher costs of infrastructure provision are therefore partially offset.

11.4. Summary of Findings

The key features of each scenario are summarised in Table 11.8.

The costs of implementation of these scenarios are either actual costs as they relate to particular projects (such as Virginia Pipeline Scheme), official budget estimates (such as water main augmentation costs from the SA Water Corporation), or design estimates based on current construction rates and unit costs. Time series of construction and operational costs have been prepared, from which the Present Value (PV) of each item has been calculated for each Scenario; refer to Table 11.9. The PV has been calculated using a discount rate of 7.95% (equivalent to the current long term Government bond rate).

The real marginal price of water for each source of supply has also been calculated. The cost of water supply from new sources has been estimated on the basis of providing an acceptable return on the investment. For example, the cost of treated wastewater from community scale wastewater treatment plants must be sufficient to cover the capital, operation and maintenance costs over the economic life of the asset (50 years, for example) and make a return on the investment of 8 percent. The Annual Equivalent Worth (AEW) is calculated on this basis, and dividing through by the mean annual consumption rate provides an estimate of the cost of water (as ¢/kL in 1996 dollars). These costs are summarised in Table 11.10.

The aggregate cost to consumers of water supply from all sources for the entire period 1996 to 2020 is presented in Table 11.11. This data suggests that during the study period 1996–2020, consumers on the whole would incur the least cost by adopting multiple water sources available under Scenario C when compared with the more conventional development course of Scenario A.

Table 11.8
Summary of the Key Features of the Alternative Water Management Scenarios for the Northern Adelaide Plains

Performance Measure	Scenario A	Scenario B[1]	Scenario C
Objective 1 Use land with fertile soils for agriculture, not urban development.	• Growers and industries consolidate their position in local and export markets. • Horticultural plantings remain limited to 3,500 ha. Yields improve by changes in the types of crops grown and improved irrigation methods. • Urban development consumes some suitable agricultural land. • 3,435 hectares open space or rural land is transformed to urban areas.	• Expansion of agricultural production on existing properties, particularly north of the Gawler River. • Additional effluent treatment raises effluent salinity by about 5 percent; crops show reduction in yield. • Nutrient rich effluent provides organic fertiliser to crops. • The additional water supplies ensure rising agricultural production.	• Urban growth is precluded from areas with soils suitable for irrigation. • Development on areas with soils unsuitable for cropping is supportive of the local industry, such as processing and packing centres, surface water storages, and so on. • Growers consolidate their position in the local market place and expand their export markets. • Cultivated land area is expanded.
Objective 2 Retain areas of existing habitat and restore other areas for native plants and animals.	• Very little native vegetation remains. • Wildlife corridors are established at the metropolitan scale as part of the Metropolitan Open Space Scheme (MOSS). • MOSS areas serve multiple purposes; very few are maintained solely for flora and fauna conservation.	• Pipelines are constructed along the edges of major road corridors, but existing remnants of native vegetation are avoided.	• Greening the northern plains. • Local political boundaries are redrawn to follow bio-regional (or catchment) boundaries. • Land is returned to open space and recreational facilities, interwoven with restoration of the indigenous environment. • Development opportunities are limited in sensitive ecological areas (e.g. St Kilda mangroves). Mangroves, wetlands and fauna habitats are conserved and available as resources for education and eco-tourism.
Objective 3 Conserve water, and recycle stormwater and treated sewage effluent for productive uses.	• Distinct drop in water consumption. • Residential consumers adopt a variety of water saving devices. • State-wide water consumption down from 235,000 ML/a to 200,000 ML/a. • Total water consumption in the region increases from 31,460 ML/a to 41,250 ML/a due to population	• Around 77% of Bolivar effluent is irrigated without resort to ASR. • 2,000 ML of raw storage capacity provided by modifying operation of the Bolivar existing lagoons. • On farm storages are required to minimise demand fluctuations and ensure uniform daily water usage.	• Water conservation and wastewater reuse and recycling. • Wastewater can be disposed to land or natural water bodies, but only after appropriate treatment. • Catchment boards merge with local government, and have responsibility for almost all water services.

Performance Measure	Scenario A	Scenario B[1]	Scenario C
	increase; per capita consumption is decreasing. • Continuing failures of ageing pipes, plant and machinery. • Asset replacement (pipes, pumps, etc) is delayed as long as possible. • Pumping from the River Murray increases from 8,300 ML/a to 19,000 ML/a, rising to as high as 28,500 ML in very dry years. • Stormwater management by Integrated Catchment Management Boards (ICMB). • Traditional stormwater drainage. • Numerous stormwater collection but the total volume used is not large. • Stormwater is treated in wetlands or collected in retention basins and used for irrigation. The storage capacity increases from 2,513 ML in 1996 to around 3,683 ML by 2020. • State Government restrictions on ICMBs prevent truly integrated land and water management. • Increase in urban impervious area by around 4.5 percent. • Mean annual runoff increases from 32,392 to 36,209 ML per annum. • Little reduction in quantity of pollutants discharged to Gulf in stormwater. • Effluent reuse remains roughly static at 6 percent of all treated effluent.	• Reclaimed water quality enables unrestricted irrigation of crops eaten raw and relaxation of controls for irrigation of beef and dairy cattle grazing pasture. • Long term viability of the VPS is threatened by: escalating mains water corresponding reduction sewage flow; increased effluent salinity from saline groundwater to the sewers; significantly reduced effluent flow from restored sewers; and on-site or localised treatment and reuse of sewage effluent.	• Only potable water supply remains within the realm of State Government. • Demand management and water conservation is highly successfully. • Household sprinklers for fire fighting; urban lakes or similar water features also provide pumpable water sources for fire fighting. • The replacement of old mains with newer, smaller mains reduces system losses to around 5 percent. • Technology development for water reuse becomes a highly competitive area of business. • Wastewater treatment at a community level (e.g. around 20,000 dwellings or 50,000 people). • Supply of reclaimed effluent for non-potable purposes. • New sewer sizes are not much different to conventional sewers. • Markets quickly develop for recycled water, particularly industrial and horticultural segments. • Inter-region transfer and sale of excess treated effluent uses old sewer mains. • Environmental flows are a 'productive use'. • Swales, ponds, urban lakes and wetlands become common features. • On-site detention (OSD) using infiltration devices is uncommon, because of the problems of the expansive soils of the Adelaide

Performance Measure	Scenario A	Scenario B[1]	Scenario C
			plains. • Urban development is precluded and progressively removed from the major flood plains. • 20 percent improvement in horticultural irrigation efficiency. • State Government assumes an advisory, regulatory, research and training role.
Objective 4 Reduce the impact of wastewater disposal on the coastal zone including fishing grounds.	• Land-based disposal of sewage effluent and ASR deemed impractical. • Bolivar WWTP upgraded for biological nutrient removal to achieve 80% removal of nitrogen. • A new marine outfall and diffuser system is required. • NAP effluent generated and discharged rises from 17,300 ML/a to 23,100 ML/a.	• Removal of large volumes of effluent from the Gulf have a significant positive impact on the coastal zone.	• Virtually no highly polluting sewage effluent enters the Gulf. • Stormwater control devices result in improved runoff water quality. • Only a fraction of pollutants that once entered the Gulf continue to do so.
Objective 5 Use groundwater no faster than it can be naturally replenished.	• Some larger growers secure attractive Asian export contracts. • A marginal increase in extraction is permitted (to 19,000 ML/a). • The potentiometric level declines with localised salinity increases. • Pumping costs increase. • Aquifer storage and recovery (ASR) does not proceed for many years. • Local expertise in ASR is lost to Government due to out-sourcing, staff cut backs and retirements. • Only a few ASR scheme are established by local governments; stormwater is treated to a high standard prior to injection.	• Consumption drops to around the sustainable yield of the tertiary aquifers. • Virginia Irrigation Trust Inc. assumes responsibility for conjunctive management of the groundwater and reclaimed water. • Reduced downward leakage from degraded wells. • Reduced upward leakage from the underlying tertiary (T3) aquifer • Reduced lateral flow from the saline aquifer margins. • Waiving of the enforced back-filling of some wells. • Reduction in pumping costs.	• Groundwater management occurs at a State level through groundwater management boards. • Groundwater extraction is reduced to the rate of natural replenishment. • Aquifer storage and recovery systems become widespread, with treated effluent and stormwater injected under pressure using dual injection-recovery well systems. In excess of 6,000 ML is recharged each year. • ASR schemes increase the allowable extraction by 80 percent of the injected water volume. • Many of the other benefits similar to those in Scenario B.
Objective 6	• Major expansion in employment and	• Expansion of employment in the	• MFP encourages local investment in

Performance Measure	Scenario A	Scenario B[1]	Scenario C
Support growth in 'clean' industrial development and employment.	services at Elizabeth regional centre. • New industries take advantage of industry clusters and the infrastructure built or programmed to support this projected economic activity.	construction (500 jobs), horticultural and support industries (1,300 jobs). • Predictions of between 1,200 and 3,100 new jobs throughout the State.	the clean, high technology areas of electronics, information technology, education and environmental management bringing with it many new jobs and export dollars. • New industries establish throughout the region, taking advantage of the new infrastructure and technologies. • Relaxation of land zoning provisions leads industry to move to their employees and resources. • Industry is subject to environmental 'performance' standards and heavy penalties. Closed loop production systems and a high level of recycling become the goal of industry. • Many more permanent and part time job opportunities, particularly for women and the elderly. • Some crude barter systems become re-established within urban clusters.
Objective 7 Develop urban areas for greater choice in housing styles, effective transportation and community living.	• Conventional patterns of residential and urban development. • Growth along a north-south axis between Salisbury and Gawler township. • Residential development at Angle Vale and in the Two Wells–Lewiston district. • Fewer persons per household, so more dwellings are required. • Population increases from 230,680 in 1996 to 317,150, including 11,000 people at MFP's 'Mawson Lakes'. • Urban area increases by 3,435 hectares from 11,823 to 15,258 ha.	As for Scenario A.	• Fewer persons per household, so more dwellings are required. • Population increases from 230,680 in 1996 to 317,150, including 11,000 people at MFP's 'Mawson Lakes'. • Development of new urban areas in form of urban villages. • Urban area initially increases, but ultimately reduces by 3,294 hectares from 11,823 to 8,529 ha. • Housing demand shifts away from the common detached house towards more compact dwellings. • Shift away from the car to public transport: local transport focussed on

Performance Measure	Scenario A	Scenario B[1]	Scenario C
	Rezoning of some Rural Living land to Residential is necessary. • Urban consolidation provides only 5 percent of new dwellings. • Traffic congestion increases. • The car remains the dominant form of personal mobility, requiring major investment in the road network. • There is little sense of community among the inhabitants of the northern suburbs.		centres of commercial and social activity centres; complimented by a mass transit/ freight system joining the industrial and metropolitan centres. • Residential streets are narrower and designed for slower speeds. Greater inter-connectivity of streets providing flexibility in route selection and less congestion.
Objective 8 Ensure that the project is commercially beneficial.	• More pumping from River Murray raises the cost of salinity consumers. • Old water mains are replaced and the system extended to Two Wells and the greater Evanston area. • Duplication of the Gawler to Elizabeth trunk sewer is required. • High costs of Bolivar WWTP upgrade, including new outfall and odour control measures. • Expenditure on stormwater drainage infrastructure increases in response to the rapid rate of urban development.	• Costs of BNR upgrade for Bolivar are reduced. • Funding primarily by private investors under a BOOT scheme, as well as Commonwealth Government. • Annual contribution of $4 million is required from State Government. • Financially self sustaining scheme after 20 years. • Doubling of farm-gate production to over $100 million per year.	• Drop in consumption means reduced cost of pumping water from the River Murray. • 20% reduction in the costs of water filtration and purification. • Ageing water mains are replaced with smaller pipes, reducing the immediate and long term replacement cost. • Bolivar BNR option is cheaper, and a new marine outfall and diffuser are not required. • Construction costs of trunk storm drainage facilities are substantially reduced by adopting multi-purpose, open channel drainage forms. • Urban renewal and re-engineering an area for smaller allotments can be very expensive compared to conventional housing developments.
Objective 9 Charge a price for a product or service that reflects the true or full cost of provision.	• Marginal price of water increases significantly between 1996–2020. • The cost of groundwater extraction remains constant, neither promoting efficiency in use or preservation of	• Users have 'take and pay' agreement with the Irrigation Trust, ensuring equitable use of the water but not committing users beyond reasonable commercial terms.	• New taxes and subsidies are introduced to internalise the environmental costs of production. • Tradeable environmental release permits are sold on the free market.

Performance Measure	Scenario A	Scenario B[1]	Scenario C
	the quality of the resource. • Government loses around $760,000 each year in the management of groundwater and consumer licensing. • Transport service prices rise and reflect full commercial rates.	• A 'resource charge' of 3 cents/kL is imposed for all groundwater withdrawals to ensure a competitive edge for the reclaimed water. • Annual license and connection fees are charged to all classes of users. • Annual Access Fees are also charged to non-groundwater license holders to reflect the cost of establishing and maintaining groundwater bores, placing all users on a relatively even financial footing. • Financial gain to State Government and tax payers by virtue of being relieved of the costs of licensing and management of groundwater users.	• Industrial facilities must treat wastewater to the quality of domestic sewage before disposal to sewer. • Revenue raised through such taxes is redistributed through the community. • Variable pricing is introduced on many goods and services, including electricity and water supplies. • Developers find allotments with good views or effective open space command higher prices, partially off-setting higher development costs.
Objective 10 Ensure easier access to public services, recreational and open space.	• 12.5% open space remains a standard feature of urban areas. • Shops and services are concentrated on arterial roads. • Some improvement in local bus services, but patronage drops in all but peak times. • Private operators have introduced higher trip fares.		• Services return to the local level and well served by public transport. • The 'corner shop' and other convenience stores re-emerge. • Shopping malls loose their grasp over their car dependent shoppers. • The condensed urban form caters for the needs of women, the elderly, children and the disadvantaged. • Greater safety on the streets during the day and night. • The open spaces that are provided are designed to be more effective for passive and active recreation.

(1) As for Scenario A except where additional information provided.

Table 11.9
Summary of Development Costs as Present Value by Scenario

Item of Infrastructure or Operational Expenditure	Scenarios A and B, PV $m			Scenario C, PV $m		
	Dry Years	Average	Wet Years	Dry Years	Average	Wet Years
Pumping from River Murray	18.45	10.03	1.02	10.12	3.24	0.00
New water supply trunk mains	7.29	7.29	7.29	4.75	4.75	4.75
New mains in Gawler rural areas	3.10	3.10	3.10	0.00	0.00	0.00
Existing water main replacement	7.26	7.26	7.26	4.74	4.74	4.74
Water treatment	19.59	18.30	17.28	16.18	15.12	14.37
Bolivar WWTP BNR upgrade	89.66	89.66	89.66	80.70	80.70	80.70
Plant upgrade for odour control	20.01	20.01	20.01	0.00	0.00	0.00
Extended ocean outfall and diffuser	36.16	36.16	36.16	0.00	0.00	0.00
Trunk sewer augmentation	12.00	12.00	12.00	0.00	0.00	0.00
Wastewater treatment	24.47	22.84	21.81	23.80	22.22	21.22
New wastewater treatment plants	0.00	0.00	0.00	62.90	62.90	62.90
Dual water supply system	0.00	0.00	0.00	34.72	34.72	34.72
Stormwater drainage	112.79	112.79	112.79	81.21	81.21	81.21
Injection/recovery wells for ASR	0.00	0.00	0.00	10.74	10.74	10.74
Sub-Total (Scenario A)	350.78	339.44	328.38	329.85	320.33	315.34
Virginia Pipeline Scheme[1]	116.87	116.87	116.87	0.00	0.00	0.00
Less Conventional Bolivar Upgrade	-89.66	-89.66	-89.66	0.00	0.00	0.00
Sub-Total (Scenario B)	377.99	366.65	355.58	329.85	320.33	315.34
Residential Infrastructure Development	309.41	309.41	309.41	980.28	980.28	980.28
Total - Scenario A	**660.20**	**648.85**	**637.79**	-	-	-
Total - Scenario B	**687.40**	**676.06**	**664.99**	-	-	-
Total - Scenario C	-	-	-	**1,310.13**	**1,300.61**	**1,295.62**

(1) Capital cost of $41.6 million and O&M of $1.045 million, plus Bolivar plant upgrades at capital cost of $45.04 million and O&M of $2.86 million.

Table 11.10
Real Marginal Price of Water over the Period 1996–2020 in ¢/kL (1996 dollars)

Water Resource	Scenario A	Scenario B	Scenario C
Mains potable water	90 - 219	90 - 219	90 - 262
Treated sewage effluent	0.59[1]	10 - 23[2]	50[3]
Groundwater	6[4]	9[4]	12[5]
Stormwater with ASR[6]	25	25	25

(1) From EWS (1993) Reclaimed Water Use in South Australia
(2) Distribution of additional infrastructure costs over users of metropolitan Adelaide sewerage system.
(3) On the basis of the construction and operation of a dual water supply system with treated effluent supplied by municipal scale wastewater treatment plants.
(4) Based on current O&M costs. Increased in Scenario B due to a 'resource charge' (refer to Section 11.2.9)
(5) Calculated construction and operation costs of an ASR scheme, distributed over all groundwater users.
(6) Covers all construction and O&M costs of ASR; storage costs not included as these are an integral part of stormwater control measures. Based on design estimates and experience of Emmett et al (1996) and others.

Table 11.11
Summary of Accumulated Water Purchase Costs to Consumers

Present Values[1], $m	Scenario A	Scenario B		Scenario C
		VPS Costs Only	Inc. Bolivar[2]	
Mains Water Consumption	555.6	555.6	555.6	499.5
Sewage Effluent Consumption	0.17	27.6	91.0	23.6
Groundwater Consumption	13.2	10.8	10.8	9.0
Stormwater Consumption	14.8	14.8	14.8	37.9
Total	**583.7**	**608.8**	**672.2**	**570.0**
Increase over Scenario A, %		4.3	15.1	-2.4

(1) Assuming a discount rate of 7.95% over the study period of 1996–2020 (25 years).
(2) Includes the full cost of wastewater treatment at Bolivar prior to supply to the Virginia Pipeline Scheme, rather than only the costs of additional treatment and distribution of the reclaimed water.

12

Trial of the MESA Methodology

12.1. The Adopted Trial Methodology

To test the functionality and value of the MESA methodology, the technique was trialed using the urban development scenarios formulated for the Northern Adelaide Plains, with the participation of the community who live and work in the study region.

Having developed the three scenarios or alternatives for comparison, the next step was to identify the performance or assessment criteria, ensuring that the criteria addressed the salient issues associated with each scenario and the region generally. The importance of each criterion was then established via a program of community consultation. The performance of each scenario with respect to the assessment criteria was determined by an Assessment Panel comprised of selected professional practitioners. These activities provided the information required to assess the value of each alternative development scenario using the MESA technique.

The outcome of the assessment was documented for distribution to the Assessment Panel for reflection on the findings and comment on strengths, weaknesses and value of MESA. Each phase of this process is discussed in more detail below.

12.2. Selection of the Assessment Criteria

Careful consideration was given to the selection of the assessment criteria, as they needed to reflect conditions and issues that were significant to the region and upon which the community would generally possess an opinion.

Many issues that are significant in a regional sense relate to the existing, adverse environmental impacts of development and socio-economic disadvantage (refer to Chapter 6). Clearly any development proposal that would be desirable under these circumstances should contribute to alleviation of the adverse environmental impacts and to the improvement of socio-economic circumstances. Each development scenario could contribute to these objectives to varying degrees. It was therefore important to identify means by which each development alternative could achieve positive progress, and that these contributions could be compared on the same

basis, i.e. compare "apples with apples". With this in mind, a preliminary set of objectives and associated performance criteria was established.

It was equally important, however, not to overlook or discount significant costs or benefits that may characterise only one scenario and thereby make it preferable to another. Therefore, each scenario was considered in turn, and a list generated of its pros and cons. A secondary set of objectives and performance criteria was compiled.

Both lists were integrated, and similar objectives combined to form a shortened list for further consideration. This list was reviewed with regard to the 33 sustainability evaluation criteria previously developed (refer to Chapter 4). Consideration was also given to the particular objective and wording of each criterion, in an attempt to ensure that each was unique. The result of this process was the selection of a reduced list of 10 unique assessment criteria, listed in Table 12.1. The criteria have been expressed as goals for development against which the performance of each development scenario can be assessed. The criteria were listed by theme; their order does not reflect a ranking of any sort.

Table 12.1
Scenario Assessment Criteria

Objective	Description of the Criterion
Objective 1	**Use land with fertile soils for agriculture, not urban development.** *Land that has rich, fertile soils that are ideal for cropping should be kept for that purpose and not consumed for housing, displacing farming to less suitable land. In many instances, these soils are not good for building upon, and are also found on floodplains where urban development is at risk of flooding.*
Objective 2	**Retain areas of existing habitat and restore other areas for native plants and animals.** *Native habitat has been cleared from 80% of South Australia, and up to 95% in some regions. To provide habitat for preservation of native plants and animals, protection of fragile ecosystems and maintenance of biological diversity, existing remnant vegetation should be kept and other areas re-planted with native species.*
Objective 3	**Conserve water, and recycle stormwater and treated sewage effluent for productive uses.** *Each year, around 40% of the water consumed in metropolitan Adelaide is pumped from the River Murray because the water collected in reservoirs does not meet demand. Yet the combined volume of stormwater and treated sewage effluent far exceeds Adelaide's total consumption. By adopting simple domestic water conservation measures, and using stormwater and treated effluent for safe applications such as irrigation, our water resources will be used more efficiently.*
Objective 4	**Reduce the impact of wastewater disposal on the coastal zone including fishing grounds.** *Discharge of urban stormwater and sewage effluent to the sea is killing marine life, resulting in deterioration of our beaches and decline in fish stocks. If pollution of coastal areas is not reduced, the marine environment and fishing industry will be damaged beyond repair.*

Table 12.1 continued
Scenario Assessment Criteria

Objective	Description of the Criterion
Objective 5	**Use groundwater no faster than it can be naturally replenished.** *Water stored in aquifers is extracted for use in industry or irrigation. The volume of stored water is often very large, but is naturally replenished at a very slow rate. Extracting the groundwater faster than the rate of natural replenishment results in poorer water quality, greater cost of extraction and could 'dry up' the source. Using the water at a slower rate would ensure the resource is available and of good quality in the future.*
Objective 6	**Support growth in 'clean' industrial development and employment.** *Supporting the growth of 'clean' industries and improving the environmental performance of existing industry, can produce new jobs and income, reducing unemployment and improving the economy.*
Objective 7	**Develop urban areas for greater choice in housing styles, effective transportation and community living.** *The form of conventional urban areas is causing destruction of the ecosystems that support our economy and life on Earth. Urban areas can be developed with a mix of dwelling styles to house our diverse population, not just the '3 bedroom home on a quarter acre block'. Walking and cycling would be good ways to get around. Other mass transit systems could enable fast transit between urban centres, and less need for cars. Urban areas could also be socially and culturally rewarding, providing greater sense of community in a more healthy environment.*
Objective 8	**Ensure that the project is commercially beneficial.** *Before deciding to proceed with a programme or project, its commercial viability should be guaranteed by undertaking a cost-benefit or financial study. The financial benefits produced by the development should exceed the costs.*
Objective 9	**Charge a price for a product or service that reflects the true or full cost of provision.** *The price charged for products or services provided by government can be less than it costs to provide them. These lower prices can result in consumption at a higher rate than is socially or environmentally desirable. Also, the cost of providing the service is not being covered, so there is not enough money to pay for repair, replacement or expansion of the service when it is required. Charging a true or full price would solve this problem.*
Objective 10	**Ensure easier access to public services, recreational and open space.** *Our sprawling suburbs and ineffective transport systems can make it difficult for people, particularly the disabled or aged, to get to public facilities such as libraries or parks that are often few in number or centralised away from where we live. It is possible to make it easier for everyone to access government services, banking, shopping, parks and libraries if we change the way cities are built so that the local communities become the focus of daily life.*

12.3. Community Views on the Assessment Criteria

According to the MESA method, the relative importance of each assessment criterion is indicated by its weighting. By allowing the general public to set the values of the weights, their values, views and aspirations can be incorporated into the assessment.

12.3.1. Community Consultation Program

A community consultation program was developed to gauge the importance of each assessment criterion. The objectives of the program were:

1. to determine the relative importance of each assessment criterion to the communities residing within the study area, primarily the northern Adelaide plains;
2. to consult a population sample that was representative of the entire NAP population in terms of spatial and age distribution;
3. to obtain feedback from a sufficiently large sample population to enable calculation of meaningful statistics;
4. to determine the accessibility or ease of completion of the pair-wise comparison method used in calculation of the weights; and
5. to effectively complete the consultation program in the limited timeframe.

The initial task was to identify the spatial and demographic distributions of the NAP population. With this understanding, and considering that a sample population numbering between 200 and 300 persons was sufficient to meet objective 3, the characteristics of the sample population were determined. Further details are provided in Section 13.3.2.

Consultation of community groups, rather than one-to-one interviews or mailed surveys, was thought to be the most effective means of simultaneously meeting objectives 2 and 5. A carefully selected group of community organisations, sporting and interest groups and schools were identified, via information supplied by local government, for invitation to participate in the survey. The community groups were subsequently contacted and invited to participate in the consultation program.

To enable the community groups to better understand the process and objectives of the consultation program, a short brochure was prepared for distribution, which was accompanied by an example of the questionnaire. Samples of the brochure and questionnaire are contained in Appendix P.

As previously mentioned, the pair-wise comparison process initially developed by Saaty (1972) was used to determine the criteria weights. The survey form contained in Appendix P was developed to facilitate this pair-wise comparison process. Only the right hand portion of the comparison matrix was presented, because the response matrix is symmetrical around the top-left to bottom-right diagonal axis; refer to Chapter 4 for further details.

The criteria assessment form was attached to a questionnaire seeking general personal details for statistical purposes, such as age, sex and income. The questionnaire was structured according to good social survey practice (Davies & Kempnich, 1991) and categories were generally selected to be consistent with those reported by the Australian Bureau of Statistics (e.g. income brackets). In order to maintain the anonymity of the participants, their names and home address were not required but would be provided if feedback on the survey was sought.

A short presentation was made to each group prior to undertaking the questionnaire, to brief the participants on the objectives of the research and the process of completing the questionnaire. In addition, further explanation was provided for each criterion to ensure that it was fully understood, and in many instances questions and extensive, fruitful discussion followed. The participants were then requested to respond to the questionnaire (with advice as required), which typically took around 30 minutes to complete. An entire group could typically be completed in less than 1 hour.

12.3.2. The Sample Population

The spatial and demographic distribution of the population within the study region of the NAP was determined from historical statistical data; refer to Chapter 6. From this data it was further determined that over 55 percent of the population resided in Salisbury, with around 20 percent in Munno Para, 15 percent in Elizabeth and the remaining 10 percent in Gawler. Notably, more than 80 percent of the population are younger than 50 years, with just over one third of the population being younger than 19 years of age!

The characteristics of the sample population were derived directly from this statistical data, to provide roughly the same age profile and local government mix as for the regional population. This sample population is summarised in Table 12.2.

Table 12.2
Characteristics of the Target Population for Consultation

Community Group	Elizabeth	Gawler	Munno Para	Salisbury	Total
Children & youth (0-19 yrs)	14	9	19	57	99
Young Adults (20-29 yrs)	8	5	11	31	55
Middle Aged (30-69 yrs)	19	12	26	77	133
Elderly (over 70 yrs)	2	1	3	8	13
Total Target Population	43	26	58	173	300

Residents associations and Parent Councils from schools were included in the list of community groups to be targeted for involvement, however, it was found that community service organisations such as Rotary International, Lions and Apex were most willing to participate (within existing scheduling constraints). Those groups that were ultimately involved in the consultation program included:

- Para Hills High School
- Salisbury High School
- Smithfield High School
- Gawler High School
- Rotary Club of Munno Para
- Rotary Club of Elizabeth
- Apex Club of Gawler
- Residents Association of Andrews Farm

The actual number of participants according to age bracket and LGA of residence is summarised in Table 12.3. It can be seen that the response target for the 'Children & Youth' category was achieved; the survey unfortunately failed to enlist sufficient support from adults to obtain the desired response.

Table 12.3
Population Involved in the Consultation Program

Community Group	Elizabeth	Gawler	Munno Para	Salisbury	Total
Children & youth (0-19 yrs)	8	22	27	42	99
Young Adults (20-29 yrs)	3	12	6	2	23
Middle Aged (30-69 yrs)	6	2	12	2	22
Elderly (over 70 yrs)	2	0	0	1	3
Total Population Consulted	19	36	45	47	147

The participation of school children was considered valuable and necessary given that their age group constitutes a significant fraction of the overall population, and that future development decisions are most likely to impact most upon this group. The participation of senior school (Year 11 or 12) students was sought, however, to ensure that the views were as far as possible, founded upon knowledge of the region, associated issues and current affairs.

Although there are approximately equal numbers of males and females in the study region, the sample population was biased toward males with only 39% being female. The participation of groups with both male and female representation, as well as solely female membership (such as Zonta and Country Women's Association) was deliberately sought. Unfortunately, the representatives contacted from these groups indicated that they were unwilling to be involved in a survey of this nature, and indeed in consultation generally. Organisations that represent the elderly members of the community (such as Probus) were similarly disinterested.

12.3.3. The Consultation Response

From the groups surveyed, responses were provided by 147 people. Eleven (11) of these responses (or less than 8%) were rejected due to unreliable data or an incorrectly completed response. (Data were generally considered to be unreliable if clear logical inconsistencies were apparent, typically due to lack of consideration or interest in the survey by school students.) A small number of the rejected responses were found to have been provided by the more elderly participants, some of whom had commented that their lifestyles rarely required them to think in such an analytical way and hence they had some difficulty focussing upon the method of response. From the survey responses, observations and discussions with participants, it was concluded that the style of questionnaire generally provided little difficulty of understanding or response, regardless of occupation or level of education.

The matrices of survey responses were transferred into a spreadsheet database. Each response matrix was analysed to determine the eigenvector corresponding to the maximum eigenvalue; refer to Chapter 4 for an explanation of this approach. Saaty (1977) showed that the resulting eigenvector is a ratio scale for the criteria under consideration, i.e. a set of relative weights.

It was found that the eigenvectors tended to be similar irrespective of characteristics such as sex, income, age or community group. Issues of water conservation and reuse, the impact of wastewater discharges on the coastal zone, and habitat protection and restoration were considered to be most important. Economic issues such as cost recovery were, by comparison, considered less important. Figures 12.1 and 12.2 illustrate these findings.

An average was calculated from the participants' responses for each criterion to produce a single set of weights reflecting the importance of the individual criterion for the whole group. The vector of weights was normalised so that the sum of the weights equalled the number of criteria. The weights for each criterion are presented in Table 12.4.

Table 12.4
Criteria Ranked by Community Assigned Weights

Abbreviated Descriptions of the Criteria	Rank	Eigen-vector	Criterion Weights
Objective 2: Retain areas of existing habitat and restore other areas.	1	0.680	1.485
Objective 4: Reduce the impact of wastewater disposal on the coast.	2	0.670	1.463
Objective 3: Conserve water, and recycle stormwater and effluent.	3	0.639	1.396
Objective 5: Use groundwater no faster than naturally replenished.	4	0.521	1.138
Objective 6: Support 'clean' industrial development & employment.	5	0.455	0.994
Objective 1: Use land with fertile soils for agriculture, not urban dev.	6	0.425	0.930
Objective 7: Develop more effective and livable urban areas.	7	0.348	0.760
Objective 10: Ensure easier access to public services and open space.	8	0.316	0.691
Objective 8: Ensure that the project is commercially beneficial.	9	0.285	0.624
Objective 9: Charge the true or full cost of service provision.	10	0.239	0.523

Statistics indicate that those more important criteria (i.e. Criteria 2, 3 and 4) have a distribution of weights (as eigenvector values) that is skewed to the left. Conversely, the weight distributions for the criteria of lesser importance are skewed to the right. In addition, there is less variability of importance associated with Criteria 2, 3 and 4 than to Criteria 8, 9 and 10. That is, the sampled population demonstrated greater collective certainty about the importance of Criteria 2, 3 and 4.

A further observation is that each criterion was ranked as the most important by at least one respondent, with the notable exception of Criterion 9 (relating to true or full cost pricing) which was also the least important criterion. Criteria 3 and 4 (ranked second and third overall, respectively) possessed the highest, minimum weight from any individual respondent.

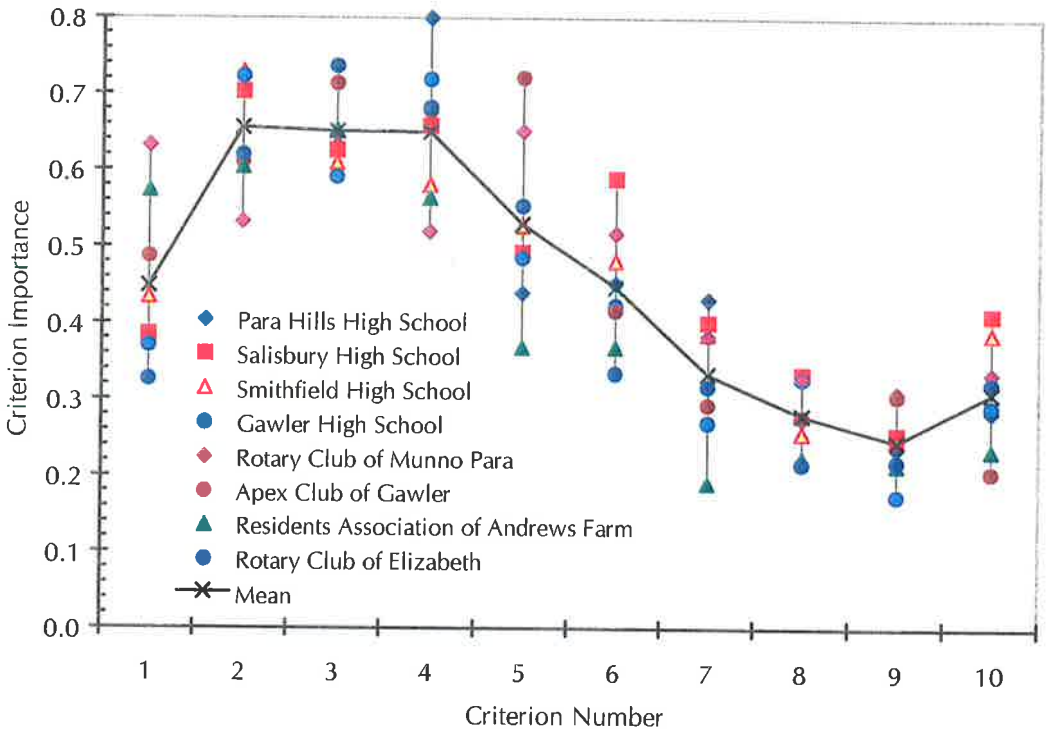


Figure 12.1
Criterion Weights by Community Group as Eigenvector Values

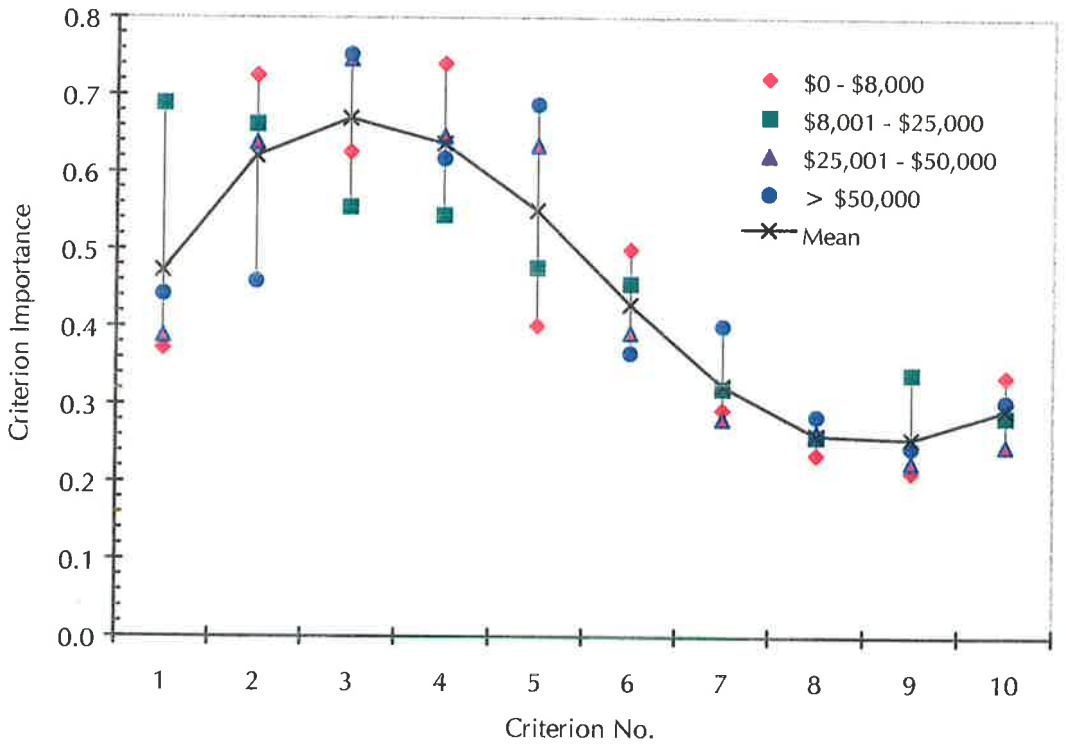


Figure 12.2
Criterion Weights by Income Bracket as Eigenvector Values

These statistical findings tend to indicate some uniformity of the strength of opinion amongst the surveyed population. This result is supported by observations during the survey events – the survey was addressed in a serious manner by the majority of respondents, with a considerable amount of time spent with some groups in discussion and constructive debate over the issues associated with the assessment criteria. It was clear that the participants were interested and the issues were topical.

Indeed, the community consultation whole is considered to have been successful in determining community sentiment on development issues, irrespective of the reduced size of sampled population and small percentage of 'informal' responses. The pair-wise comparison method used to make judgements on the importance of each criterion has been demonstrated to be accessible to the majority of the sampled population, and useful in obtaining a relative ranking of criterion importance. The consultation program has therefore been effectively completed in the limited timeframe, meeting another consultation objective.

12.4. Scenario Evaluation Against the Assessment Criteria

12.4.1. The Evaluation Process

An experienced, high profile, multi-disciplinary panel of 6 professionals was formed to assess the development scenarios according to the MESA methodology. The members of the Panel were selected on the basis of their particularly relevant and extensive experience, such that their combined knowledge and understanding would enable an accurate assessment of the value of each alternative development scenario. Each member of the Panel was required to assess the 'performance' of the existing conditions and each alternative development scenario against only those criteria within their field of expertise. The members of the Assessment Panel are listed in Table 12.5.

Table 12.5
Membership of the Professional Assessment Panel

Panel Member	Organisation	Area of Expertise
Mr Michael O'Connell	City Planner, City of Adelaide	Urban and Strategic Planning
Ms Angela Hazebroek	Manager, Northern Adelaide Regional Organisation of Councils	Social Planning and Community Consultation
Ms Kathryn Bellette	Principal Adviser - Stormwater, SA Environment Protection Authority	Environmental Science and Habitat Issues
Mr Nabil Gerges	Senior Hydrogeologist, South Aust. Mines & Energy Department	NAP Groundwater Systems
Mr Harry Pitrans	Manager - Engineering, City of Tea Tree Gully	Urban Infrastructure and Stormwater Management
Mr Bob Ritchie	Principal Consultant, Dept of Premier & Cabinet, SA Government	Public Accountability / Economics

The Assessment Panel was involved in a staged process of evaluation, which incorporated both an assessment of the development scenarios as well as of the MESA methodology itself. In particular, the evaluation process included:

- ***An Introduction to MESA***
  Postal distribution of brochures introducing the MESA methodology to the Assessment Panel so that an understanding of the method was held prior to the workshop. These brochures are contained in Appendix Q.

- ***Meeting of the Assessment Panel***
  An initial meeting or workshop for the Assessment Panel, including an informal presentation explaining the theoretical and practical application of the MESA method. Documentation of the alternative water management strategies was distributed, and a brief introduction to each alternative provided.

- ***Assessment of Alternative Strategies Using MESA***
  Each member of the Panel undertakes an assessment of the alternative strategies using only those assessment criteria that fall within their area of expertise. Assessment results are returned on the form provided. Discussion between members of the Assessment Panel is encouraged; contact details were provided with the option of holding a second workshop if required.

- ***Distribution of Assessment Results & Questionnaire***
  The results of the MESA assessment were distributed by post for consideration by the Assessment Panel. A questionnaire was also included seeking feedback on the assessment process and outcomes.

- ***Assessment Process Complete***
  The final brochure is distributed to the Assessment Panel summarising the findings of the assessment process and questionnaire.

At the first meeting of the Assessment Panel, Chapter 11 was provided to all members of the Panel as descriptions of the alternative development scenarios. Chapters 6 and 7 were also provided for additional background information on social and environmental, or water resource issues respectively.

The document was supplemented by the extensive local knowledge of the Assessment Panel, most of whom had particular knowledge of the NAP region. In fact, to confirm the accuracy and credibility of the documented information, Panel members were invited to critique the baseline information and identify shortcomings or areas where amendments were possible. Some, however, were not able to provide corrections although they knew some of the information to be erroneous. In particular, some economic information was biased in favour of Scenario C.

12.4.2. Comments of the Assessment Panel

The initial response of the Assessment Panel was that the MESA matrix is a very useful and comprehensive assessment tool. The process of problem definition, establishment of objectives and criteria, development of strategies, and the testing

through qualitative and quantitative means was considered to be particularly valuable for consideration of development options.

In general, the view of the Assessment Panel was that the data and scenarios for infrastructure engineering and water resources management were accurate and comprehensive.

Comment was made on the scenarios presented for groundwater management. While the current circumstances and management policies were accurately reported, an alternative groundwater use policy could have been explored. The alternative scenario involve mining of the water stored in the unconfined system. The volume stored in the unconfined situation within the entire Tertiary aquifer system is many times greater than that currently termed the 'sustainable yield'. Gerges (1997) notes that the 'train of thinking' in which the aquifers would be mined is currently unacceptable to managers of water resources, largely because it is difficult for them to conceptualise.

Feedback from the Assessment Panel also confirmed that the interpretation and reporting of environmental and agricultural issues was accurate and representative of existing conditions. It was considered that a more comprehensive perspective of alternative development scenarios could have been provided had the problems of monoculture farming, use of agricultural chemicals, and general land management practices been explored. The possibility of replacing current practices with small local farms based on permaculture practices, and the possibility of harvesting local flora and fauna would also have added to the discussion.

While the profile work summarising the urban development and water features of the NAP was considered to be "extremely good", concerns were expressed over the socio-economic aspects of the alternative development scenarios. These concerns particularly related to issues of community and social impact. O'Connell (1997) notes that while there is socio-economic disadvantage in northern Adelaide, it is not the sole area experiencing such problems and there are strong community dimensions to the area. O'Connell considers that the scenarios have inherent problems, for there is a need to separately define each scenario but the aspects that are separate are "never totally one way or the other". A likely scenario was considered to comprise a mixture of those presented, with the future of the NAP including:

- continuation of conventional development and management practices in existing urban areas; with
- a significant shift to 'urban villages' or 'eco suburbs' in areas of new development; and
- the Virginia Pipeline Scheme substantially implemented in the proposed form.

Furthermore, it was considered by O'Connell that achieving higher density communities can be very difficult due to current market expectations, partly due to planning policy and decision making, and in the main due to falling numbers of persons per household. In addition, the growth scenarios do not incorporate migration out of the area to central and southern Adelaide, which he considers will be significant.

There was a general acceptance that 'urban villages' offer advantages over conventional urban development and sprawl, however the implementation of the concept is in reality influenced greatly by external decision making and government policies. It is noted that villages (like neighbourhoods) are a good planning concept but do not in themselves necessarily create community. For example, a rural district can have a strong community without a consolidated built form.

US and Queensland data support the adoption of urban villages for improved public transport use. At the intra-village level, the data indicates a shift from car to walking in villages (within 5 minutes) but not necessarily public transport. Hazebroek (1997) considers that local area public transport connected to rapid and frequent long distance bus and train services would be achievable.

The view was that higher levels of access to services and open spaces could be provided by the village style of urban form proposed under Scenario C. Although the area of open space may be reduced, better attention to its location and design would mean that more people will live close to and therefore use open space.

With regard to the issues of industrial and employment growth, quantitative assessment was not found to be easy because there are so many external, political and economic factors. It was anticipated, however, that if the Virginia Pipeline Scheme were to proceed, then more local income would be generated, likely to result in more community and recreation facilities, as has been evidenced with the expansion of the wine industry in Angaston and Tanunda in the Barossa Valley.

The assessment of performance against the economic issues was found to be equally difficult, due to the enormous range of subsidies and the complexity of the economic and political system. The adopted method of assessment is discussed below.

In summary, the initial feedback from the Assessment Panel has been positive regarding the MESA assessment process. Shortfalls or inadequacies have tended to relate to the social and economic impact assessment presented in the alternative development scenarios. The full commentary and assessment details provided by each member of the Assessment Panel are contained in Appendix R.

12.4.3. The Performance Evaluations

Each member of the Assessment Panel undertook an assessment of the performance of each scenario and the existing conditions against each of their allotted selection criteria. This involved the interpretation of the documented development scenarios and application of the data from the modelling exercise, together with their own personal experience and understanding of the issues, to rate the performance of each scenario.

Where numeric data existed, such as volumes of extracted groundwater or project costs, the data were used to establish the respective ends of the performance spectrum [0,1]. The levels of satisfaction under each scenario were then scaled

within this range according to the professional's judgement. In some cases, the assessment was purely subjective, based upon the detailed information provided for each scenario. In such a case, the value 0 on the range [0,1] is considered to correspond with the linguistic classification of a 'very bad outcome', whereas 1 corresponds to a 'very good outcome'. The performance ratings for the existing conditions and development scenarios are summarised in Table 12.6.

Because the MESA method aims to avoid placing monetary values on intangible items, the traditional cost-benefit analysis has been restricted in this case to an assessment of the commercial viability of each scenario, i.e. a financial analysis rather than an economic analysis. The focus is thus upon whether a project provides a financial return upon the investment, and does not place an arbitrary dollar value upon externalities.

Some uncertainty surrounds the financial assessment of the scenarios. Although considerable research and effort was directed into calculation of the capital and O&M costs of each development scenario, a detailed financial analysis was outside the scope of the research. For this reason, some assumptions were necessarily made about the distribution of financial costs and benefits during the assessment of the scenarios. In particular, the complexity of government policy, pricing strategies, taxes and subsidies and their affects upon cost recovery and resource allocation can rapidly complicate the issue. The financial assessment was, however, considered to adequately represent the relative merits of each scenario.

Performance ratings were provided to Criteria 1, 7 and 10 by two members of the Assessment Panel. Although the 'strength' of their opinions relating to the performance of each development alternative varied, the relative merits of each alternative were viewed similarly. An average was calculated directly from their responses to provide the performance ratings indicated in Table 12.6.

It is notable that no performance rating for the 'existing conditions' exceeded 0.5. That is, the conditions existing on the NAP, with respect to the 10 performance criteria, are considered to range from average to very poor.

A particularly poor performance was recorded against those issues relating to habitat and wastewater disposal.

Scenario A was considered to make no positive contribution to the achievement of any objective, and therefore exacerbates the existing mediocre conditions. In contrast, the conditions of Scenario B were seen to provide improvements over the existing conditions in most instances. Exceptions are the protection and restoration of native habitat; access to public services and open space; and housing and transport conditions. Some improvement in these three areas was considered to have occurred, however, relative to Scenario A. The benefits of Scenario B are largely a direct result of the elimination of effluent disposal to sea and its reuse for horticultural irrigation, or its consequential flow-on effects. Scenario B also provides the greatest economic benefits of any development alternative.

Table 12.6
Summary of Performance Evaluations

Criterion and Performance Description	Perf. Rating
Criterion No. 1: Use land with fertile soils for agriculture, not urban development	
Existing Conditions: Uncertain permanence of farming land with urban pressures	0.50
Scenario A: Gradual erosion of farming land by urban development	0.45
Scenario B: Virginia Pipeline Scheme improves productivity, value and permanence	0.70
Scenario C: Reduced pressure on land for development, ensuring continued farming	0.83
Criterion No. 2: Retain areas of existing habitat and restore others	
Existing Conditions: Ongoing marine degradation, no terrestrial habitat improvements	0.20
Scenario A: Ongoing marine degradation, no terrestrial habitat improvements	0.20
Scenario B: Improved marine environment, but no terrestrial habitat improvements	0.40
Scenario C: Improved habitat conditions, especially as LGAs redrawn to catchments	0.70
Criterion No. 3: Conserve water and productively recycle stormwater and effluent	
Existing Conditions: Poor stormwater & effluent reuse on average; poor conservation	0.32
Scenario A: Catchment plans have positive effects; poor conservation and effl. reuse	0.40
Scenario B: Improved stormwater and effluent reuse; conservation remains poor	0.52
Scenario C: Good levels of stormwater and effluent reuse and water conservation	0.68
Criterion No. 4: Reduce wastewater disposal impacts on coast and fishing grounds	
Existing Conditions: Serious coastal and marine degradation from effluent disposal	0.10
Scenario A: Some improvement from removal of nitrogen (not P) from effluent	0.20
Scenario B: More substantial reduction in nutrients and fresh water entering Gulf	0.50
Scenario C: Benefits through reduction in effluent generation and discharge	0.70
Criterion No. 5: Use groundwater no faster than it can be naturally replenished	
Existing Conditions: Current groundwater extraction rate thought to be unsustainable	0.36
Scenario A: Continuing or Increased over-extraction exacerbates pressure decline	0.29
Scenario B: Groundwater extraction returns to near sustainable yield	0.70
Scenario C: Groundwater recharge exceeds sustainable yield and pressures rise	1.00
Criterion No. 6: Support growth in clean industrial development and employment	
Existing Conditions: Industry env'l standards met if necessary, employment problems	0.50
Scenario A: Few new industry clusters in Elizabeth; some infrastructure development	0.40
Scenario B: Industrial (agriculture) and employment growth with effluent reuse	0.70
Scenario C: Industry and employment diversification; benefits not as high as Scen. B	0.60
Criterion No. 7: Provide greater choice in housing, transport and community living	
Existing Conditions: Socio-econ. disadvantaged but generally cohesive community	0.40
Scenario A: Trend to urban consolidation and alternative housing	0.35
Scenario B: Improved housing and community with more local income	0.40
Scenario C: Transport use & housing choice improved, community change unknown	0.85
Criterion No. 8: Ensure that a project is commercially beneficial	
Existing Conditions: Problem covering repair or construction of public infrastructure	0.50
Scenario A: Public infrastructure extended as required	0.50
Scenario B: Substantial private investment with good return for growers and region	0.63
Scenario C: Cheaper public infrastructure but much higher house allotment costs	0.36
Criterion No. 9: Charge a price that reflects the true or full cost of service provision	
Existing Conditions: Marginal costs of operating public infrastructure are covered.	0.50
Scenario A: Marginal costs of operating public infrastructure remain covered.	0.50
Scenario B: Resource charges increase revenue and reflect true cost; costs covered.	0.53
Scenario C: Some good pricing measures; income covers cost, but costs are higher.	0.46
Criterion No. 10: Ensure easier access to public services, recreational & open space	
Existing Conditions: Quantity not quality of open space; some local centres exist	0.40
Scenario A: Open space req'ts are more site specific and more local centres emerge	0.35
Scenario B: Open space & rec. Facilities probably improve with more local income	0.40
Scenario C: Improved access to open space and services and better urban amenity	0.85

Scenario C appears to rate most highly against the assessment criteria, with the exception of the economic, employment and industry issues on which it rates below Scenario B. Scenario C offers some substantial improvements in the areas of urban development, access to public facilities and open spaces, agriculture, and the use of groundwater resources.

These performance ratings were combined with the criterion weights using the MESA matrix. These results of the consolidated option assessment are discussed below.

12.5. The Preferred Scenario According to MESA

The MESA matrix containing the criterion weights and scenario performance ratings is included as Table 12.7. The following discussion is based upon the information contained in this matrix.

The performance ratings for the existing conditions are multiplied by the rating for each scenario by criterion; this mathematical product corresponds to the linguistic 'and' condition. This takes into account the potential cumulative impact that a development alternative might have over existing circumstances. Raising this product to the power of the criterion weight serves to further modify the rating and incorporate the importance of each criterion in the overall result. The minimum such value for a particular development alternative is referred to as the 'Minimal Aggregation'.

On the basis of the Minimal Aggregation alone, Scenario C was superior to Scenario B, which was also superior to Scenario A or maintenance of the existing conditions. Scenario A provides marginal benefit over perpetuation of the existing conditions.

A similar result occurs when the importance of the selection criteria are taken into consideration via the Dominance Matrix. Now, however, it becomes clear that Scenarios B and particularly C offer substantial improvements over either the perpetuation of the existing conditions or Scenario A. Furthermore, Scenario A is determined to be regressive with respect to the existing conditions, in line with the observations of individual performance ratings discussed above.

The Virginia Pipeline Scheme and other developments that constitute Scenario B are found to have the potential to substantially improve the conditions on the NAP. The benefits exist as economic gains, effective financial cost and benefit distribution, improvements in agricultural productivity, and gains in industry and employment.

Yet greater cumulative benefits could be achieved by the adoption of development measures proposed under Scenario C. According to the final measure of project performance – the Modified Fuzzy Minimal Aggregation – Scenario C has twice the benefit of Scenario B, and very many times greater than Scenario A.

Table 12.7
MESA Matrix for NAP Development Scenarios A to C

No.	Assessment Criteria	Criterion Weight	Existing Condition	Project Performance			Fuzzy Set Combination			
				Scenario A	Scenario B	Scenario C	Make No Changes	Scenario A	Scenario B	Scenario C
1.	Use of fertile land for agriculture	0.930	0.50	0.45	0.70	0.83	0.276	0.250	0.377	0.442
2.	Maintain and develop habitat	1.485	0.20	0.20	0.40	0.70	0.009	0.009	0.024	0.054
3.	Efficient water use and reuse	1.396	0.32	0.40	0.52	0.68	0.042	0.057	0.082	0.119
4.	No wastewater disposal to sea	1.463	0.10	0.20	0.50	0.70	0.002	0.004	0.013	0.021
5.	Sustainable groundwater use	1.138	0.36	0.29	0.70	1.00	0.098	0.077	0.209	0.313
6.	'Clean' industry and employment	0.994	0.50	0.40	0.70	0.60	0.253	0.202	0.353	0.303
7.	Env. friendly urban renewal	0.760	0.40	0.35	0.40	0.85	0.249	0.225	0.249	0.441
8.	Commercial viability	0.624	0.50	0.50	0.64	0.39	0.422	0.422	0.492	0.361
9.	True or full cost pricing	0.523	0.50	0.50	0.54	0.45	0.485	0.485	0.505	0.459
10.	Easy access to public spaces	0.691	0.40	0.35	0.40	0.85	0.282	0.258	0.282	0.475
						Minimal Aggregation =	0.002	0.004	0.013	0.021
						o Changes 20.269	-	2.859	8.553	8.857
						Scenario A 23.374	4.513	-	10.004	8.857
						Scenario B 7.863	0.000	0.000	-	7.863
						Scenario C 4.435	1.147	1.147	2.141	-
						Maximum Dominance = 30	5.660	4.006	20.698	25.577
						Dominance Factor =	0.062	0.030	0.510	0.727
						Modified Fuzzy Minimal Aggregation =	0.12	0.12	6.63	15.3
						Project Rank =	3	4	2	1

In all instances, the issue of wastewater disposal to sea is of considerable importance and an important factor in the identification of a preferred course of development. This issue has nearly the highest criterion weight and the lowest performance rating of an 'existing condition'. Clearly, this issue must be addressed and mitigated for any development on the NAP to contribute to regional growth in an holistic sense.

Scenario C would be recommended as the primary direction for future development of the Northern Adelaide Plains.

12.6. Feedback on the MESA Process and Outcomes

As previously mentioned, the results of the MESA assessment were distributed for consideration by the Assessment Panel. A questionnaire was included seeking feedback on the assessment process and outcomes. An example of this questionnaire is provided in Appendix Q; the results are presented in Appendix R. The discussion below is a summary of the combined views of the Assessment Panel.

12.6.1. Decision Making Processes

Through the questionnaire, the Assessment Panel indicated that the 'best' development option could not be identified from a range of alternative projects on the basis of an economic analysis alone. Rather, social and environmental impacts must also be addressed. A quantitative assessment of social and environmental issues was considered to be beneficial, desirable and superior to a subjective analysis. A consensus was not reached on the acceptability of using estimated monetary values for intangible items (such as scenic beauty) in cost-benefit analysis and project selection processes.

It was considered that the public sector could benefit from the use of a tool such as MESA. By supporting MESA with a statement of the influence that (estimated) social and environmental impacts had on a final decision, the transparency of decision making would be enhanced, thereby strengthening democratic processes.

Decision making on development proposals by a team of professionals, without public involvement, was considered to be unacceptable. Technical experts can overlook or be insufficiently sensitive to certain aspects of any major development proposal. Public involvement is therefore desirable, if only to highlight important issues. At the same time, a majority of the Panel members felt that there are insufficient opportunities for the general public to become involved in the decision making process. Community consultation was thought to be more like community information, with inadequate mechanisms to provide for public feedback. Going through the motion of consultation was often seen as the aim rather than consultation itself. Bellette (1998) comments that community consultation feedback is often used in minor ways to promote changes at the fringe but not to make 'yes' or 'no' decisions. Where feedback is received, all responses (rather than a subset) should be considered.

12.6.2. The MESA Methodology

The objective of the MESA methodology – to simultaneously address economic, environmental and social factors of a development problem, using a formal decision framework based upon a non-monetary scale – was unanimously supported as a desirable goal. The majority viewed MESA as a decision making tool that is logistically sound. The incorporation of community views by expressing them as criterion weights was seen to be a particularly valuable element of MESA.

While broadly supportive of the benefits offered by the MESA methodology, Ritchie (1998) cautioned that the methodology should not be applied beyond its usefulness. He comments that the best use of MESA may be at the preliminary assessment or early feasibility stage, providing a process for representative public consultation without being overly expensive. Concern was expressed, however, over the potential for simultaneous consideration of criteria relating to *absolute* and *relative* merit. Ritchie explains by commenting that some objectives for a project may be absolute; that is, they have only a 'yes' or 'no' answer. If such an objective is not met, a project will not proceed. A criterion of a relative nature, on the other hand, can be satisfied to various degrees, and will not individually determine the fate of a particular development proposal. He therefore argues that it is important to ensure that *absolute* criteria are separated from *relative* criteria in the aggregation process incorporated in the MESA methodology. More work must be done to determine the limits of MESA's capabilities.

The system of rating a project's performance against a decision criterion, represented by a value on the scale 0 to 1, was clearly understood and accepted by the Assessment Panel. However, in some instances the application of the performance rating system was found to be less simple. The difficulty often emerged from problems associated with criterion definition, 'flawed' information, or a general lack of available data. The criteria relating to financial viability and cost distribution were examples where this problem was particularly evident. Scoping of cost-benefit analysis and financial decision criteria is always problematic, and in hindsight, the involvement of an economist at a much earlier stage of this research would have been desirable.

The Assessment Panel indicated strong support for the inclusion of information on existing conditions, so that cumulative impacts could be examined. Improvement in the presentation of the assessment data was considered necessary, however, to aid the interpretation of the matrix. Possible improvements could be made by the use of colour-coded cells to indicate the level of satisfaction of the performance criteria. The elimination of the jargon of fuzzy set theory (such as Minimal Aggregation) and use of more descriptive titles may also be useful. Further research and testing is required to provide improvement.

On the whole, the review of the application and methodology of MESA has been positive. Significant findings of this research are:

- There was unanimous support for MESA as a practical decision making tool.
- MESA is suitable for the assessment of alternative development proposals and for the extension of environmental impact assessment.
- MESA is not too time consuming or costly to be prohibitive in its use.
- Most participants saw future application of MESA in their own work, and felt that it would improve the outcome of their decision making processes.

12.6.3. Development Scenarios for the Northern Adelaide Plains

It was the consensus view that the conventional form of urban development causes environmental and social harm. Economic problems were also thought to accrue, although the extent of any adverse economic impact was less certain.

The Assessment Panel tended to indicate that government policies and initiatives were generally unsupportive of environmental protection and restoration, although there was some uncertainty on this issue. It was felt that greater leadership was required of the government on environmental issues.

The alternative development scenarios were found to be genuinely appropriate for consideration, and the assessment criteria were considered to be accurate. Exceptions were the Objectives 8 and 9 which had an economic focus. These issues were found to be more complex than initially presented, and required more detailed information for an accurate assessment.

There was some uncertainty as to how applicable or representative the findings of the community consultation program were to the Northern Adelaide Plains community as a whole. Hazebroek (1998) comments that young rather than older people may be more attuned to thinking in the analytical manner of the MESA methodology. Therefore the sample required more older people to be sure that the picture obtained was accurate.

The Assessment Panel indicated their support for the village style of urban development presented in Scenario C. Whether this scenario constitutes a likely outcome was less certain. The scenario's higher cost could potentially prevent its adoption. Strategic lobbying may be required to engage government support for this more expensive course of action. At the present time, while there appears to be broad community support for environmental improvement, rigorous examination of major development proposals is scarce. This may be due to the prevailing conditions where development that provides economic growth is desperately sought. However, if this hypothesis is true, it confirms the existence of a 'development versus environment' mindset.

12.7. Conclusions

The assessment of water management strategies and urban development options for the Northern Adelaide Plains using the MESA methodology has provided the following outcomes:

- The consultation process has provided a snapshot of the views of the population of the Northern Adelaide Plains. Whether entirely representative of the whole NAP population or not, there is anecdotal and observatory evidence to confirm the results. Furthermore, because community groups were directly approached during the survey, rather than encouraged via an open invitation, the views of radical groups did not dominate the result and therefore the outcome should be relatively unbiased.

- The public appear to place a higher value upon factors affecting their lifestyles and the urban and natural environment. At least in the context of selecting a desirable course for urban development, economic considerations were considered to be of substantially lesser importance.

- The community has demonstrated that they are 'in touch' with regional issues. Importance in the form of a high weight was placed upon issues that the professional panel judged to be of concern (e.g. the impact of wastewater disposal upon the marine environment).

- There can be considerable uncertainty about financial analysis of the development alternatives. This is largely due to the complexity of government policy, pricing strategies, taxes and subsidies. Appropriate boundaries for economic evaluation are also difficult to define. Many of the problems encountered during the economic analysis conducted in this research should be overcome by the involvement of suitable independent professionals in any real application of the MESA technique.

- Perpetuation of the environmental, social and economic conditions that currently characterise the NAP region would provide few, if any, positive benefits. Similarly, Scenario A would be a regressive approach to development. Neither option would support the pursuit of sustainability.

- The Virginia Pipeline Scheme and other development initiatives encompassed by Scenario B can provide substantial benefits. Economic gain, effective financial cost-benefit distribution, improvements in agricultural productivity, and improvements in industry and employment prospects are the primary benefits.

- The greatest cumulative benefit to the NAP community and environment would appear to be provided by the integrated village style of urban form described by Scenario C.

The process that has been followed has also demonstrated the value of MESA as a practical and understandable decision making tool. While the process is valuable in itself, it also enables the participation of a diverse community, truly incorporating

their views and aspirations. MESA is suitable for application in preliminary through to detailed project assessments, and need be neither too time consuming or costly to be prohibitive to wide spread application. The assessment data and outcomes are structured in a way that is totally transparent, open for debate and discussion, and provides information on the relative merit of one alternative over another.

Further work is required to develop the most effective means of communicating the decision making data, and to determine the limits of applicability of the method.

13

Summary & Conclusions

13.1. Sustainability – A Response to the Development Dilemma

The course of evolution of the human race during the past century has been extraordinary. The size of the global population has tripled to more than 5.2 billion (WRI, 1991), and technological progress has realised what were once only fanciful ideas. Other more subtle changes have been occurring, but with perhaps more significant implications – those of environmental degradation. Examples abound of land degradation, water and air pollution, and the profligate use of non-renewable resources, all of which are contributing to environmental collapse at local, regional and global scales. The very technologies that have provided the improvement in people's quality of life now threaten their ability to survive. The collapse of many Asian economies in late 1997, and the flow-on effects to the global economy, has provided a clear demonstration of economic interdependence among nations. It will be necessary to become accustomed to an accelerating ecological interdependence among nations (WCED, 1987). The days when the 'greenies' were viewed as extremists have gone, and an era has emerged where a concern for the environment is borne by the broader community.

In response to the growing concern for the natural environment, a thorough investigation into the issues and potential responses was initiated by the United Nations. The outcome was arguably the most important statement on environment and humanity in history, at the core of which was the concept of 'sustainable development'. The essential goal of sustainable development is the improvement of the quality of life of present and future generations. Fundamental to the achievement of this goal is the recognition of the interdependence of the environment and economy. There is no necessary conflict between economic and environmental goals – both need to be pursued simultaneously. It is how economic development is obtained that is significant.

The environment must be treated as an asset and not as a free good. Strategies should ensure that the environment is properly valued and polluters are made to pay for using or damaging the environment. A new growth measure is needed to incorporate natural capital as an asset, and to accurately reflect the extent to which development has been achieved at the cost of environmental degradation.

A fundamental requirement is a cultural shift throughout much of the modern world. Existing 'western' cultures have become characterised by expectations and values which are inconsistent with sustainability. The solution to the 'culture problem', as with the problem of over-population, is non-technical. It has little to do with natural science and everything to do with human values. Making the difficult choices involved in achieving sustainable development will depend on the widespread support and involvement of an informed public, government and non-government organisations, the scientific community and industry. A general education in environmental matters is imperative, particularly for the information and persuasion of consumers, though economic instruments will remain very important.

Fortunately, there are some positive signs, that people are beginning to rediscover their place in nature. In Australia, the emergence of local and national programs for land and water management, and the assessment, protection and enhancement of biodiversity is encouraging. Changes at the corporate, institutional and economic level have been slow to follow, however. A set of environmental, economic and social indicators are required to measure performance with regard to sustainability and target areas for improvement.

13.2. Can Sustainability Be Measured?

If the pursuit of 'sustainable' development is a valid and accepted goal, then it is necessary to *define* sustainability in meaningful terms, so as to guide and *measure* the performance of the development process. Numerous broad definitions of sustainability have been offered, each reflecting the interests and characteristics of the proponent. Useful measures of sustainability are far more scarce, presenting a hurdle to meaningful progress.

The selection of a preferred project or policy from a range of choices is often made on the basis of economics. Economic methods alone are unsuitable. This is because economics is based upon the fundamental assumption that market processes are endless and reversible, whereas life is only ongoing and irreversible. Economic cost-benefit analyses ignore many elements of society and the environment because they are impossible to value, while simultaneously discounting the future so as to be less valuable than the present. The equitable and effective allocation of resources is also frustrated by conflicting taxes, subsidies and other economic instruments. Therefore, economics should only be applied to items that are traded, and used as one *element* in a broader decision making framework.

A range of multi-objective planning methods have been devised for project planning and environmental impact assessment (EIA). EIA imposes a problem centred rather than outcome orientated focus, because its primary goal is to identify and mitigate potential environmental damage. EIA fails to consider the positive environmental outcomes that could be achieved through some redefinition of the development project. In addition, the EIA process is often plagued by subjective triggering mechanisms, ineffective public involvement, a lack of adequate scientific information, ignorance of the less well understood issues, and little monitoring of a development following completion. For these reasons, EIA is unsuitable as a method for promotion of sustainable development.

A more rigorous, proactive planning and development effort is required. In practice, however, decision makers 'muddle through', making changes in an incremental way where alternatives differ only marginally from the status quo (Lindblom, 1959). There are a few, well understood objectives and the role and context of evaluation is relatively simple. Unfortunately there are many examples of severe social and environmental problems that have resulted from this incremental approach that tends to entrench past practices. It is therefore important to understand the implications of 'muddling through' and the influence of change that is unguided, or that which fails to incorporate feedback and improvement mechanisms. A conceptual model has been developed to understand this issue better.

13.3. The Sustainability Whirlwind

Attempts to implement sustainable resource management are often based upon strategies that embody a 'static' view of the world. The intent is to maintain existing ecosystems as they are, or to return them to a state that was believed to exist at some time in the past. Whether this constitutes useful change is rarely questioned.

While the reality of natural, ongoing change is accepted, it is unusual for sustainable development strategies to recognise evolutionary or self-organising systems. Yet natural ecosystems continually adapt in response to external influences, the future nature of which is unknowable. The control of natural systems based on scientific prediction of their behaviour is thus impossible. The effect of attempting to 'engineer out' natural fluctuations may, in the long term, be infrequent but large system discontinuities rather than more frequent but smaller adjustments. Hence, resource management techniques must be flexible and adaptable, enhancing the capacity of man-made and natural systems for self management. This requires the adoption of the best available technologies (subject to social and economic constraints), integrated planning, the active involvement of the community, and a commitment to continual review and improvement. These ideas align closely with the philosophy of Total Quality Management (TQM) or continuous improvement.

The need for a precautionary approach that embodies 'predict and prevent', and 'react and cure' mechanisms, makes the continuous improvement approach a sensible foundation upon which to base new resource management strategies. The process of continuous improvement forms only one part of a larger picture though. The 'sustainability whirlwind' in Figure 13.1 provides the broader context.

To check on progress, performance indicators are required. The set of indicators must reflect the need for an integrated approach to the achievement of economic, environmental and social goals. The nature of the indicators, and the decisions made, are often subject to political influence rather than purely scientific processes. The envelope which describes the potentially achievable degree of sustainability is determined by the state of technology. The measure or degree of sustainability achieved is dependent upon the state of knowledge and management decisions. A longer and less sustainable path is followed when an unbalanced approach to economic, environmental and social issues is adopted. The direction or path taken is dependent upon decisions made in the political arena. Governments therefore

have a responsibility to 'get the balance right' through appropriate economic, legislative and policy levers.

This model demonstrates the vital importance of undertaking strategic planning and the provision of integrated development frameworks to coordinate activities. Priority setting efforts must account for subjective judgement and contain formal, rigorous strategies to replace intuition. A method is needed that includes perceived quantitative and qualitative values, with a convenient method of scaling these values to evaluate trade-offs between money, environmental quality, health, happiness and social entities. The complex problem should be dealt with holistically. Without this, development can be fragmented and support conflicting goals.

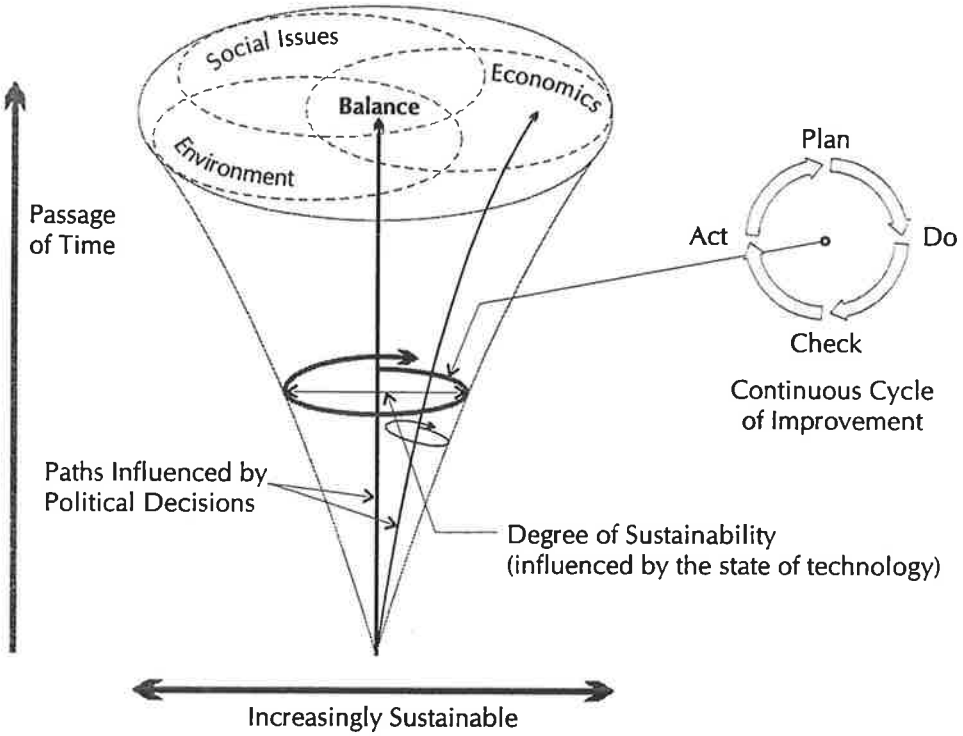


Figure 13.1
The Sustainability Whirlwind

To facilitate the performance review process, new evaluation methods must be developed which can integrate a broad range of criteria and both long- and short-term perspectives. Sustainability requires additional goals to the economic process, to complement rather than replace the conventional ones. The principle of comparing social benefits with social costs must be adhered to in making decisions. The Matrix for Evaluation of Sustainability Achievement (MESA) has been developed to meet these needs.

13.4. The Matrix for the Evaluation of Sustainability Achievement

The MESA technique is designed to indicate whether a project assists or retards the achievement of sustainability, and to ensure:

- public involvement in the establishment of priorities;
- concurrent evaluation of qualitative and quantitative information;
- assessment and comparison of multiple projects or alternatives;
- consideration of the consequences of development relative to current conditions (ie. 'with' versus 'without' the project);
- combination of impact assessments in a methodologically sound way without resorting to estimated monetary values for intangible items; as well as
- a simple, logical technique that allows a relatively quick appraisal, and is inexpensive to conduct.

To eliminate the need to place monetary values on all costs and benefits, coupled with the desire to use the unavoidable subjective responses to some criteria, use was made of the theory of fuzzy sets. The performance of development alternatives with respect to the evaluation criteria are rated on a scale from 0 to 1, where the function representing each scale is defined for each particular criterion. Simple fuzzy set mathematics enables the combination of the performance assessments to indicate which project is most beneficial and by how much in relation to the other alternatives.

The MESA methodology has been applied to a case study which relates to urban development and the management of one of the Earth's most basic and precious resources – water.

13.5. Sustainable Management of a Basic Resource: Water

Life on Earth started in water and without water it could not continue. Water is the most abundant substance on Earth, the principal component of all living things, and a major force shaping the Earth's surface. Water is also the main greenhouse gas and the key to the global energy budget, helping redistribute heat from one part of the Earth to another.

Apart from sustaining the life of communities, water is fundamental to almost every economic activity. It is withdrawn from natural systems, from rivers and lakes on the surface, and from underground aquifers for a variety of uses. Most water is used for irrigation, although large quantities are also consumed for industrial use in manufacturing and power production, as well as for municipal uses. While the water that is withdrawn from natural systems is eventually returned, it may be contaminated or thermally changed, making its reuse further down the natural pathway difficult or impossible.

The simple message is that the world is facing an impending water crisis, largely a result of a massive and growing global population, and the associated forms of development and water use. If water scarcity or catastrophic flooding are not a problem, then it is likely that the quality of the available water resources has been

seriously degraded. Often, numerous land management, water quantity and quality problems are present together and are inter-linked. The challenge is to resolve these problems to sustain the health and welfare of human communities, while restoring the natural environment, a vital component of any sustainable development strategy.

It has been suggested that the solution to these problems involves a new approach of "some for all, rather than more for some", with special attention paid to low cost technologies and cost recovery schemes (Grover, 1992; Kindler, 1992; and Niemczynowicz; 1997). A greater recognition of the need for integrated land and water planning is also emerging, with land capability and ecological capacity being used to determine appropriate limits for water resource development. Flexibility to deal with environmental shifts or discontinuities, such as those that may occur from changes in the Greenhouse Effect, are yet to be effectively dealt with. A creative approach to water management is clearly required.

The particularly arid nature of Australia and the tremendous variability in its climate provides a range of unique characteristics, problems and opportunities. Not only does Australia have the lowest precipitation and runoff in proportion to its area, but also the lowest percentage of runoff to rainfall. In terms of per capita runoff, however, Australia is well endowed with water. But because of marked irregularities in space and time of the availability of water, over two thirds of Australia can be classified as desert, or at least semi-arid. Apart from the northern and southern extremities of the continent, rainfall deficiency is a frequently recurring hazard.

Within this harsh environment, water authorities have succeeded in developing hydraulically efficient and reliable water reticulation and wastewater treatment and disposal systems to urban centres. The demands for irrigation water from a large agricultural industry have also been met through the construction of dams and diversion systems. However, past methods of meeting supply requirements and treating wastes has caused widespread harm to the water sources and natural environment. Some problems include excessive water demand; increased peak stream flows and associated riverine erosion; wastewater discharge above the assimilative capacity of the receiving environment resulting in water pollution; vegetation clearance, over irrigation and dryland salinity; raised and lowered water tables; and extensive water infrastructure that is costly to maintain and replace.

Many of the initiatives to address sustainability and water related problems have emerged during the 1990s. Strategies for integrated water management, stormwater and effluent reuse, aquifer storage and recovery, and catchment restoration are being prepared and implemented. Centres for cooperative research and development with industry have been established, and a National Water Quality Management Strategy has been developed for the first time. In addition, the AUSRIVAS program is targeting the restoration of river systems, with many millions of dollars being provided from the Federal Government's Natural Heritage Trust to local action groups for more diverse environmental rehabilitation works.

The challenge for the next century in terms of the provision of urban water services is to introduce innovative water technologies, management systems and institutional arrangements which are able to meet simultaneously, the multiple objectives of

equity, environmental integrity and economic efficiency, while maintaining a high level of service (Newman & Mouritz, 1992).

13.6. Case Study: The Northern Adelaide Plains

A case study was undertaken to test the application of the MESA methodology, and to explore the implications of the principles of sustainable development as they relate to urban development and water resources management in particular. The Northern Adelaide Plains (NAP) was selected as the case study due to its groundwater exploitation and management problems, and the region's significant role in the future development of the city of Adelaide in South Australia.

In socio-economic terms, the NAP region may be described as young but maturing. Some areas are nearly fully developed, but the region will continue as a major metropolitan growth area well beyond the turn of the century.

The region's coastal areas are low lying, ecologically significant and sensitive to change, while supporting valuable economic activities, such as fishing and salt extraction. The NAP is also a significant agricultural district with production valued in excess of $130m each year. The mix of good soils, good quality groundwater, mild climate and proximity to markets, reinforced by a skilled workforce and extensive established infrastructure, makes the area an excellent horticultural region. Long term planning of resource use is essential if these important contributions to state wealth are to be maintained.

Unfortunately, the NAP and its horticultural industry is plagued by a perceived shortage of water. Although 3,000 ha is currently cropped within the 'Virginia Vegetable Triangle', a further 5,000 ha to the north could become productive if not for the shortage of good quality irrigation water. The coastal mangroves are also being severely degraded by discharge of treated sewage effluent and stormwater.

There are a range of possible futures for this region, which are likely to incorporate: the protection of horticultural areas from further encroachment of urban development; a multi-million dollar treatment plant and pipeline to deliver treated sewage effluent to horticultural properties for irrigation; and a new high technology, environmentally friendly city incorporating innovative water management technologies and energy efficient, computer controlled housing in urban 'villages'. Beyond these initiatives, the future is uncertain. The question may be asked: are these developments environmentally sustainable? Might some other form of peri-urban development provide greater benefits and be more sustainable. If so, what shape does it take? In an attempt to answer some of these questions, 3 alternative development scenarios were compared using the MESA methodology.

Scenario A, *Business As Usual*, assumed the continuing urban sprawl following conventional patterns of residential and urban development and resource consumption patterns.

Scenario B, the *Virginia Pipeline Scheme*, has many of the same features as Scenario A. Tertiary treatment of municipal sewage is provided, however, with a reticulation system for reuse of around 80% of the treated effluent for irrigation in horticulture.

Scenario C, a *Rejuvenated Urban Form*, differed more markedly from Scenarios A and B. Development and renewal of urban areas occurs producing more condensed, efficient and more community orientated urban environments.

The scenarios present hypothetical courses for urban development over the period of 1996 to 2020. They were developed from existing planning strategies, using actual demographic forecasts and cost estimates where available. The sustainability of the provision of water services and urban infrastructure is the primary consideration, with costs typically reflecting necessary expenditure of public (government) rather than private money. Extensive simulation modelling was undertaken to determine the nature of key components in the system of urban infrastructure.

The three scenarios were compared using the MESA methodology, involving a panel of 6 local professionals with expertise in their fields and the study region. The Panel assessed the satisfaction of each criterion under existing circumstances and the alternative development scenarios. The assessment was made against 10 carefully selected performance criteria. A community consultation program was used to determine the importance attached to each of the assessment criteria. The key outcomes of this process are summarised below.

13.7. Key Findings of the Research

The concept of sustainability has provided a range of useful and widely accepted principles for development. Translating these principles into practice is a complex task, however. Traditional decision making tools are unable to gauge the contribution of a project, policy or initiative to the achievement of sustainability.

Fuzzy set theory has re-emerged in recent years, moving out of the theoretical sphere into a diverse range of practical applications. The use of fuzzy sets in the new MESA decision making tool, to enable the aggregation of a series of unlike factors, has proven to be valuable. It would seem that fuzzy sets have an important and expanding role to play in dealing with complex issues as they exist without simplification to fit some particular monetary or similarly limiting scale.

Just as the traditional array of decision making tools does not adequately meet the needs of sustainability, there is a lack of generic system simulation and 'gaming' tools to explore alternative development strategies. A toolbox of inter-connectable models is required to simulate human and environmental development and response patterns. GIS has emerged as one important new tool, but the toolbox is still in its infancy.

Artificial neural networks (ANNs), like fuzzy sets, are attracting increasing interest, particularly in the field of modelling or responding to natural systems. A particular strength is their ability to learn and simulate highly non-linear patterns of behaviour,

a characteristic of natural systems. ANNs have been applied to the prediction of urban water demand using climatic variations as the primary causal variables. It was shown that ANNs provided superior modelling and prediction capabilities over regression and time series methods.

Volumetric runoff coefficients (VRCs) have been derived for urban and rural areas within the temperate climates that characterise southern Australia. The coefficients are a useful addition to the hydrologists tool box, now enabling the prediction of stormwater yield at a monthly rather than annual or longer time step. With the harvesting of stormwater for reuse becoming increasingly popular, the VRCs may become widely used in practice.

Stormwater reuse is only one of a number of measures required to achieve greater sustainability in water resource management. Future efforts in this regard must focus on the *integrated* use of land and water resources, with the aim of ensuring a high level of water quality; use of water within the sustainable yield of the resource; and maintenance of biological diversity. The major initiatives in achievement of these goals should be:

- development of a better understanding of ecosystems and their functioning, with recognition of the environment as a genuine user of water;
- adoption of total catchment management for integrated land and resource use planning;
- adoption of demand management and conservation strategies, with the controlled allocation of water resources where necessary;
- recovery, recycling and reuse of wastewaters and effluents;
- application of 'appropriate' and 'clean' technology that are adaptive to changing conditions;
- revision of the roles of government and private enterprise in the provision of water supply and wastewater treatment services, with associated legislative reform;
- community participation with all levels of government and private enterprise in the decision making and policy implementation processes;
- establishment of a new long-term commitment to data collection, with improvement in the data collection systems, as well as the availability of information; and
- adoption of the Total Quality Management (TQM) philosophy.

The (simulated) application of these philosophies in the context of the Northern Adelaide Plains has provided an important insight to the potential of alternative development approaches. The investigation demonstrated that an integrated approach to land and water management in a peri-urban setting (Scenario C) can

offer numerous environmental and social benefits, and some economic benefits over the more conventional approach (Scenario A). The potential benefits can be broadly summarised as:

- the accommodation of a substantially larger population in an equivalent urban area via a more dense and diverse development style;
- a substantial reduction in potable water consumption by 2020, even under conditions of substantial population growth;
- the requirement for essentially no diversion of water from the River Murray for municipal water supply under 'typical' conditions, with up to a 63 percent reduction in drought conditions compared to 1996 levels;
- little more than a 10 percent reduction in the volume of sewage effluent over the period to 2020;
- a 400% increase in the volume of treated effluent used for irrigation and in industry (to 10,000 ML/yr), which is only modest compared to the 35,000 ML/a or more that could be used under the Virginia Pipeline Scheme (Scenario B) for horticultural irrigation;
- more than a 40 percent reduction in the volume of effluent discharged to Gulf St Vincent, which is less than the 80 percent reduction achievable under the Virginia Pipeline Scheme;
- an ultimate reduction in stormwater yield in the order of 10%, but with a 60% reduction in the volume discharged to the Gulf because of greater capture and productive use of stormwater;
- reduction in groundwater extraction to the sustainable yield (i.e. a volume equivalent to or less than that required to maintain the semi-confined nature of the aquifer); and
- cost savings in the areas of water main replacement, provision of new wastewater treatment facilities, stormwater drainage, and the cost of water purchase by consumers.

It was also found that although stormwater is regarded as a valuable resource, it should perhaps be seen more so as a reserve, in an analogous way to mineral deposits that are uneconomic to retrieve and are therefore not regarded as a resource. Stormwater may initially appear to be a more suitable resource for urban use. However, due to the intermittent nature of rainfall and runoff and its variable quality, there are substantial difficulties associated with full utilisation of this resource. By comparison, sewage effluent is a far more reliable and consistent source of water, both in quantity and quality and over time. As a result, it is often easier to match supply with demand using sewage effluent without the need to construct large storages.

Additional tertiary treatment of sewage effluent to enable full potable reuse may be an appropriate course to pursue. While unlikely to be implemented at anything but a small scale for some decades, there are a number of water practitioners and initiatives in Australia that are supportive of this proposal.

The conclusion remains that environmental and social benefits are available by adopting a total or integrated water management approach, but at some additional economic cost. The question then becomes whether the additional cost outweighs the social and environmental benefits, and whether this question can be reasonably resolved. The MESA methodology was developed to address precisely this problem.

The assessment of development options for the Northern Adelaide Plains using the MESA methodology has provided the following conclusions:

- The general public appear to place a higher value upon issues affecting their lifestyles and the urban and natural environment over economic considerations.

- The community has demonstrated that they are 'in touch' with regional issues, by placing importance upon issues that the professional panel also judged to be of concern.

- There can be considerable uncertainty about financial analysis of development alternatives, in large part due to the complexity of government policy, pricing strategies, taxes and subsidies.

- There are considerable benefits to the NAP community and environment by pursuing the integrated village style of urban form.

Through the MESA process of evaluating the alternative development scenarios, the Assessment Panel indicated their support for the village style of urban development presented in Scenario C. Whether this scenario constitutes a likely outcome was less certain. The scenario's higher cost, and a prevailing societal focus on economic efficiency and growth, could potentially prevent its adoption with strategic lobbying of government and demonstrated public support.

MESA has also been demonstrated to be an understandable decision making tool. While the MESA process is valuable in itself, its characteristic of enabling the participation of a diverse community, and truly incorporating their views and aspirations, is a particular strength. The assessment data and outcomes are structured in a way that is totally transparent, open for debate and discussion, and provides information on the relative merit of one alternative over another. On the whole, the review of the application and methodology of MESA has been overwhelmingly positive. MESA has emerged as a genuine tool to aid progress toward sustainability.

At the present time, much of the progress that is being made for sustainability is attributable to the efforts of local government, private enterprise and the public, who are demonstrating that they are willing to absorb some additional expense in order to improve their environmental and social conditions. State and Federal governments have failed to act in a comprehensive and focussed manner, beyond the preparation of strategy documents. Without strong and visionary leadership

from the higher levels of government, there will be duplication of effort, waste of resources, conflicting economic and development policies, and ongoing environmental deterioration (Fleming, 1996).

The success or viability of such an approach will therefore ultimately be determined by the willingness of consumers to pay and the existence of the political courage to depart from conventional methods.

13.8. Conclusions

The initial goals of this research, as presented in Chapter One of this thesis, have been met, providing a unique contribution to the fields of multi-objective decision making and urban engineering. In particular:

- MESA has proven to be a simple and effective decision making tool that enables the economic, environmental and social aspects of development proposals to be addressed simultaneously; and

- a condensed, village style of urban form has been shown to be more sustainable than traditional development patterns in the region of the Northern Adelaide Plains in South Australia, particularly in the provision of water services and infrastructure.

Other innovative features of this research include the use of Artificial Neural Networks to model regional water consumption; the development of Volumetric Runoff Coefficients to enable the prediction of stormwater yield; and the development of the Sustainability Whirlwind to illustrate the causes and consequences of development decisions.

13.9. Further Thoughts and Recommendations for Future Work

In the desire to develop an improved understanding of the concept of sustainability and its practical implications for urban development and resource management, it has been necessary to undertake research in numerous fields that fall outside the traditional scope of civil engineering but within the broader field of environmental engineering. Unlimited interdependencies are inherent to any practical application of sustainability because its definition, provided by the Brundtland Commission (WCED, 1987), is necessarily simple. *To add detail to the definition of sustainability is to deny its true and basic meaning.* Constancy in the breadth of investigation has therefore been required throughout this research. It is little wonder that multi-disciplinary teams are rapidly becoming the norm for both large and small development planning and design studies.

If there were no other conclusion from this research, the most fundamental and incontestable outcome is that: *there is much more work to be done.* While this may be obvious and unnecessary to state, its significance emerges when linked with a further observation. The proposition, for which a very strong case can be put, is that: a *sufficient body of knowledge already exists in many fields of science to*

commence the journey, and to make meaningful progress, toward sustainability. Thus, a lack of clear guidance or need for further scientific 'facts' cannot be, and is not, an acceptable basis upon which to perpetuate traditional forms of development that are known to be degrading to the environment and humanity.

There is a need for improved development and **urban planning** at the regional and local level. The *entire basis and structure of development plans must be reviewed,* and restructured to reflect a goal of sustainability. This planning should be undertaken through the cooperative efforts of State and local governments, with recognition of the vital importance of continuous review and improvement of plans, and the need for high level scientific, social and environmental inputs. Strategic development plans should be established for a region, within which local area plans can be developed, to ensure the integration and efficiency of effort and pursuit of a common goal. A vision for future development will not necessarily emerge from consultation with the general public, however. It will therefore be necessary to involve professional planners, engineers and others who display lateral and forward thinking, and for courage to be shown on the part of governments in their support and promotion of alternative development patterns.

Clearly, there is also a need for **technology development**. The provision of 'clean' and efficient energy supplies is a very important goal for two reasons. Firstly, the generation of energy using conventional technologies consumes large quantities of fossil fuels and emits many gaseous and liquid wastes that are harmful to the environment. If solar, wind, geothermal or other energy sources could be economically developed for general supply, then the potential would exist to place large amounts of energy into beneficial industrial processes and waste treatment facilities for further environmental benefit.

Much of the effort in technology development should also be focussed upon the needs of the **developing nations**. The continued, direct transfer of existing western technologies in urban development and infrastructure would certainly result in disastrous consequences, for which there are already many examples. Rather, basic human needs must be met by the provision of low cost, operationally simple and effective technologies.

The examination of **scale**, in terms of time and space, is a most essential area of research in relation to the practical pursuit of sustainability. Architects and scholars such as Calthorpe, Arkin, McHarg, Lovins and Register have made some excellent contributions to environmentally responsible urban design. But much of this work implies that sustainability can be achieved at a local level, without reference to the increasing globalisation of the economy (Pezzoli, 1997), of trade and resource consumption. While today's economic activity is concentrated in the world's urban and industrial regions, few if any of these regions are ecologically self contained. The ecological capital of a region may be found thousands of miles from the region in which it is used, forming the 'shadow ecology' of an economy. The oceans, atmosphere and other 'commons' form part of this shadow ecology (MacNeil *et al,* 1991).

Sustainability at the local level doesn't necessarily translate to the global level. While an individual family may be able to live in a completely sustainable manner

on their own small farm, it is impossible simply from the perspective of land consumption for the entire global population to live in this way. It is likely that the optimum scale and nature of systems of infrastructure and production will all be very different. It is therefore imperative that further research be conducted to determine the most sustainable manner in which to provide essential services to the community. Clark & Tomlinson (1995), Pikusa & Dandy (1997) and others have undertaken investigations into the optimum scale of urban water systems.

The use of **computer simulation models** and optimisation methods will be an intrinsic element of the planning and research work. Greater integration of simulation and optimisation tools will be necessary, together with advanced data retrieval (capable of accessing databases with entirely different structures) and visualisation capabilities, such as those offered by new geographical information systems currently under development (*pers comm*, Kirkby, 1997). The facility will be needed to test various scenarios of infrastructure development and operation, where the analysis routines are based upon systems of artificial intelligence or expert knowledge, but where the operator need not necessarily be a specialist in any particular field. Bender (1996) notes that the field of multi-criteria decision analysis has been moving from optimisation methods to more interactive decision support tools. This demands a great leap in technology integration because there is no formal practice for negotiation and mitigation of interdependent impacts and goals in poorly-defined technical problems (Simonovic & Bender, 1995). A few computer simulation systems have been developed to provide the capability for multiple impact analysis (Fedra, 1993), however these have tended to be unique projects at very high expense. A suite of generic and interlinkable simulation tools is required.

Once the modelling and analysis has been conducted, some sense must be made of the outcomes and decisions taken on the future course of development. There is a need for further development of **decision support systems**. With increasing pressure on decision makers to allocate scarce resources (including money) between competing demands, decision makers will require guidance through a structured yet flexible decision making process that has a logically sound basis and is acceptable to the community.

Further work is required to define a set (or sets) of **assessment criteria** to evaluate the contribution of alternative policies, strategies and projects to the pursuit of sustainability. This work might build upon the range of environmental indicators already defined (Mather, 1994; Adams, 1996; Venning, 1996; Walker & Reuter, 1996), and expand to include issues of economics and social health.

The **MESA methodology** has emerged as a valuable decision making tool that meets many of the requirements for a good decision support system. However, further work is desirable to develop the most effective means of communicating the decision making data, as well as to determine the limits of applicability of the method. The derivation of a standard set of functions translating environmental quality or performance relative to a particular assessment criterion onto the fuzzy set range [0,1] would be particularly useful. Some of these transfer functions would emerge from rules or relationships established for simulation modelling (discussed above).

Further investigation into the method of identifying the best alternative using MESA may also be warranted. Bender *et al* (1994) consider that uncertainty in the selection of objectives for future generations, as well as in choosing the combination of weights, may result in the selection of a best-compromise solution which is not realistically sustainable. Some of these aspects of sustainable decision-making indicate that the best compromise solution should be replaced with the concept of most robust solution (Simonovic, 1989). Simonovic has demonstrated that the idea of combining sensitivity analysis of the multi-objective solution to objective values and preference (weight) structures results in the most robust solution. The most robust solution is defined as a multi-objective alternative selection that is least sensitive to changes in the objectives and preference structure. The MESA structure is ideally suited to the performance of sensitivity analyses of this nature.

The recommended areas for further research and development are therefore:

- environmentally benign systems for energy production and electricity supply;
- appropriate technologies for the developing nations to provide sustainable services and infrastructure for an improved quality of life;
- the scales of development that can provide sustainable systems of infrastructure and service provision;
- computer simulation, 'gaming' tools and decision support systems to aid decision making;
- decision criteria that are publicly acceptable and reflect the goal of sustainability;
- standard transfer functions to translate expected project or policy impacts into performance measures;
- the best method of undertaking sensitivity analysis using MESA; and
- the best method of communicating the results of decision making using MESA.

14

Abbreviations

AHD	Australian Height Datum
AMG	Australian Map Grid
AMCORD	The Australian Model Code for Residential Development
ANN	Artificial neural network
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agricultural Resource Management Council of Australia and New Zealand
BOD_5	Fifth day biochemical oxygen demand
BOOT	Build, own, operate and transfer
CBD	Central Business District; the main commercial centre of a city.
c.f.	compare with
CD	Collection District
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DENR	Department of Environment and Natural Resources, SA
DEHAA	Department of Environment, Heritage and Aboriginal Affairs, SA
DHUD	Department of Housing and Urban Development, SA
DRCS	Defence Research Centre – Salisbury
DSTO	Defence Science & Technology Organisation
e.g.	for example
EIP	Environment Improvement Programme
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EPA	Environment Protection Agency
ERP	Estimated Resident Population
ESD	Ecologically Sustainable Development
EWS	Engineering and Water Supply Department (now SA Water Corporation)
GL	Gigalitres: 1,000,000,000 litres or 1million cubic metres of water
ha	hectare (equivalent to 2.471 acres)

i.e.	that is
IGAE	Intergovernmental Agreement on the Environment (1 May 1992)
km	kilometre (equivalent to 0.6214 miles)
LGA	Local Government Area
LRWE	Long Range Weapons Establishment, Department of Defence
MFP	Multi Function Polis
MOSS	Metropolitan Open Space System
ML/a	Megalitres per annum
ML	Megalitres: 1,000,000 litres or 1,000 m^3 of water
NAP	Northern Adelaide Plains
NAPPR	Northern Adelaide Plains Proclaimed Region
NHMRC	National Health and Medical Research Council
NPV	Net present value
pH	Acidity, negative logarithm of the hydrogen ion concentration
PER	Public Environment Report
PV	Present value
RAAF	Royal Australian Air Force
SAEPA	South Australian Environment Protection Authority
SAHC	South Australian Health Commission
SAHT	South Australian Housing Trust
SIA	Social Impact Assessment
SLA	Statistical Local Area
SAULT	South Australian Urban Land Trust
SAUPA	South Australian Urban Projects Authority
SS	Suspended solids
STW	Sewage Treatment Works
TDS	Total dissolved solids
TKN	Total Kjeldahl Nitrogen
VIA	Virginia Irrigation Association
VIT	Virginia Irrigation Trust Inc.
VPC	Virginia Pipeline Committee (subsequently replaced by the VIA)
VVT	Virginia Vegetable Triangle
WRE	Weapons Research Establishment (Salisbury)

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